

Future City 15

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*Editors*

# Rethinking Sustainability Towards a Regenerative Economy



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# Future City

## Volume 15

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As of 2008, for the first time in human history, half of the world's population now live in cities. And with concerns about issues such as climate change, energy supply and environmental health receiving increasing political attention, interest in the sustainable development of our future cities has grown dramatically.

Yet despite a wealth of literature on green architecture, evidence-based design and sustainable planning, only a fraction of the current literature successfully integrates the necessary theory and practice from across the full range of relevant disciplines.

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*We would like to dedicate this book to the thousands of researchers, practitioners and innovators across Europe and globally, who are tirelessly thinking and working to make our planet a better place, while providing colleagues and decision-makers with growing evidence of disruptive solutions towards sustainability and a regenerative economy.*

*We would like also to thank Carlo Battisti, Ilaria Alberti and Eurac Research, for all their support and interest as the book evolved and became a reality, and express our gratitude to all the Authors for submitting their valuable work.*

*—Maria Beatrice, Antonino, Milen & Preben*

# Foreword

Nature! We are surrounded and embraced by her: powerless to separate ourselves from her, and powerless to penetrate beyond her. Without asking, or warning, she snatches us up into her circling dance, and whirls us on until we are tired, and drop from her arms. She is ever shaping new forms: what is, has never yet been; what has been, comes not again. Everything is new, and yet nought but the old ...

Goethe in the first edition of *Nature* 1869

RESTORE was founded on inspiration from the philosophy of the Living Building Challenge and to further explore the established restorative/regenerative thinking of writers. RESTORE has certainly been an adventurous journey over four years, a journey of Rethinking Sustainability Towards a Regenerative Economy, from initial deliberations in Faro through to an imagined future city, RESTORD 2030, a truly regenerative city that applies all the outcomes from RESTORE.

RESTORE has indeed taken inspirational regenerative thinking, explored further insights, research, practice and development and added to the body of regenerative knowledge through creating important publications, papers and dissemination that will move the built environment towards a regenerative culture and economy. The initial premise of RESTORE was to affect a paradigm shift in sustainability thinking, in practice, in academia & education and importantly in members of RESTORE. That paradigm shift is evident as discussions, debates and thinking have matured in understanding the differences between sustainability, restorative and regenerative.

Working Group One in Faro established the framework for following working groups, through establishing several key definitions relating to sustainability and regenerative economics

**Sustainability** was defined as minimising and eliminating impact, the bridging point between not doing less bad and starting to do ‘more good’. It was Yvon Chouinard, founder at Patagonia, who said that we should not use the word sustainable until we give back as much as we take.

**Restorative** Sustainability was defined as restoring ecological and social systems back to a healthy state, and then

**Regenerative** Sustainability as creating the conditions that enable vital social and ecological systems to thrive.

In essence embracing regenerative sustainability is embracing deep change, not only for the built environment processes and buildings, but for people and for the planet. It is vital that regenerative sustainability is seen as holistic, and should not be approached in the siloed fashion business as usual sustainability has been addressed, but to recognise the complexity of ecosystems, and the role and responsibility that we and our buildings have within our highly connected planetary ecosystems. Wrapped up within social and ecological systems are the concepts of being culturally rich and economically just.

It is encouraging that as I write this, following our renewed understanding of nature from Covid-19 and on social and climate justice from Black Lives Matter movement, to note that XR USA within their 4th Demand (and a 'demand' much debated in XR across Europe) calls to establish legal rights for ecosystems to thrive and regenerate in perpetuity. Where we are today, this does not seem so radical or rebellious.

The strap line from RESTORE, to move towards a Regenerative Economics, necessitated an economic definition, as 'a product of human and societal vitality, rooted in ecological health and the inclusive development of human capabilities and potential'.

And it is interesting to note that early RESTORE deliberations and the Working Group One publication acknowledged Doughnut Economics model as being a viable application, embracing many of the regenerative economic definitions.

The thinking that has matured throughout the working groups would most likely now not separate social and ecological aspects, but recognise that we are part of nature, not apart from nature, with social and ecological aspects intrinsically connected. And it is the inter-connectivity across themes, definitions and paradigms that formed golden threads running through the life of RESTORE, and will continue beyond into legacy, future work and practice development.

Perhaps one of the most important aspects arising from the first working group was the exploration of SEVA as the mindset necessary to truly move into a regenerative economy. The sustainability journey that we have made over the last 100 years or so, from the industrial revolution to today and one that continues into new territory can be summarised as Ego Eco Seva

**Ego** – our tyrannical domination over nature, taking what, even more than was needed and dumping our surplus, our waste into the land, sea and water courses, often without treatment, and with a lack of respect for human life.

**Eco** – could be defined within the modern, current era, as defined by Brundtland in 1987 where we, business and governments proudly proclaimed to do nothing today that would compromise future generations. Throughout our eco era, all significant indicators are heading in the wrong direction, and here we are a generation later, with young and future generations severely compromised through our actions and inactions.

**Seva** – from the Sanskrit word Seva, of 'being in service to others' and interpreted as being in service to other humans and non-humans alike. It is a worldview paradigm, required to truly see ourselves as part of nature, not apart from, and to do the right thing.



It was this philosophy that was taken as the guide for the very first training school 2016 in Lancaster UK, using the words from Aldo Leopold 'to teach the student to see the land and help the student understand what they see.

Conceiving and designing buildings and cities based on life's principles, is or should be, the foundation of sustainable construction, embedded into all aspects of the built environment. The International Living Future Institute translated this philosophy into advocacy, standards, education programmes and tools most notably the Living Building Challenge.

The transition from Eco to Seva, that important transition from restorative to regenerative, has been debated and reflected through the thinking in working groups 2 3, 4 and 5, and with the work of WG5, scale jumping beyond regenerative.

## Health and Wellbeing

Through our Ego's we have paid a terrible price, and still do, even in our current Eco mindset, in forgetting that we are part of the complex, connected ecosystem, a connectivity that allows all individual organisms and species, including us as humans to flourish. The built environment is recognising the importance of buildings as fostering human health, through salutogenic design, with the purpose of buildings seen as enabling life to flourish and thrive, not just to reduce or prevent ill health.

Buildings, their concept design and construction can be viewed as writing a prescription for the built environment towards a regenerative, ecological and socially just future. Biophilic design has morphed and matured into a core integrative design process – becoming mindful, creating a state of mind where we see it right to ask the land and cultures for permission to build.

We can learn a lot from the application and thinking of rewilding in nature ecosystem regeneration. Defined as the visible demonstration and evidence of restorative and regenerative approaches, there is potentially a powerful hierarchy of rewilding people, regaining that sense of being part of nature through rewilding nature within cities and of cities and buildings themselves.

## Words

*Beware of all enterprises that require new clothes*

Henry David Thoreau

Words, often more than definitions, shape our sense of place and culture, our design and build practices and the way that we live, work and play within buildings. Sustainability words give the power to be inspired or deflated, or give a hiding place to do nothing or just to greenwash.

The first training school in Lancaster was challenged with the concept of Living Buildings being sentient. It is a question that continues to be asked, and four years

later we have better, different insights. Robin Kimmerer Wahl in *Braiding Sweetgrass* points out that indigenous languages have far more verbs and fewer nouns than English languages, with nouns in general reserved for non-living things. Trees are verbs, not nouns, living, not dead, which makes the *thinking like a tree* proposition far more understandable. The question remains though, are buildings or indeed 'living buildings' nouns or verbs? The mindset switch to the later will allow us to think like a living building, and see its place, and importantly its role and responsibilities in local and planetary ecosystems.

The RESTORE workshop in Koper, exploring construction and maintenance of the built environment challenged the language of construction, of end-users and of occupants. This is important. We need to see those who live work and play in buildings as inhabitants, inhabiting a purposefully designed ecosystem that has a role within its place and environmental ecosystems. People are not passive end-users or occupants but are active agents, inhabitants, having roles and responsibilities in the care and love of the building. Similarly, the construction industry would benefit from a shift to pro-construction thinking (a term coined by Eric Fred) not being consumers of resources, but prosumers, improving resource value.

*We need to enable a regenerative revolution in the built environment – one that supplants our extractive economic model, and goes beyond “sustainability,” to draw down carbon and reverse course on climate change. (World GBC From Thousands to Millions)*

## Healing the Future

We are in the critical decade. It is no exaggeration to say that what we do regarding emission reductions between now & 2030 will determine quality of human life for hundreds of years' (@CFigueres @tomcarnac Tweet)

2020 has added unprecedented aspects to the concepts and scope of sustainability and the built environment. In what has become known as the anthro-pause, for a while the whole of humanity came to a standstill. Nature had our undivided attention. And now as we move into an era of living with coronavirus we are seeing the future through a different lens. We may have crossed a Rubicon. We now have to question whether our pre-covid19 approaches, education and tools have really prepared us for a sustainable or regenerative future.

For many, the Covid crisis has prompted us to turn our attention to elements of the nature around us, opening new insights about our human, non-human and built environment relationships and has allowed us to glimpse new ways of being. We had seen a preview of what the world could be like, with clear skies, fresh air, low emissions, quietness and peace, and importantly time to notice the daily, even hourly progress of the seasons. We may have experienced, for a short moment, what it is to feel human and to feel as part of nature.

This is not to take away the grief and pain of the lockdown, but being in that lockdown, shielded, often unable to move, we gained a little understanding and a

small degree of empathy of the impact and pain we inflict on nature and the environment. An inflexion that nature has to bear, unable to move, or hide.

While the shape of the future built environment remains unknown, amid this rupture lies an opportunity, a wake-up call that provides us with a unique opportunity for re-evaluation and reimagining, for looking forward, for healing the future and to stop adding further layers of codes and legislation that only solve the last crisis and not prepare us for our future. Every aspect of the built environment will be examined, with a shift to a salutogenesis paradigm following renewed attention to health and wellness, on social connectivity, collaboration and public health data, questioning what were former best practices. Indeed we are now asking deeper questions, questions we would not have thought to ask earlier in 2020. We are seeking better understanding on the relationships between individual, community, ecological and planetary health. Our built environment is seeing a renewed and sustained focus on the inextricable connection between human health and the health of our climate.

Yet the old discourse, the old normal was, is and will become ever more dominating unless we work for a new regenerative normal. But that new, regenerative future is possible. If we can imagine it, we are already moving towards envisioning and realising that future. As Buckminster Fuller said, to make real progress we have to "*Design new patterns and models that make the old obsolete*". RESTORD 2030 (WG5) is that imagined and envisioned regenerative city, shaped by new patterns and models.

And it is happening; new patterns and models are emerging. It is heartening to hear of the gathering momentum under the New Green Deal label, the regenerative Doughnut Economics model, seeking to re-balance the needs of humanity with planetary needs, increasingly linked to new covid era economics for cities such as Amsterdam and Copenhagen. As Kate Raworth, founder of Doughnut Economics, commented, "*The most powerful tool in economics is not money, nor even algebra. It is a pencil. Because with a pencil you can re-draw the world*".

Where now for regenerative sustainability and RESTORE? The publications and outcomes from the five working groups, along with the chapters within this final book, significantly move the regenerative needle, they refine our compass for understanding and application of regenerative thinking. And, importantly will open further doors, prompting deeper questions on the roles, functions and responsibilities of ourselves and our structures within our planetary ecosystems.

COST Action RESTORE Vice Chair,  
and WG 1 "Restorative Sustainability" leader,  
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Martin Brown

# Preface

Climate crisis is real. Building and Construction is responsible for the greatest amount of CO<sub>2</sub> emissions when compared to other sectors. We live for 90% of our time (and more, during the pandemic lockdown) indoor. The refurbishment of the huge European building stock is our hidden oil and next huge opportunity. Materials Transparency matters. Water as a precious resource. Waste as a resource. Reduce, reuse, recycle. The Circular Economy. Nearly Zero Energy buildings, and then Zero Energy, and then Zero Carbon, or even Energy/Carbon positive. And everything will not be the same as before, after Covid-19 ...

How many times did we hear about these quotes? Isn't it the indicator of something insufficient or even wrong with our current concept of sustainability? Is sustainability adequate, as a framework to manage the gigantic climate challenge we are urgently called to address? Are green buildings enough to slow down the increase in carbon emissions we have been accumulating in the atmosphere for the latest decades? And, maybe first, what does sustainability really mean, after twenty years from our entrance in the third millennium?

Despite the spreading of the green buildings' movement in the last thirty years, the progress in effectively addressing the big climate issues has been barely visible so far, and we are still seeing a constant increase in greenhouse gases global emissions and yearly average temperature level. Where did we fail? What did we miss? Is the current framework of sustainability we conceived wrong or outdated, or have we been lacking in implementation?

These are main questions that the COST<sup>1</sup> Action “*REthinking Sustainability TOwards a Regenerative Economy*” (RESTORE) tried to answer in its four years' (2017-2021) journey. Born in 2015, as an idea to establish a Europe based network of regenerative design thinkers, RESTORE has further developed into an Action submitted and approved by COST Association in Autumn 2016, and then started in Spring 2017. Managed as a Project with clear goals and a road map, the COST

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<sup>1</sup>European Cooperation in Science and Technology (COST) is the longest-running European funding framework, supporting trans-national cooperation among researchers, engineers, and scholars across Europe.

Action RESTORE is a network dedicated to scientific collaboration, complementing national research funds, open to researchers and innovators, that collaborate in a field of science and technology of common interest, based on a joint work programme lasting four years.

Starting from a small core group of proposers, the RESTORE network relies nowadays upon the commitment of more than 160 researchers and professionals from forty European countries as well as USA and New Zealand, representing around one hundred universities, research centres, and industries. This book summarises a set of analysis and ideas emerged from our four years' work. From the very beginning, we understood the great potential of a Europe focused geographical spread network, representing different needs, cultures, economic and political systems, and climate zones.

Moreover, we worked to ensure a robust multidisciplinary approach, with experts in more than forty disciplines, including e.g., sustainable design, wellbeing, human geography, environmental policies, business management, urban planning, etc. This allowed us to address the global issue of the impact of the building sector on the climate emergency with an integrative approach, creating the opportunities to transfer knowledge and best practices between different areas and countries of Europe more and less developed from a research perspective.

I mentioned the need for a paradigm change. Quoting Richard Buckminster Fuller “You never change things by fighting the existing reality. To change something, build a new model that makes the existing model obsolete.” Following this, we firstly discussed the concept of sustainability as we considered it to date. What is sustainability? Within our Working Group 1 on “Restorative Sustainability”<sup>2</sup> we developed three different definitions or “levels” of sustainability, establishing a common and grounded understanding.

Sustainability is “simply” an approach limiting the damage caused,<sup>3</sup> or in other terms, the situation in which we are giving back to the environment what we are taking from it. But what about the damage we already made? So, instead of being satisfied in doing “*less bad*”, what about doing “*more good*”? What if every single act of design and construction made the world a better place?<sup>4</sup> This is the paradigm shift RESTORE aims to provide, envisioning two further conceptual levels. A “*restorative*” sustainability, aiming to restore social and ecological systems to a healthy state. And a “*regenerative*” scenario, enabling social & ecological systems to evolve, continuously. From this new perspective, architects, engineers, practitioners, researchers, and decision-makers (the target group of this book) are called to action, with a different evolved role to play. From planners of the built environment, to advocates and change-makers of a better (living) future.

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<sup>2</sup><https://www.eurestore.eu/working-groups/wg1-restorative-sustainability/>

<sup>3</sup>“Our Common Future”, also known as the Brundtland Report (1987).

<sup>4</sup>A quote from the International Living Future Institute, introducing the Living Building Challenge framework <https://living-future.org/lbc/>

In the frame of a holistic, multidisciplinary, integrative approach, RESTORE addresses the whole construction supply chain and process. After redefining sustainability, as described in the first RESTORE publication “*Sustainability, restorative to regenerative. An exploration in progressing a paradigm shift in built environment thinking, from sustainability to restorative sustainability and on to regenerative sustainability*”<sup>5</sup> the Action moved to the Working Group and package 2 on “Restorative Design Process”. We developed processes, methods, and tools, with the intent to provide a “hands-on” guidance to the practice of restorative design. In an era of continuous digital transformation, the focus has been primarily on how to use digital tools to put a restorative and regenerative sustainability into practice, as it has been detailed in the book “*Regenerative Design in Digital Practice. A Handbook for the Built Environment*”.<sup>6</sup> The principles of regenerative design require the design process to be inclusive and collaborative, aiming to create a further positive impact to allow ecological systems to recover and maintain a healthy state.

The new design process anticipated by RESTORE needs a coherent rigorous implementation. This is even more important in a lifecycle scenario. As analysed in the RESTORE WG3 publication “*Regenerative Construction and Operation. Bridging the gap between design and construction, following a Life Cycle Approach consisting of practical approaches for procurement, construction, operation and future life*”,<sup>7</sup> we tried to answer the following basic question. How can a building be built, operated, and maintained in a regenerative manner, from procurement and construction, to the operation and maintenance phases, considering also future life concepts?

To achieve the ambitious goals set up by this new approach, building products, technologies and solutions play a hugely important role. Sustainability goes beyond a single facet. Not only, if we consider a building as an assembly of materials, we understand that most of the effort to ensure a regenerative approach for the building industry is in the hands of solutions providers and systems integrators, more in general of building products manufacturers. This has a lot to do with the quality of the indoor environment, the spaces where we live, learn and work for more than 90% of our day. RESTORE Working Group 4 has been working towards proper characterization and identification of the technologies and the solution-sets for a regenerative indoor environment, as analysed in the RESTORE publication “*Regenerative technologies for the indoor environment. Inspirational guidelines for practitioners*”.<sup>8</sup>

From general to particular, from defining the overall restorative and regenerative framework, to addressing building projects design and construction, technologies, and products. Finally, the RESTORE network has been working on scaling up this

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<sup>5</sup> <https://www.eurestore.eu/publications-and-articles/>

<sup>6</sup> <https://www.eurestore.eu/publications-and-articles/>

<sup>7</sup> <https://www.eurestore.eu/publications-and-articles/>

<sup>8</sup> <https://www.eurestore.eu/publications-and-articles/>

approach to a larger level, from buildings to communities, districts, and cities, addressing some infrastructural questions. For example, when it is too challenging for a building to be net or positive in its balance between produced and consumed resources, is it possible to achieve this result at a broader scale (e.g., a cluster of buildings)? Moreover, how these concepts of regenerative sustainability are transferable to a city level? And, from a methodological perspective, how can we scale up to a greater extent these regenerative best practices? Is it possible to provoke the shift of the whole building industry and the built environment – in Europe, but not only – from a business as usual (including most of the *green* status) to a regenerative scenario? This has been the focus of the 5<sup>th</sup> and final RESTORE Working Group, package, and publication on “*Scale Jumping*”.<sup>9</sup>

As a natural conclusion and overarching output after our RESTORE previous Work Package specific dissemination products, this book extends the target group to all the decision makers, including – but not limited to – real estate developers, public administrators, entrepreneurs, politicians, citizens. That is because the global environmental, social, and economic challenges we must address – now much more effectively – require a systemic change that involves everyone, including those whose decisions can create a larger impact.

There is not a fit-for-all recipe or set of solutions. The challenge, and the vast opportunity that brings within, need a global paradigm change, a systemic approach, engaging all the actors in the supply chain, in an integrative, multicultural, and multidisciplinary approach. This book has the ambitious goal to describe a new scenario, being at the same time a practical guide with useful insights for a restorative and regenerative approach to the built environment, a body of knowledge deriving from researchers and practitioners’ experience, a business case for regenerative buildings and construction, and an amplifier of these positive effects to an urban scale.

The work from the Editors and many members of the RESTORE network here represented will provide to the reader an overview of several best practices to make a regenerative design approach possible, highlighting its social and cultural linings, including the barriers to deploy it at a global level, and some suggestions on how to overcome them.

In the end, this a choral result of an amazing international collaboration network I have been humbled to coordinate and I am a proud member of, demonstrating that when the best minds from research, academia and industry are put in the ideal conditions to cooperate – doing “*more good*” – the chance to successfully manage and resolve the tremendous challenges we have been called to address, become very likely to be achieved.

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<sup>9</sup><https://www.eurestore.eu/publications-and-articles/>

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András Reith



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# Part I

## Processes, Methods and Tools for Regenerative Design

### 1.1 Foreword by Emanuele Naboni and Lisanne Havinga

Emanuele Naboni and Lisanne Havinga

#### *1.1.1 Regenerative Design in Practice: Digital Design Tools to Enhance the Well-Being of the Inhabitants of the Natural and Built Environment*

Architectural design should not be merely concerned with developing artefacts that limit environmental impacts on the ecosystem or people's health. Instead, cities, buildings and technologies must be designed to enhance both the quality of natural systems and their relationships with the built environment, and their inhabitants. The COST Action RESTORE, presented and reviewed a variety of emerging digital practices that can support the implementation of such a relationship within the framework of Regenerative Design. These were introduced via a series of literature reviews, digital design approaches and real-world cases, fostered by international practitioners and researchers who participated in the network.

RESTORE developed digital workflows that are programmable to cope with customised and multi-domain issues. As such, tools that are open to being customised by users, beyond the typical building engineering and architectural sciences problems, were studied and applied. This allowed responding to a set of performance targets such as those linked to the local ecosystem and human health. The spectrum of adopted tools allowed to manage big data (concerning the climate, ecosystem, flows of materials, emissions, human health and individual physiological parameters), and to support the interdisciplinary simulation and evaluation of performance across scales. Computational optimisation techniques were used to achieve regenerative design targets by informing the shape, size, orientation and other design and

material choices by digitally mapping their relationships to climate, ecosystem and human health.

The work on Digital Design Tools was organised around 3 focus areas to be digitally supported and integrated:

1. Climate Change Mitigation and Adaptation, Urban Microclimate and Decarbonization. The regenerative urban design focuses on how the built environment and its local current and future climate can be designed in ways to optimise both outdoor and indoor comfort while balancing energy use and seeking nature-based solutions (NBS) that are part of nature (rather than apart from nature).
2. Carbon and Ecology. Circular Design. In line with the four laws of ecology, regenerative design is holistic. It integrates and tracks the energy, material and emission flows of cities, buildings, components and products (i.e., it takes a life-cycle perspective). Instead of the current take-make-dispose system, natural ecosystems are circular: there is no waste. Regenerative Design brings products and components from previous lives into buildings and ensures future lives through circular design principles.
3. Human Well-being. Biometrics. Regenerative Design aims to promote and enhance human wellbeing and health in the built environment. While a reductionist approach targets the absence of ill-health, regenerative design focuses on *Salutogenesis*, a term coined by Aaron Antonovsky, which means “generation of health”. Strategies for indoor and outdoor environments must demonstrably improve inhabitant health and well-being, and not merely seek to reduce ill-health.

The integration of such areas was pursued by exploring the possibilities offered by parametric design. The latter has been identified as having the potential to be an integrative part of the multi-domain design process. New environmental parametric plugins were developed in activities such as the training school in Malaga (Spain), thereby allowing the evaluation of the multi-disciplinary ecological and health-related targets of regenerative design. The software Grasshopper was used to couple architectural and non-architectural domains by modelling phenomena described via a set of equations, as well as the geometry of cities, buildings and components. This required the integration of aspects from the realms of, among others, ecosystems, climatology, material sciences, environmental sciences, synthetic biology, biology, botany, human comfort and physiology. Therefore, they enabled the designer to deal with the highest levels of complexity of environmental issues, transcending traditional disciplinary boundaries.

These activities are summarised in the book “Regenerative Design in the Digital Practice”. The book demonstrates how the long-anticipated ability to process data from natural ecosystems, the built environment and its inhabitants holistically within digital models, allows the design of regenerative cities and buildings. It highlights that the orchestration of data from various domains is central to regenerative



design and presents digital scenarios and examples of data collection that support it. It reveals to the international community of planners and designers how increased access to parametric simulation could unlock their ability to understand and act on their designs' contribution to issues such as climate change and human health, which have long been considered to be outside of the scope of the designer's expertise.

COST RESTORE WG 2 "Processes, Methods and Tools for Restorative Design" leaders

# Chapter 1

## Axiomatic Design in Regenerative Urban Climate Adaptation



Clarice Bleil de Souza and Ilya Vladimirovich Dunichkin

**Abstract** This chapter invokes the urban design community to provide transparency in design decision-making by discussing the role of design specifications and the production of evidence in enabling scrutiny and accountability of design proposals in relation to fulfilling sustainability goals and fighting climate change. It claims that original and verifiable regenerative design solutions emerge from clear design specifications supported by evidence, rather than normative sustainability alone. Evidence is understood as going beyond targets and extended to design specifications which are constantly tested in terms of flexibility and robustness, positively contributing to the ecosystem they are inserted in, once further decomposed towards a more detailed design proposal. Principles from Axiomatic Design are proposed as an approach to develop design specifications for regenerative climate adaptive urban design. This work attempts to illustrate the use of this method to practitioners through an example in which human-centric needs, values and aspirations are transformed into joint urban air pollution and outdoor bioclimatic comfort design requirements to be fulfilled by greenery, a regenerative design parameter common to both knowledge domains at the pedestrian layer of the urban environment.

**Keywords** Regenerative design · Integrated design · Urban climate adaptation · Green infrastructure · Climate-responsive design

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## 1.1 Problem Definition

Sustainability standards which focus on multi-criteria evaluation systems (such as the Building Research Establishment Environmental Assessment Method – BREEAM, Leadership in Energy and Environmental Design – LEEDS) are being surpassed by more comprehensive certification processes. These new certification processes contain challenging mandatory requirements to be integrated within a design narrative based on solid arguments supported by evidence, such as performance in-use (Living Building Challenge and the WELL Standards). Requests for narratives in supporting accreditation requirements are threefold: First, they acknowledge that only integrated design, rather than a collage of Key Performance Indicators (KPIs) from different knowledge domains, can produce truly regenerative solutions which positively contribute to the ecosystem they are inserted in, restoring the original qualities of the site and context to its original conditions and beyond (Brown, 2016; International Living Future Institute, 2017; Sonetti, Brown, & Naboni, 2019). Second, they set design teams free to use their own expertise and creativity in proposing integrated solutions to incorporate mandatory requirements in an integrated way despite imposing targets that are more rigid. Third, they increase the potential for real innovation to happen in a transferrable format, as narratives can be stored and analysed to extract knowledge.

Whereas this idea is sound and has a true potential to produce radical transformations on the built environment, practitioners still face the question of how to generate robust design narratives, substantiated by evidence so that integrated and restorative design solutions can emerge?

Approaches to integrate different KPIs are traditionally undertaken via Multi-Criteria Decision Analysis (MCDA) (Li et al., 2020; Rodríguez-Espinoza, Aguilera-Benavente, & Gómez-Delgado, 2020), Analytical Hierarchy Processes (AHP) (Aksu & Küçük, 2020; Bivina & Parida, 2019) and optimization routines of different types (Eicker, Weiler, Schumacher, & Braun, 2020; Jia, Li, & Liu, 2020). These methods are highly deterministic as they constrain problem framing to the setting of weighting systems or predefine ranges of acceptable solutions without transparency and real control in the rationale behind different parametric design combinations. There are also some studies in the area of applying ‘Parametric Design methods’ to neighbourhood scale projects (De Luca, 2019; Naboni et al., 2019), interpreting it as a decision-making method whereas it is actually an environmental ‘tool’ developed to undertake sensitivity tests to understand the effects of specific design actions into one or more KPIs rather than a rationale or overarching framework to analyse and control decisions.

What the design community does not realize is that none of these methods addresses the problem in its essence. Designers and consultants use evidence that comes from domain-specific models of reasoning to make decisions. However, domain-specific models are fed by input parameters (physical variables) that are common to different disciplines. These input parameters (physical variables) are optimized in disciplinary silos, to achieve domain-specific performance targets. Decision-making in relation to how physical variables are manipulated needs to be

reconciled among different disciplines as it emerges from different scientific approaches to the problem and/or different ‘social constructions’ of it which are mutually irreducible (Thompson & Beck, 2014). Take for instance the case of a design team in which a landscape designer, who proposes specific types of greenery as a barrier to configure a quiet sitting area, is in conflict with a wind expert, who after some wind tests, proves that the position of this wind barrier actually creates higher wind speeds leading to uncomfortable and/or potentially dangerous spaces to sit. The conflict arises from the fact that each expert has a different goal – ‘provide a quiet sitting area’ and ‘protect from the wind’ – but both propose the use of the same physical variable to achieve it – ‘greenery’. Reconciliation in this case can be lengthy and pursued using trial and error through several experts’ interactions (a time-consuming, costly and therefore unrealistic option), ‘adjusted’ by attributing different weights to expert goals (with the ultimate criteria of prioritizing safety in this case), abandoned and adopted based on the worst-case scenario (follow the wind expert to avoid future liabilities). The likelihood of achieving an integrated solution in this scenario is low because, with the exception of the costly trial-and-error approach, others will favour reconciliation only at the level of the solution, rather than coordinating expert knowledge by examining the pair ‘solution–design parameter’ proposed to achieve it by assessing the implication of manipulating them in subsequent experts’ actions.

The authors hypothesize that since regenerative urban climate adaptation is a multi-domain problem, which traditionally uses evidence from different types of models sharing common input parameters; it needs to be approached from a multi-expert problem framing perspective starting from specifying common, potentially human-centric, goals. These goals should control the development of scenarios used as trials for a series of design specifications from multiple domains with associated design parameters common to many domains, which are constantly tested in terms of flexibility and robustness in relation to all domains involved, once further decomposed towards a more detailed design solution. Principles of Axiomatic Design (Suh, 2001) are proposed as an approach to develop design specifications for regenerative urban climate adaptation.

By specifically focusing on the domains of urban air pollution and outdoor bioclimatic comfort, the authors propose to demonstrate how, in theory, Axiomatic Design can be used to control decisions, which involve the selection and manipulation of greenery, a design parameter common to these two knowledge domains. Centring the problem around providing a physical environment suitable to human well-being, the work initially proposes a list of well-being requirements to be satisfied, followed by combined thresholds of optimum ranges of wind speed, concentration of pollutants and adaptive comfort ranges to be addressed by greenery, a common response to well-being requirements, and at the same time, a shared input parameter between fluid flow and bioclimatic comfort models. This approach shifts the focus of decision-making from a collage of weighted KPIs at the end of the process to the negotiation of acceptable ranges for common design parameters based on overlaid acceptable ranges for targets, which are part of a larger framework with common ultimate goals.

## 1.2 Current Trends in Urban Climate Adaptation

There is a reasonable number of studies from the perspective of the environmental and physical sciences which focus on quantifying the effects of green infrastructure in urban climate adaptation. Several examples can be found for frameworks and/or tools to determine and map ecosystem service capacity, flow and demand. These initiatives comprised the development of computational tools to be used at regional or urban scale to enable the quantification of green infrastructure in NO<sub>2</sub> removal and outdoor recreation (Baró et al., 2016); the location of green and blue infrastructure to improve storage capacity for flooding mitigation drought and heat stress (Voskamp & Van de Ven, 2015); the assessment of mismatches between ecosystem services supply and demand based on air quality standards and temperature regulation (Baró, Haase, Gómez-Baggethun, & Frantzeskaki, 2015). Several studies can also be found to quantify effects of green infrastructure on mitigating urban heat island effects. At the urban and regional scale, Buchholz, Kossmann, and Roos (2016) compare different adaptation measures based on changing amounts of greenery, water surfaces, surface permeability, reflectivity and conductivity in relation to their impact on air temperature. Makido, Hellman, and Shandas (2019) propose the use of ENVI-Met and Computational Fluid Dynamics (CFD) to examine the use of green infrastructure to change ambient temperature in different land uses. At the neighbourhood scale, Fahmy et al. (2020) use ENVI-Met and Design Builder to assess the effect of greenery (trees, green walls and green roofs) in indoor energy consumption; Vahmani, Jones, and Patricola (2019) couple weather prediction models to urban canopy models to forecast the effect of green roofs in building energy demands in future weather scenarios. Culligan (2019) monitors green roofs to quantify their potential; to retain rainfall, reduce surface temperatures and sequester CO<sub>2</sub>. Scharf and Kraus (2019) couple ENVI-Met and GreenPass to assess the effect of different green roof areas in air temperature, Physiological Equivalent Temperature (PET), indoor air temperature, energy flux, thermal load, heat storage, comfort, run-off and CO<sub>2</sub> sequestration. Dunichkin, Poddaeva, and Golokhvast (2019) use CFD and wind tunnel tests to examine the placement of greenery in pedestrian comfort. Despite intentions to provide clear cause and effect relationships, these studies tend to be rather performance oriented detached from human and well-being needs.

Studies on bioclimatic comfort tend to be far more human-centric. There is a significant literature in the area of producing bioclimatic maps through Geographic Information Systems (GIS) to establish relationships between PET and urban density (Cetin, Adiguzel, Gungor, Kaya, & Sancar, 2019); identify optimal areas for comfort around cities (Cetin, Adiguzel, Kaya, & Sahap, 2018) considering meteorological factors and land coverage; assess suitability for tourism considering PET (Daneshvar, Bagherzadeh, & Tavousi, 2013) and Universal Thermal Climate Index (UTCI) (Roshan, Yousefi, & Błażejczyk, 2018); identify relationships between tourist activities and Temperature–Humidity Index (THI) (Ciobotaru, Andronache, Dey, Petralli, et al., 2019); automate the calculation of Heat Index (HI), Humidex (HU) and Wind Chill Temperature (WCT) for any region based on commonly available

meteorological data (Shartova & Konstantinov, 2018). The vast majority of these studies focus on the regional or city scale and are based on identifying or describing relationships between different temperature indices and land use or urban characteristics primarily in hot or moderate seasons. They do not explore cause and effect relationships between different urban parameters and greenery in temperature indices and pollution dispersion. They are difficult to be transferred to the neighbourhood scale as they do not consider microclimate effects in temperature and wind speed as well as how wind speed actually affects thermal perception particularly in cold climates. Authors (Andrade, Alcoforado, & Oliveira, 2011; Dunichkin et al., 2019; Oliveira & Andrade, 2007; Poddaeva, Dunichkin, & Gribach, 2018; Shartova & Konstantinov, 2018) emphasize wind as an important factor in comfortable environments particularly for cold regions. Liu and Kenjeres (2017) propose an integrated CFD and Computational Reaction Dynamics (CRD) model to couple wind speed with pollution dispersion but from a diagnostics perspective, whereas De Luca (2019) focuses on using sensitivity tests as a resource to explore changes in building clustering to modify outdoor wind patterns in the winter to improve the comfort of pedestrians. Dunichkin et al. (2019) discuss the role of greenery to manipulate wind patterns and, based on Dunichkin, Poddaeva, and Churin (2016) and Poddaeva and Dunichkin (2017), the authors propose a framework to discuss wind as a common factor of different environmental models coupled with greenery as a common design solution to manipulate wind to address different well-being goals.

### 1.3 Methodology

Most designers accept that design proposals come from the generation of a single option, from a repertoire of patterns compiled during long training through experience, from which plausible solution or options are identified by analogy, retrieved and evaluated through mental (or computer-based) simulations (Broadbent, 1988; Goldschmidt, 2001; Schon, 1991 to cite a few). Either when approaching design from this perspective or from a more ‘modern’ perspective undertaken in parametric design environments, in which causal effects of specific design actions are assessed in relation to a series of, primarily formalistic, KPIs (Hudson, 2010; Oxman, 2017; Woodbury, 2010), there is normally a lack of clarity in relation to how, or according to which criteria, plausible options are assessed or evaluated. Design scholars (Lawson, 2005; Schon, 1991, to cite a few) claim this is because the designers tend to assess their design proposals based on what they like better.

[Design] moves are evaluated in terms of how desirable their consequences are in relation to intentions, how desirable the moves are in terms of their conformity to or violation of implications setup by earlier moves and how desirable the moves are in terms the designer’s appreciations of the new problem or potentials they have created. (Bleil de Souza & Tucker, 2015: 60).

Whereas this workflow is flexible and adaptable to the pursuance of integrated design solutions and this is already recognized by standards demanding narratives to explain compliance, it needs clarity in relation to how design specifications are written and can be achieved, so that tight mandatory regenerative targets, from different expert domains, can be fulfilled through integrated/common design parameters. This work elucidates, in theory, that Axiomatic Design is a plausible method to assess design decisions throughout the design process, so multiple domains can interact in factual discussions substantiated by evidence.

Originally developed as a product design method, Axiomatic Design provides a design specification model based on.

[...] principles of functional independence and complexity minimization [in which] problem and solutions are systematically specified in parallel, moving down along the hierarchy and design decisions are made in an explicit way maintaining data. (Marchesi & Matt, 2016: 157).

As displayed in Fig. 1.1, design specifications are built considering customers' needs and aspirations, functional requirements needed to achieve them, design parameters to fulfil these requirements and manufacturing parameters to build the proposed solution (Suh, 2001). Two axioms need to be fulfilled: (i) Functional requirements need to be independent from each other and displayed in a matrix to relate them with design parameters in a controlled format; either diagonally showing full independence (see Fig. 1.1) or triangularly showing their independence can be guaranteed only if design parameters are determined in a proper sequence. (ii) The design content must be kept to a minimum, and the design success with its inherent complexity in terms of information content, is judged in relation to the range of tolerances provided by each design parameter to fulfil required range of tolerances for each functional requirement, as displayed in Fig. 1.1.

## 1.4 High-Level Requirements and Their Tolerances

Figure 1.1 provides a theoretical framework to be followed when developing specifications for regenerative climate adaptive urban design. It starts by inviting designers to carefully examine what are people's needs and aspirations in relation to outdoor urban environments. These needs and aspirations need to be translated into functional requirements, that is, the aims that a project needs to fulfil at an abstract level to be successful. Providing comfortable and inviting outdoor spaces that promote well-being through human interaction and interaction with nature can be translated into the following non-exhaustive list of functional requirements (expressed as 'level 1' in Fig. 1.1):

- Provide comfortable spaces to walk
- Provide comfortable spaces to wait/stay
- Provide opportunities to meet other people
- Provide spaces for children to play

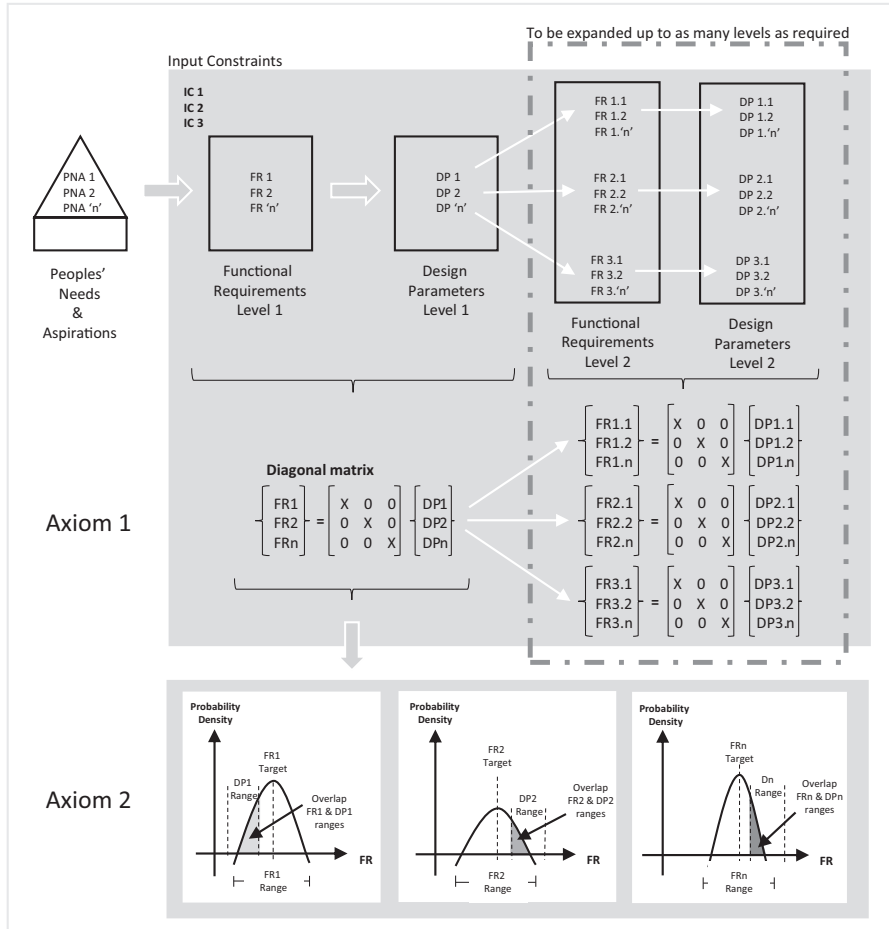


Fig. 1.1 The Axiomatic Design approach and its two main axioms

- Provide adults with space for outdoor activities and sports
- Provide spaces to relax and contemplate
- Provide greenery

The aforementioned functional requirements are solution neutral, that is, they do not determine space configurations or shapes to be used in the proposed solution and can be transferred and reused in multiple projects. This promotes clarity and transparency of specification criteria facilitating the dialogue among different disciplines in achieving integrated concrete solutions as experts from different domains will share common design objectives. In addition, it facilitates the catering for these requirements through ideally independent design parameters (as per Fig. 1.1 ‘Axiom 1’). Functional independence is not supposed to be confused with physical independence (Suh, 2001) but guarantees all the needed requirements to be met, producing important benchmarks for quality control.

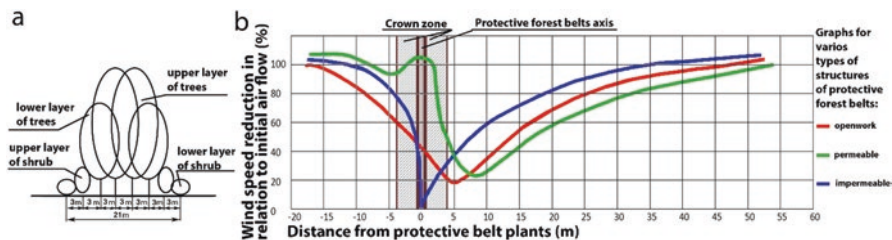


Regardless of what design parameters are proposed to address these functional requirements, these design parameters have to fulfil another set of environmental requirements related to safety (particularly to extreme climates) and comfort (expressed as 'level 2' in Fig. 1.1). These requirements have prescribed tolerances in relation to human heat balance which need to be met through acceptable outdoor temperature ranges and acceptable ranges for wind speed considering avoiding snow drifts, excessive pressure on the eyes and the concentration of harmful substances in the air. The authors recognize that acceptable noise, humidity, daylight and insolation levels should also be factored in as part of these environmental parameters, but want to illustrate the importance of wind as a key environmental parameter to enable mobility (through avoiding snow drifts and disorientation due to excessive eye pressure), safety (through preventing frostbites) and comfort (through regulating outdoor temperatures), a gap highlighted in the literature review.

Wind speeds are defined based on Dunichkin et al. (2016). They are calculated considering wind gusts and acceptable ranges to reduce concentrations of chemically active dust (rubber, soot and benzopyrene) as well as bio-pollutants (aeroplankton, spores of fungi and mould etc.). Acceptable ranges to avoid eye discomfort and acceptable ranges to prevent snow drifts are also based on Poddaeva, Churin, and Dunichkin (2016), and combined effect on human heat balance is based on the results of solving the heat balance equation limits which is a better indication for cold climates (Shartova & Konstantinov, 2018) as it enables the assessment of 'possible health danger for pedestrians due to frostbite' (De Luca, 2019).

From an overlay of the aforementioned information, acceptable temperatures vary from  $-15\text{ }^{\circ}\text{C}$  to  $30\text{ }^{\circ}\text{C}$  and acceptable wind speeds vary from 1 m/s (below which there is a high concentration of pollutants and a likelihood to increase the height of snow drifts) to 5 m/s (above which there is discomfort in the eyes). These ranges for functional requirements need to be fulfilled by design parameters with tolerance ranges which are able to meet these requirements. However, the design content must be kept to a minimum, meaning an integrated physical solution needs to fulfil each functional requirement independently. Greenery is proposed as the integrated solution to control wind speed and direction. It contains design parameters which will help coordinating desirable density and permeability in relation to wind in addition to properties which enable the control of daylight, insolation, pollution, temperature and humidity.

Design parameters related to windproof, snow and dust containment properties were extracted from semi-parametric studies of green belts. Several scientific organizations during the Soviet Union (USSR), including the Dokuchaev Scientific Research Institute of Agriculture of the Central Black Land Strip, developed protective forest belts that had windproof properties and contained the transferring of snow and dust. Smalko (1961) and Vinokurova (1953, 1970) assisted in parameterization and introduced new terms on the openwork of forest belts (i.e. definitions for different greenery arrangements with corresponding percentages of permeability for different greenery layers), which were used to develop recommendations for greening cities in the works of Mashinsky and Zalogina (1978), as well as in the work of Chistyakova (1978). Results from these studies were included in terms and



**Fig. 1.2** (a) Example of a recommended planting scheme for protective forest belts with trees and shrubs based on the work of Pokrovsky (1991–1996); (b) Typical graph for wind-protective properties of a forest belt with various types of structure based on the work of (Gorokhov, 1991)

definition of the state standard GOST 26462–85 for Agricultural afforestation developed by the USSR Ministry of Agriculture (GOST, 1986) and later listed in the Small Medical Encyclopedia (Pokrovsky, 1991–1996) as useful to regulate the effects of harmful substances and noise.

Figure 1.2a displays an example of forest belt profile showing an arrangement of rows of shrubs (lower layer and upper layer), auxiliary trees and main species (lower layer and upper layer respectively) with a total configuration width of 21 m based on the work of Pokrovsky (1991–1996). Figure 1.2b shows a typical graph for the pattern of change in wind speed behind a protective forest belt depending on the distance from it based on Gorokhov (1991), illustrating the parameterization of wind speed in relation to distance from greenery for a given configuration.

In relation to snow containment, the general rule is ‘snow is eroded from the surface where wind speed increases and deposited where the wind speed decreases’ (Thordarson, 2002: 17). Wind speed affects snow saltation due to shear stress and this contributes to the ejection of snow particles from a surface. Higher wind speeds also promote snow suspension and therefore transport, which depending on the height of travelling can result in sublimation. However, conditions for snow drifting also depend on the properties of snow cover, with recent or loose snow likely to be dispersed at lower speeds compared to hardened snow.

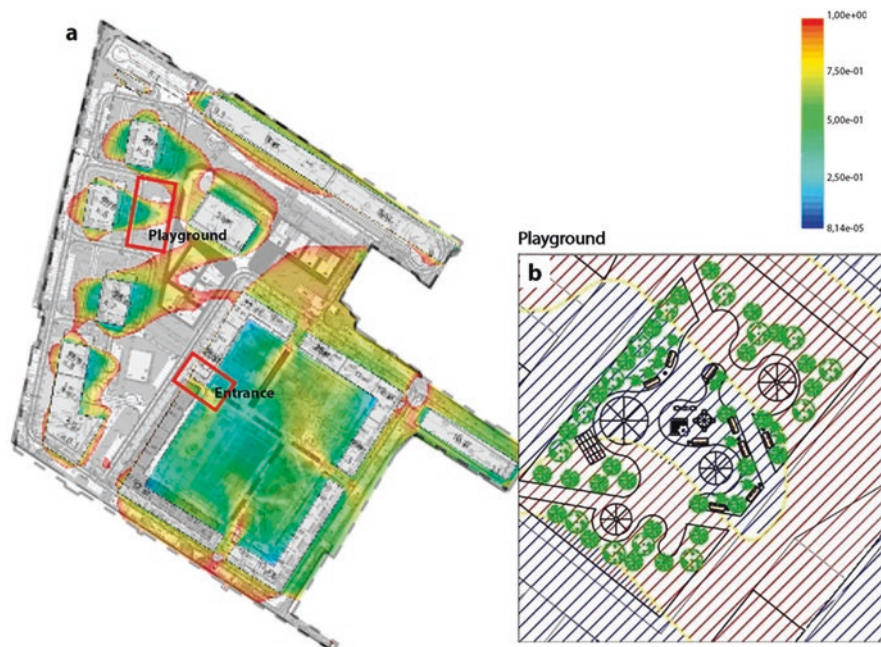
From the aforementioned studies related to the semi-parameterization of wind speed in relation to different green belt configurations, a set of suitable alternatives of greenery can be selected to test their likelihood to respond to specified ranges of functional requirements. Thus, the probability of success of an outdoor space to be safe and comfortable is governed by the intersection of the design range specified to satisfy the aforementioned requirements and the ability of the system to deliver the conditions within the specified range (as expressed in Fig. 1.1 ‘Axiom 2’). Wind tunnel tests or CFD simulations can then be undertaken to examine how successful a design proposal is considering the stochastic nature of wind speed, frequency and direction in a given urban environment.

Section 1.5 illustrates findings from a previous study summarized in Dunichkin, Poddaeva and Golokhvast (2019) which provides an example of this testing to improve the outdoor conditions of a residential development in Moscow. These were undertaken at the Laboratory for Aerodynamic and Aero Acoustic Tests of

Building Structures, Department of Physics and Building Aerodynamics of Moscow State University of Civil Engineering. They recorded wind speed attenuation as well as height reduction of snow drifts for a set of preselected greenery configurations likely to provide acceptable design tolerances to fulfil functional requirements related to mobility, safety and comfort. Full results of this testing can be found in Dunchkin, Poddaeva and Churin (2016).

## 1.5 Application: A Case Study in a City

Figure 1.3a shows the result of overlaid thresholds for functional requirements in space after wind tunnel tests and CFD simulations for the Varshavskoye Highway development from the case study undertaken by Dunchkin, Poddaeva and Churin (2016) and Dunichkin, Poddaeva and Golokhvast (2019). Coloured areas indicate zones with wind speed of less than 1 m/s for the most frequent wind directions. They offer low risk of frostbite in the winter as average temperatures are around  $-15\text{ }^{\circ}\text{C}$  and average wind speed is 3.2 m/s. However, they are poorly ventilated when the wind blows from east and west (0.45 m/s). When this happens, an accumulation of pollutants and the formation of snowdrifts can occur. Ideally, the wind



**Fig. 1.3** (a) Overlaid thresholds for acceptable ranges of wind speed in m/s in the case study; (b) a zoom into an area in which mitigation strategies are proposed based on Dunichkin, Poddaeva and Golokhvast (2019)

speed in these areas should be on average 2.2 m/s and the wind speed outside these areas reduced respecting the 30 min of time restriction for an adult to stay outside at average monthly wind speed and air temperatures as low as  $-18^{\circ}\text{C}$ . This figure is based on the recommendation from the Federal Service for Supervision of Consumer Rights Protection and Human Well-Being from the Russian Federation official document (Onishchenko, 2006). The document states that the time limit for staying outside is approximately two times greater than the WCT time recommended by Nelson et al. (2002), due to the use of warmer clothes, hats with face protection from the cold and considering the type of physical activity performed.

From the overlay displayed in Fig. 1.3a, it is possible to determine what kind of greenery should be used and where it should be placed to promote urban climate adaptation of outdoor spaces in this settlement. Zones of excessive wind speed were treated with specific rows of trees and shrubs to direct wind flow and reduce wind speed whereas zones of wind speed above the pollution threshold (i.e. very low wind speed) were treated with greenery to avoid snow drifts and absorb pollutants. The initial selection of greenery is based on parametric guidelines provided by the literature as discussed in Sect. 1.4, as it contains design ranges likely to fulfil functional requirement ranges specified for mobility, safety and comfort. Once positioned in space, another round of wind tunnel tests and CFD simulations are undertaken to verify the effectiveness and ability of the system to deliver the conditions within the specified range, that is, how successful is the strategy in improving outdoor space conditions. Results are provided in quantitative terms (%) and therefore can be easily audited.

Figure 1.3b illustrates the use of greenery as a mitigating strategy to promote climate adaptation to enable a space for children to play. In Fig. 1.3b, zones of excessive wind speed are shown in blue hatch and rows of shrubbery are positioned around the perimeter of sitting areas with 0.5–2 m spacing, followed by a second row of trees with 5–8 m spacing, configurations which proved to reduce wind speed by 14–21%. Greenery is also used at the borders of the playing area within the red hatch zones to reduce the height of snow drifts by 19–27% where they could also, in theory, absorb pollutants. Figure 1.3a also shows the areas around building entrances as potentially problematic due to high wind speed which were reduced by 10–17% through a single row of coniferous trees or ordinary plantings of deciduous trees (spaced by 8–12 m), intercalated with single-row plantings of coniferous shrubs with thick dense crown (spaced by 1–3 m) or dense single-row plantings of deciduous shrubs (spaced by 0.5–2 m). A summary of the full set of urban climate adaptation measures for this settlement can be found in Dunichkin, Poddaeva and Golokhvast (2019).

## 1.6 Discussion and Conclusion

This chapter illustrated how Axiomatic Design can be an efficient method to develop transparent design specifications for regenerative climate adaptive urban design. It showed that the whole design process can be rationally described and therefore

becomes easier to coordinate, as well as opened to scrutiny by any of the stakeholders involved. It also provided benchmarks for design quality control through the application of axioms 1 and 2. Applications of the first Axiom resulted in the development of high-level functional requirements which are human-centric, non-discipline specific and need to be fulfilled independently. Applications of the second Axiom resulted in design solutions expressed in terms of their probabilities of fulfilling the range of functional requirements they should cater for.

These applications illustrated that a human-centric set of high-level functional requirements can be a powerful coordinator for environmental requirements related to safety and comfort to be listed and overlaid with regard to their acceptable tolerances. These tolerances can then be used as boundaries to set acceptable tolerances for the different design parameters to be proposed. It focused on the role of wind in affecting different environmental requirements and proposed the use of greenery as an integrated mitigating strategy to manipulate wind speed in order to fulfil different functional requirements. The matching 'requirements-solution' was illustrated through an example of previous work which showed that acceptable tolerances for wind speed once matched with semi-parameterized greenery arrangements in relation to acceptable ranges of wind speed attenuations can minimize trial and error to position design solutions in situ.

The matching pair 'problem-solution' is not new and was originally proposed by Alexander, Ishikawa, and Silverstein (1977) using an archetypal language in which recurrent problems are described in an abstract way so they can be recalled and reused several times without yielding the same design solution. By comparing results of this experiment with the archetypes proposed by Alexander, Ishikawa and Silverstein (1977), the authors suggest that future work could be developed around integrating the environmental domain with the social domain. The work in this chapter, for instance, relates in particular to patterns 60, 106, 68, 102, 115 and 121 from Alexander, Ishikawa and Silverstein (1977). The idea of using greenery as an integrated design solution fits with pattern '60 Accessible green', which states greenery needs to be 3 min away from users, so distance does not overwhelm the need. It also fits with pattern '106 Positive outdoor space' which enclosed by greenery responds to specific outdoor functions rather than being a 'left over' between buildings. The positioning and configuration of the playground somehow fit with the pattern '68 Connected play' as greenery is used to configure a more comfortable environment to play, safe from traffic, whereas the treatment of building entrances somehow fits with pattern '102 Entrance transition' as greenery is used to mark a change of feeling, protecting entrance areas from the wind. Notable connections can also be found with pattern '115 Courtyards which live' and '121 Path shape' in which walkability and spaces to wait can be merged, facilitated by outdoor comfortable conditions shielded from the wind. More discussion is needed to integrate the environmental with the sociocultural, but the establishment of human-centric functional requirement as coordinators for environmental requirements and design parameters is a promising start.

To the best of the authors' knowledge, no similar methodological approach was proposed using clear scientific tested examples for coupling wind speed and

greenery, with wind speed being a common environmental parameter to many different types of comfort and pollution models and greenery being a common type of integrated design solution to urban climate adaptation. This being the case, the authors also suggest that future studies can be developed to transform the second Axiom into an assessment process embedded in a parametric software design library to inform designers of potential ‘problem-solution’ matches to minimize trial and error as well as the number of simulations to verify in situ response.

Robust design specifications are an under-explored domain of urban design, perhaps because urban design problems traditionally fall within the umbrella of wicked problems, in which contradictory and changing requirements are to be reconciled. This work attempted to provide better means for design scrutiny, essential not only to organize and reconcile arguments but also to evidence regenerative solutions. Beyond that, it expects to have opened avenues to structure design knowledge in an instrumental way to urban designers facilitating knowledge transfer and management without hindering creativity by remaining open to the use of different concept generation methods but providing a robust test base for solutions which emerge from them, at the same time feeding back on the climate impact on humans in the urban environment.

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# Chapter 2

## Regenerative Design Tools for the Existing City: HBIM Potentials



Carlo Bianchini, Martina Attenni, and Giorgia Potestà

**Abstract** The first 25 years of the so-called ‘digital revolution’ have deeply changed the methods and tools of our interaction with the ‘architectural domain’. Traditional lines sketched on traditional paper have been soon replaced by digital mathematical entities created by Computer Aided Design (CAD) systems. Nowadays, we are witnessing a similar shift this time from CAD to the Building Information Modelling (BIM), a system that shows the ability to manage the fragmented but interconnected information needed in building workflow in an ‘all-in-one’ environment. However, while BIM is already a powerful option for new structures, for existing ones (especially when historical) it still reveals inadequate. This issue, seriously affecting the future of the built environment, cannot be ignored in order to control the ‘shaping’ of buildings and cities and especially when their design aims at becoming ‘regenerative’. In this framework, this chapter will try to outline the many difficulties connected with the application of BIM to the existing building stock: a problem that is generally regarded as ‘sectorial’ but that on the contrary will be crucial in view of a probable generalized adoption, considering that existing constructions represent about 70% of the whole European stock.

**Keywords** BIM · HBIM · Level of development · Level of detail · Level of reliability · Semantic structuring

### 2.1 Introduction

Existing buildings always represent for designers a prickly subject to handle. The core of the problem is that they keep undisclosed the majority of information about their inner nature, structure and consistency. Designers and all other actors involved in their transformation (restoration, retrofitting, rehabilitation etc.) must address this

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issue and continuously try to fill the gap between the desirable and available information (Bianchini, Inglese, Ippolito, Maiorino, & Senatore, 2017).

This well-known condition has been always assumed as a constraint by designers, a sort of red line to coexist with during any project involving existing buildings (Brusaporci and Trizio, 2013).

The first 25 years of the so-called digital revolution have deeply changed this consolidated scenario. Digital technologies have in fact produced a wide bundle of hardware and software tools paving the way to a renovated interaction between our real world and its virtual version (Addison & Gaiani, 2000; Carbonara, 2009). On one side, terrific advancement has been made in the field of capturing data from objects (Bianchini and Russo, 2018); on the other, the digital modelling software has disclosed the possibility of virtually reconstructing them, interacting with them and simulating their possible transformations (Bianchini, Viscogliosi, & Aglietti, 2017).

Core of this interaction is the Model, namely the virtual simulacrum of a real element, which represents the goal and the medium of this interaction (Bianchini, Inglese, & Ippolito, 2016b).

While for many years now the Model has been a major topic of research (and concern) for scholars and technicians, more recently the focus has been shifting towards the ‘Modelling’. This last term does not refer in fact to the simple output, but better to the set of decisions and actions guiding the process of construction and information (in the sense of defining an informative content) of all digital elements composing, together, the final object (Bianchini & Nicastro, 2018).

From this standpoint, Modelling certainly implies *constructing* in accordance with logical and practical rules not afar from those that typically govern a construction site. In fact, as in the building practice, we must disassemble the fabric into an analytic catalogue of elements and organize the site and the sequence of works, in the same way the construction of a 3D Model must approximately respect the same workflow and constraints. In a BIM process, the identification and generation of BIM digital objects is generally called Semantic Segmentation (Grussenmeyer et al., 2008).

In this framework, the construction of 3D Models is a real *heuristic* activity: differently from graphic 2D models (drawings), in a 3D Model one cannot afford to leave any portion of the object undefined, as anything can become visible and anything is visible during its exploration.

Moreover, buildings are a coordinated set of basic elements (Bianchini, Inglese, & Ippolito, 2016a) following design patterns and construction workflows to a certain extent predictable and governable. Besides, any element must be *augmented* with additional content in order to show not only its quantitative properties (i.e. geometry) but also its qualitative ones (material, physical parameters, performance etc.).

BIM systems actually provide a digital environment capable to host, organize and interact with all this information by means of the 3D Model that, at a certain extent, could become an access door to the building’s informative database.

This well-known feature of BIM systems and models corresponds to their utmost benefit during the decision-making and construction workflow as it corresponds to an overall optimization of processes in terms of cost reduction and efficiency.

However, the potential impact of BIM complex informative models exceeds the mere technological sphere representing instead an actual cultural progress, thanks to their ability to foster the readings of architecture through its constitutive elements (Brusaporci, Maiezza, & Tata, 2018).

However, BIM works quite well when addressing new buildings essentially because being ourselves the decision-makers, at least in principle, we can know in advance all information about both the elements and their assembling.

This mechanism fails if analysed in the context of existing buildings. Although they can be disassembled into recurring elements, yet their modelling (parametric and informative) is far more difficult. It must in fact deal with both the geometric conversion of the real-world continuity and the definition of its qualities and semantics. These problems must be regarded also in connection with the essential inelasticity of parametric modelling, subjected to digital ‘libraries’ of objects that predictably would clash against the holistic character of the built environment, especially when it is layered or deteriorated.

This evidence has led scholars and professionals to introduce a specific name for the BIM systems applied to existing buildings adding the prefix ‘H’ that stands for Historic or Heritage.

Apart from this linguistic definition, the more the HBIM approach is studied and analysed, the more it appears separate from ‘classic’ BIM (López et al., 2018). Although sharing the same digital infrastructure, in fact, HBIM shows very specific problems, limits and workflows that in some occasions seem not to have much relationships with the ones typical of BIM (Baik, 2017).

## 2.2 Knowledge Versus Modelling

The study of any built artefact implies to the setup of a Knowledge System appropriate for collecting, storing and querying the information retrieved (Apollonio, Gaiani, & Sun, 2013; Bianchini, 2014).

As mentioned in the previous paragraph, several are the components of this system: ‘quantitative’, (generally coming from surveying/diagnostic activities) and ‘qualitative’.

While the former can be labelled as ‘scientific’, the latter draw instead on the scholar’s sensitivity and skill, often the most relevant ingredient for understanding the essence of buildings.

This process is paramount when dealing with existing buildings when the construction of a consistent and rigorous multidisciplinary database represents a key task as well as the cooperation of different skills in suggesting interpretations that transcend the single expertise.

Moreover, while Popper's irrefutability concept (Popper, 1963) still marks the qualitative component, the quantitative one depends on the contrary on Survey, one of the most acknowledged tool set up overtime by scholars in order to enlighten the metric and geometric consistency of artefacts (Docci, Ippolito, & Bianchini, 2011).

Survey actually encompasses the notion of 'measurement', that is, the possibility of turning into quantity some qualities of a phenomenon by using the ratio between the measured quality and a suitable unit of measure.

However, measurement itself cannot give access to the qualitative level of information that instead can be collected and interpreted by mining data from very different (in many cases scattered) 1D (texts) and 2D (images, drawings, instrumental readings etc.) sources. In this phase, we cannot even neglect less structured information coming from intuitions or suggestions.

The 3D Model represents the synthesis of the process, more intellectual than operational, the Modeller (i.e. the maker of the Model) has used to show his/her reconstructive hypothesis. HBIM systems actually implement tools both to build the geometry of the model and to attach the related information to its single digital components. As for the first aspect, the leading BIM authoring software currently allows for an overall smooth editing and management of massive 3D data (point cloud) (Logothetis, Karachaliou, & Stylianidis, 2017).

While the passing from a numeric to a geometric model implies the transition from isolated points (in billions by now) to a continuous surface (Mesh or NURBS – Non-Uniform Rational B-Splines) or an aggregation of 3D solids, the construction of the BIM model encompasses an additional interpretative effort: the semantic structuring of its composing elements. This ontological and subjective step exceeds the simple geometric identification of elements. The Modeller, in fact, must shift from the real to the digital continuum (Inzerillo, Lo Turco, Parriniello, Santagati, & Valenti, 2016) exploring a realm, hierarchical and additive, where all digital objects must find their own place within the BIM environment. Hence, the combination of these objects, subject to mutual relationships of nesting or belonging and to rules and constraints of interaction, controls the progressive construction of BIM and HBIM models.

Assuming the reading of an existing building not as a simply quantitative task, one must couple the mere metric investigation to the study of the cultural, technological and historical features making that particular object 'one of a kind'. Currently, automatic systems are not a viable option in order to reach this level of understanding and this is why the semantic structuring of the HBIM model is crucial to transcend the mere taxonomic description of buildings (Acierno, Corsi, Simeone, & Fiorani, 2017; (; Fallavolita, Ballabeni, Foschi, & Perugini, 2015; Quattrini, Pierdicca, & Morbidoni, 2017).

Although concerning Cultural Heritage computer-based visualizations, still the London Charter (Denard, 2016) provides many hints about the role of new digital tools in connecting different pieces of information. In particular, the Charter defines as Dependency Relationships the implications (that) each piece of knowledge might be for each other piece of knowledge by means of the iterative, systematic comparison between hypotheses and data. These remarks can be usefully adopted to describe

also the relationship between quantitative and qualitative information stored in a HBIM model.

### 2.3 Geometry and Semantics in HBIM Models

In the last years, the problems described in the previous paragraphs have been tackled in some research projects with the objective of outlining a common scientific framework.

As a collateral product, these projects have led to the setup of a workflow for the decomposition/recomposition of existing buildings in a HBIM environment based on geometry and semantics.

The main issues tackled are listed below:

- Semantic modelling versus continuity of surfaces
- Standardization of HBIM components versus geometric and material heterogeneity
- Reliability of models as ratio between a subjective version of the object and the almost objective captured data

The research presented in this chapter describes three different case studies: in Rome, the Faculty of Botany by the architect Giuseppe Capponi in Sapienza University Main Campus and the Temple of Claudius, and in Florence, the Baptistery of Saint John (see Fig. 2.1).

The Faculty of Botany is a rationalist building, easier (ostensibly) to model in a HBIM environment due to its typological, geometric-morphological and compositional clarity. The Temple of Claudius is instead a much-layered building, dating back to the first century AD, with a strong archaeological character. The Baptistery of Saint John is a worldwide-celebrated monument that reached its current form mainly in the XIV/XV centuries.

The theoretical implications of the workflow described in this chapter are rather complicated because in many occasions the modelling must go beyond the measurable features of the artefact. As we have already mentioned in the previous paragraphs, this refers to the subjective skills and approach used by the Modeller during his/her interpretative work.

However, the collection and analysis of survey, semantic and typological data have proved to be necessary steps for the discretization of visible parts, the definition of materials, the conjecturing of construction rules and the identification of the transformations the building has undergone (see Fig. 2.2).

This cognitive aspect is also fundamental for the setup of consistent HBIM libraries. These repositories of digital objects provide in fact information (like materials and building components/nodes, their historical and cultural relevance and state of conservation) that go beyond the skin of the building.

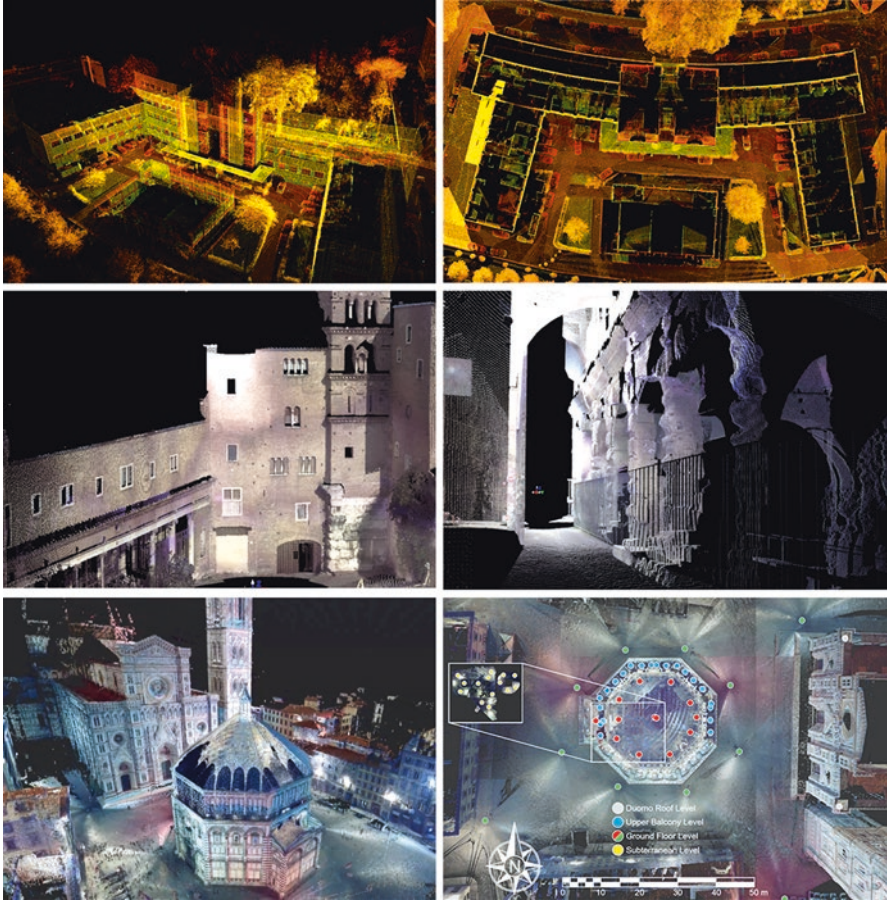


**Fig. 2.1** The analysed case studies. Top left: the Faculty of Botany at Sapienza University (Rome); right: the Temple of Claudius (Rome); bottom: the Baptistery of Saint John (Florence)

However, parametric and informative modelling clash against the difficult geometrical shaping of the real-world continuity both in terms of poor libraries/reality correspondence and simple lack of information.

Referring to the Faculty of Botany, the coding and modelling of objects have mirrored the original design logic (see Fig. 2.3) trying to respect their serialization that has been managed in the HBIM process by acting on the dimensional parameters of structural elements and windows (see Fig. 2.4).





**Fig. 2.2** Surveying of analysed case studies, views of the numerical model, RGB reflectance and RGB colour. Top: the Faculty of Botany at Sapienza campus, middle the Temple of Claudius; bottom: the Baptistery of Saint John

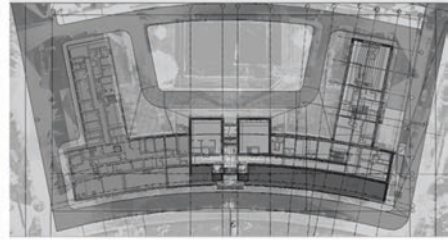
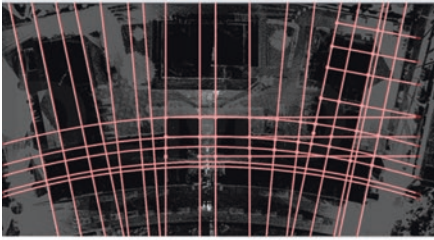
The 3D capturing campaign provided information about dimensions, geometry, materials and state of conservation of surfaces becoming, eventually, the actual backbone of the entire informative database.

For the Temple of Claudius, instead, it was impossible to refer to the original design and thus the surveyed data were taken as fundamentals for interpreting the irregularities of that layered complex while the proportional and metrological analysis guided the modelling phase (see Figs. 2.5 and 2.6).

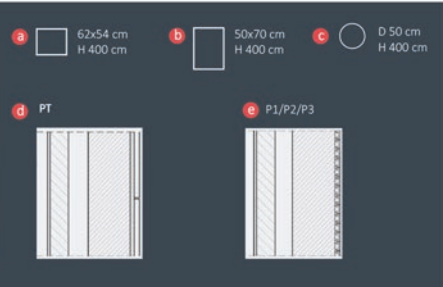
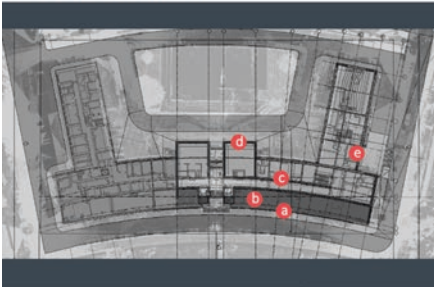
For the Baptistery of Saint John, the approach was somewhat halfway between the previous two.

The original design was not available also in this case, but many documents were providing valuable information about its evolution starting soon after its completion. The comparison between this wide documentation and the detailed 3D data

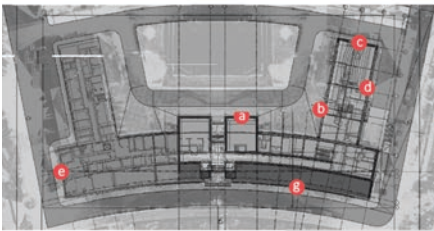
# 1 Construction grid



# 2 Vertical structure



# 3 Curtain wall/windows



# 4 Horizontal structure

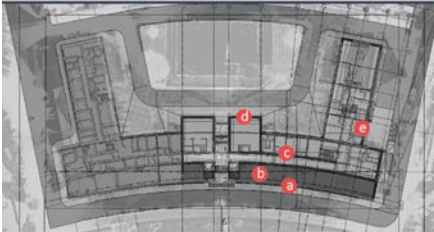
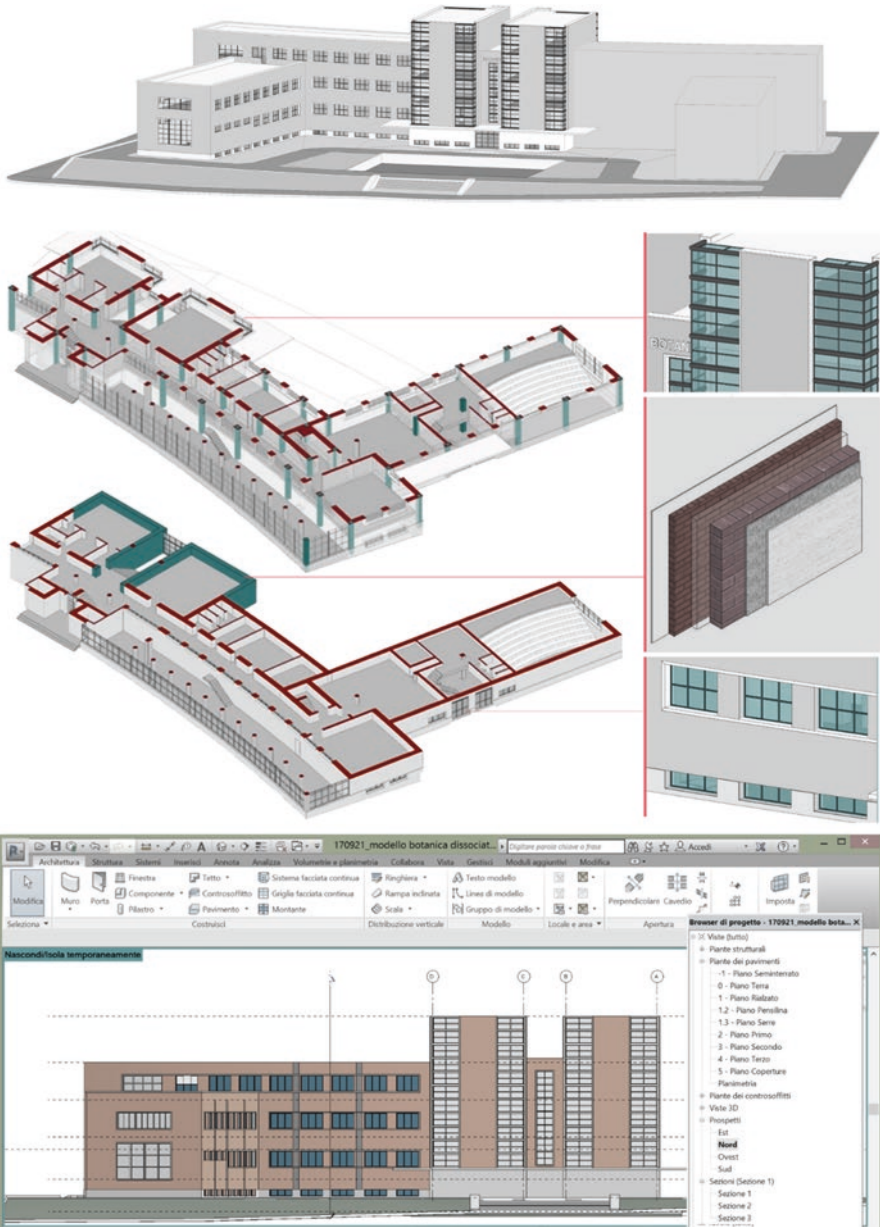


Fig. 2.3 The Botany Institute. Breakdown of architecture



**Fig. 2.4** The Botany Institute. Architecture reconstruction through BIM processes. Details of ground floor, windows and walls

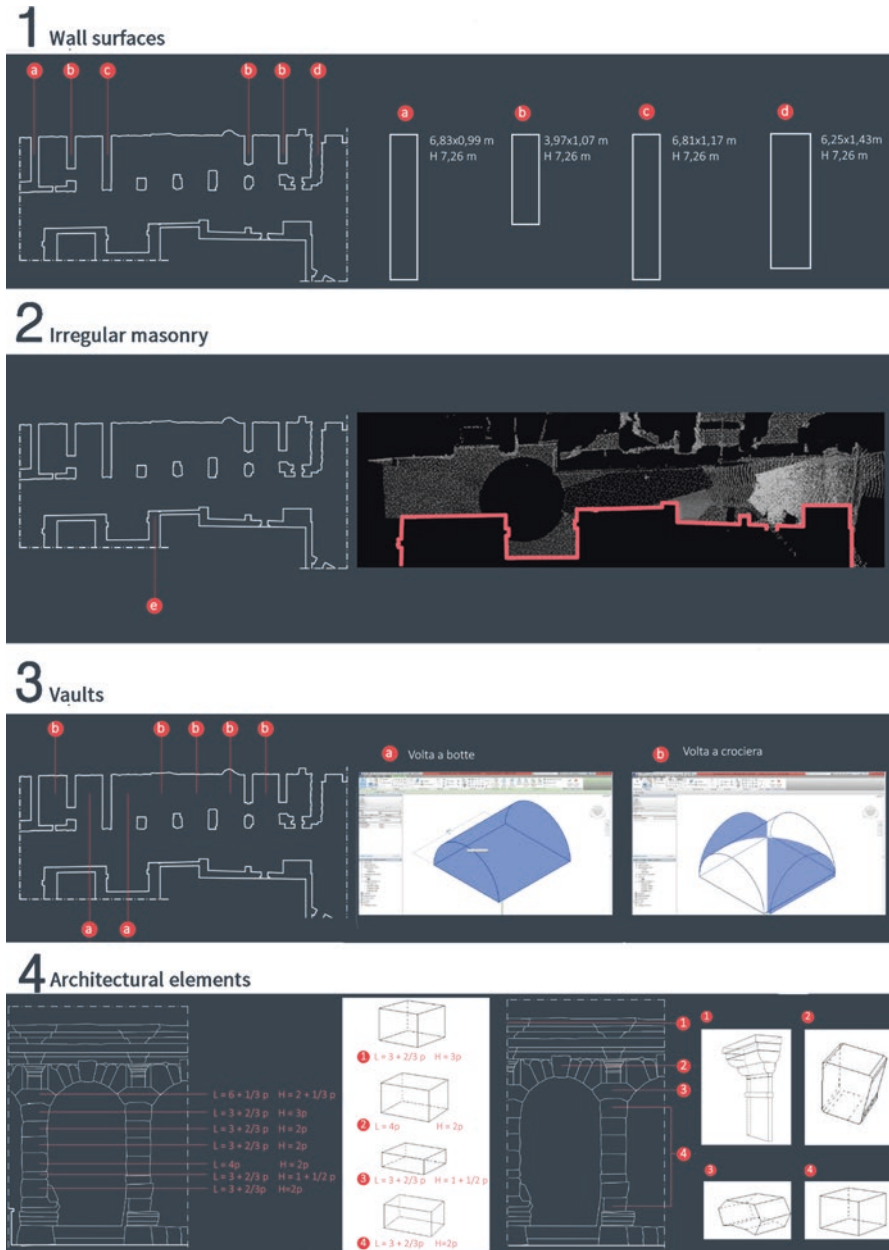
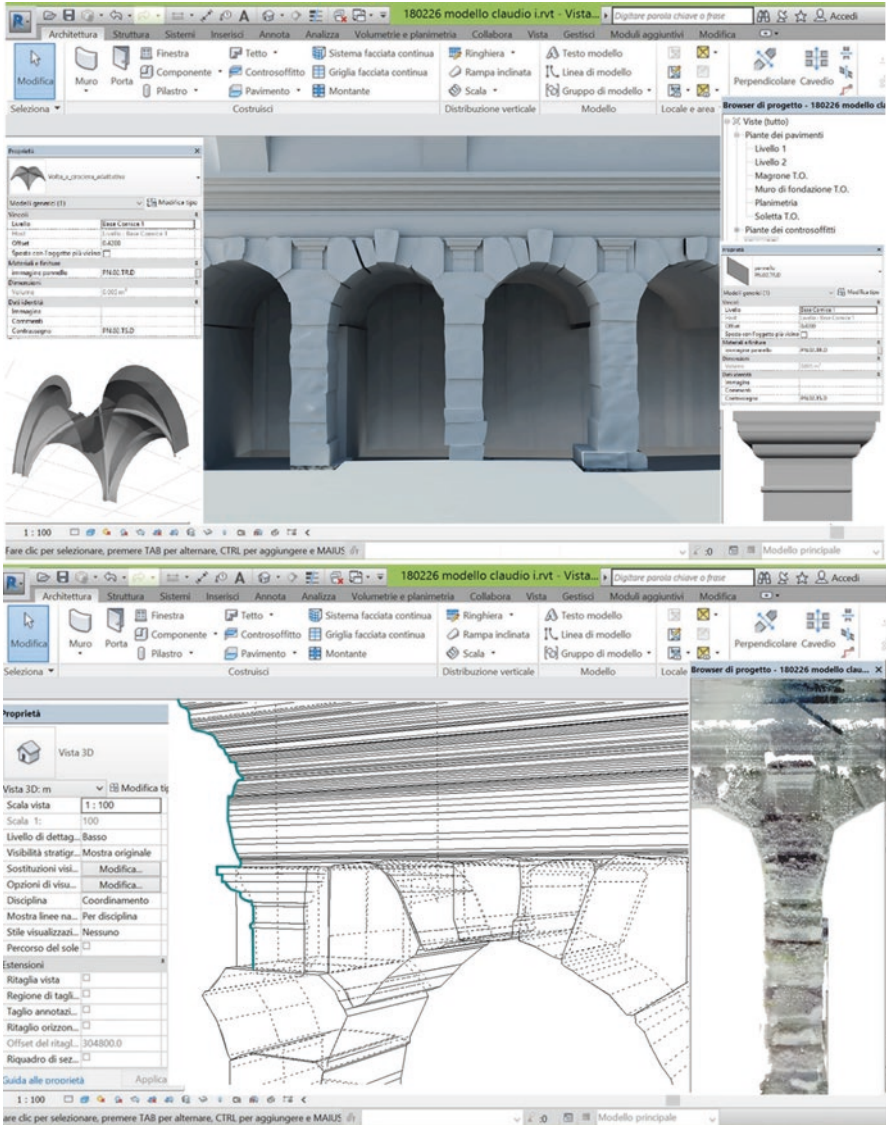


Fig. 2.5 Temple of Claudius. Breakdown of architecture



**Fig. 2.6** Temple of Claudius. Architecture reconstruction through BIM processes: structural and architectural elements

coming from a survey campaign carried out in 2013 by the Center of Interdisciplinary Science for Art, Architecture and Archaeology (CISA3) from University of California San Diego led to the HBIM modelling of the monument (see Fig. 2.7).

After these preliminary analyses, we began to work at the HBIM model of our three case studies.



Fig. 2.7 Baptistery of Saint John. Breakdown of architecture

For the Faculty of Botany, we started from the analysis of 1D and 2D data coming from archival and bibliographic research, and from an in-depth analysis of the 3D data collected during a survey campaign. The data processing has been followed by a general setup of the HBIM model with the main objective of creating a database that could be enriched over time.

Given these theoretical and methodological remarks, the preliminary study on the most effective layout of virtual informative models has proved crucial and actually propaedeutic to the actual modelling phase.

In this gradual process of acquaintance and information structuring, we constantly tried to depict a workflow valid and coherent in terms of scientific rigor and of expected results. Thanks to the application to this first case study, we soon realized how much the HBIM systems could affect the methodological and procedural choices since the very early stages (i.e. since the survey project). While designing a HBIM-oriented survey, in fact, we must already imagine the working methodologies to be adopted in the modelling environment.

Therefore, we cannot establish a standard workflow valid regardless of the peculiarities of the object. On the contrary, we must provide tailor-made indications based on the preliminary study about the most appropriate approach vis-à-vis the decomposition and parameterization of the specific studied building. In brief, we should mistrust simplistic theorizations in favour of some-what holistic methods and strategies.

In our case, the different sub-models (for type and source) composing the general database coexist in the unique workspace created by the HBIM system. This is in fact the environment where the interactions among the 1D information, the 2D support drawings (including the project documentation) and the numeric model made by the captured point clouds (topographic, 3D scanning and Structure from Motion) have taken place.

The goal of HBIM processes is to transform the material elements into digital correspondents: in our case the level of this relationship has been quite satisfactory as the model of the Institute of Botany corresponds quite closely to its present state. In other words, the differences between the original and current layout introduced by the construction itself still allow for a full exploitation of the parametric modelling approach typical of BIM systems.

This method had to undergo some modification for the Temple and the Baptistery.

As for the latter, although we have no trace of the original design, we could nonetheless guess much information from the documents and the many available drawings. Its original layout, even if with less reliability in comparison with Capponi's project blueprints, was still a sound option to start the modelling.

Yet in this specific case, we experimented an automatic approach to the semantic segmentation of part of the building applying a deep learning algorithm (Bengio, Courville, & Vincent, 2013). In brief, this particular method uses artificial neural networks with the objective of performing complex recognition tasks. In our case, we adopted a supervised learning approach based on a set of already available training examples.

In our preliminary tests this method has shown an interesting impact due to its ability to segment and organize potentially any model in the form of a knowledge system. The algorithm, in fact, can help on one side in disassembling the building in a collection of hierarchically organized elements referred to a specific architectural vocabulary. On the other, the segmentation of the model into sub-elements can be based on the analysis and composition of the formal structure of objects, organized in hierarchical levels and aggregation's classifications.

Nonetheless, these systems are still quite rudimental even if promising. This is why we still had to analyse manually how all the identified objects were assembled (typologically and morphologically), to understand and establish how each element was made and how it referred to the others within the model.

The simplifications and approximations made for the Temple of Claudius aimed instead at finding a balance between a geometric and aggregative logic of elements and the holistic character of the artefact.

The breakdown of its components starting from its design layout would have made in fact no sense being what we see today only a small part of the huge ancient complex it used to be.

In this case, the modelling could refer to evidences coming almost completely from the 3D capturing of present remains, thus leaving to the subjective interpretation of the Modeller the construction of the HBIM model exploiting essentially proportional, stylistic and comparative analysis.

The first, in particular, enlightened a number of compositional rules and the basic module used both in the plan and in the elevation components suitable for guiding the parametric modelling phase.

The proportional rigor of the bays and of the blocks that make up the pillar's clashes, however, with the rear wall structures, characterized instead by sections and profiles in which it is not possible to trace a regular geometry.

The modelling of travertine blocks has been subjected to the above-mentioned constraints. The analysis of the dimensional differences and proportional ratios led us to use as a parameter the generator module. In this framework, we treated individually the capitals of the pilasters, the hexagonal blocks and finally the key stones, avoiding considering the slightest local variations.

The capitals were modelled as nested families while the architrave was constructed identifying the mouldings directly in the point cloud. As for the wall surfaces, generally showing irregular sections, we generated profiles every 20 cm and, finally, for the barrel and rib vaults, we adopted this same approach varying though the dimensions of the profile.

### 2.4 Level of Development, Level of Detail and Level of Reliability

The activities performed on the previous case studies have pointed out some key general issues related to the international standard parameters used in the BIM and HBIM process, that is, the Level of Development (LOD) and the Level of Detail (LoD). Whereas the first intends to ‘measure’ the reliability of the information characterizing a BIM model, the second defines the graphic detail of digital objects in case of visualization or representation (Rossi & Palmieri, 2019).

The increasing importance of BIM in the construction workflow justifies a deep discussion about the traditional concept of graphic detail in comparison with the LOD of BIM models (Rossi & Palmieri, 2019). It has become evident, in fact, that there is a certain confusion about the real meaning of LoD and LOD among the various actors involved in the BIM process (see Fig. 2.8).

Assuming that it is somehow ‘natural’ for a BIM model to increase its informative content as the project proceeds, the first information associated with the model is usually referring to the starting situation, moving then to the concept, the executive layout up to the ‘as-built’ after the construction.

LOD 100	LOD 200	LOD 300	LOD 400	LOD 500	LOD A	LOD B	LOD C	LOD D	LOD E	LOD F	LOD G
Modello concettuale di massa utile allo studio di fatto, l'edificio, inclusi i suoi elementi di base e volume, orientamento e stile generale dei costi.	Modello concettuale di sistemi generalizzati con quantità, dimensioni, forme, posizione ed orientamento approssimativi.	Modello di produzione o "pre-costruzione", a partire dagli "elementi progettuali".	Modello accurato con requisiti di costruzione e gli elementi costruttivi specifici.	Modello "as built" dell'edificio che mostra il progetto così come è stato realizzato.	Geometria bidimensionale verticale o pseudo-verticale rappresentata mediante un simbolo 2D.	Geometria strutturale bidimensionale verticale o pseudo-verticale rappresentata mediante un simbolo di struttura abbozzata con possibili aperture.	Geometria strutturale bidimensionale verticale o pseudo-verticale rappresentata mediante un simbolo avente dimensioni reali, secondo la normativa tecnica.	Geometria strutturale bidimensionale verticale o pseudo-verticale rappresentata mediante un simbolo avente dimensioni reali, tutte le scalfature.	Geometria strutturale bidimensionale verticale o pseudo-verticale rappresentata mediante un simbolo avente dimensioni reali, sono modellate tutte le scalfature, ammassi e dati del fornitore.	Geometria Come LOD E (quasi uguale)	Geometria Nuovi interventi come LOD F (con aggiornamenti), abbozzature e gestione su elementi esistenti, come LOD C o D.
Progetto preliminare.	Progetto definitivo.	Progetto esecutivo.			Oggetto Grafico 2D	Oggetto Sotto 3D	Oggetto Sotto 3D complesso	Oggetto Sotto 3D complesso	Oggetto Sotto 3D complesso	Oggetto Sotto 3D complesso	Oggetto Sotto 3D complesso
					Caratteristiche Posizionamento di massima.	Caratteristiche Materiali (spessori), incidenza di anneriture, armature e nomenclatura.	Caratteristiche Anzichè (spessori), incidenza di anneriture, armature e copricola.	Caratteristiche Elementi (spessori), dettagli costruttivi, armature e inserti 3D.	Caratteristiche Elementi (spessori), dettagli costruttivi, armature e inserti 3D.	Caratteristiche Certificato di collaudo, piano manutenzione.	Caratteristiche Dati di manutenzione, collaudo, tipologia intervento.

Fig. 2.8 Level of Development and the Level of Detail in BIM processes



This workflow implies development in terms of both geometry and information that for many reasons tend to advance at different speeds.

When we consider an existing building, we face more or less the same problems, although with some substantial differences. First, the starting level is already an ‘as-built’ (or better an ‘as-is’) where the current situation is the building in front of us, characterized by a series of attributes not homogeneously known and knowable.

LoDs aim at precisely defining the level of detail of the various types of information associated with the model: in the initial phases of a BIM-oriented design, in fact, the commissioner would draw up a document named EIR (Employer’s Information Requirements) containing the fundamental requirements to be included in the design.

The definition of these Levels is a topic addressed by two important regulatory references, one American and one Italian.

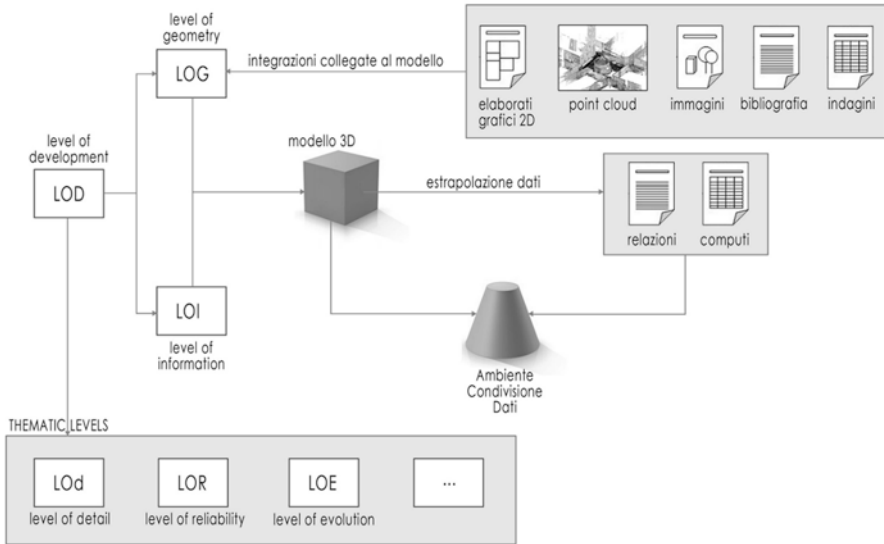
In the American context, the American Institute of Architects (AIA) has published a LOD framework for the AIA Protocol G202–2013 Building Information Modelling, where the term LOD refers to the Level of Development in terms of content associated with the modelled elements. ‘Level of Development’ is used instead of ‘Level of Detail’ because an element, apparently detailed on screen, could nonetheless show a rudimentary geometry. According to this document, the development achievable through the drafting of a model within a BIM project is divided into five levels arranged by hundreds. From the LOD 100 in which the element is represented in a generic way, to the LOD 500 where the element strongly corresponds to the real one being an ‘on site confirmed’ representation.

The Italian legislation (STANDARD UNI 11337–4: 2017) provides an alternative articulation of LODs ordered in alphabetical sequence: levels from A to E correspond to 100/500. However, in this case, we find additional levels F and G in comparison with the American rule.

The F level refers to the state of the element detected on the site (as built) defining also its maintenance, management and/or repair works to be performed over a period. The LOD G, instead, deals with the updated digital version of an element during a certain period. In other words, it aims at providing information about the changes occurred during an interval of time due to its transformations.

Modern BIM authoring software provides tools to model digital objects with different graphic detail, from a schematic display up to a high detailed one. Therefore, there seems to be a close analogy between LOD and LoD so that we can easily conclude that simply increasing the detail of an object we can pass from one LOD to another assuming the Level of Development as equivalent to its graphic details.

Reality is quite different though. While modelling a 3D component, in fact, we can define progressively different LODs affecting its Level of Development and its features but not necessarily its actual geometric detail. In this framework, LODs can differ only for the attributes of the BIM object, that is, their Level of Information (LOI). On the other hand, however, any BIM object in its higher LODs must show correspondingly higher non-graphical information (the info attributes) and this evidence makes the sequence of LODs somehow independent from the Level of Detail that seems to describe only the geometric component of the modelled element.



**Fig. 2.9** Level of Details, Level of Reliability and the Level of Evolution in BIM processes

We can conclude that LODs are somehow independent from LoDs and actually intend to provide a standard for digital objects' consistency (see Fig. 2.9).

Still they do not take into account the quality of the information on which they are constructed. In any HBIM model, in fact, objects can vary a lot in term of reliability either because of the quantity of information available or of the quality of the Modeller's reading.

This is the reason why we concentrated on the coding of the Level of Reliability (LOR), an additional parameter aiming at assessing the coherence of the workflow guiding the generation of digital objects in a HBIM model. It is actually a numeric score resulting from the balancing of several factors considered as individual items and with respect to their general role within the model. Besides, we outlined some key aspects that could influence the LOR of one single object, of a collection of objects and eventually of an entire HBIM model.

The LOR coding considers the geometric reliability of digital objects together with their ontological correspondence to the real item they represent.

The following factors seem to have a strong influence on the geometric reliability of the model:

- Parameterization of the geometric shape
- Acknowledgement of compositional and geometric rules
- Availability of archival sources
- Comparison between the measured data and the model constructed
- Access to metadata associated with the capturing phase

The ontological correspondence of digital objects is instead influenced by factors more difficult to analyse. They are in fact the product of more subjective tasks but also conditioned by the issue of ‘going beyond’ the skin of the building. At a certain extent, the Modeller is somehow ‘obliged’ to establish also the tectonic rules of digital objects populating the BIM environment.

In this framework we took into account:

- The evolutionary phases of the object
- The materials used and construction techniques
- Supplementary investigations (e.g. stratigraphy, layout of architectural or structural elements etc.)
- Assessment of construction technologies or materials by similarity
- Assessment of the state of conservation of materials

Given the previous general parameters, the LOR takes the form of a numeric scale spanning from 0 to 10 as you can see in the prototype diagram associated with a real architectural element and its digital doppelganger. Moreover, the diagram, helpful to evaluate the LOR key influencing factors, can be also beneficial while ‘decomposing’ the built artefact. Depending on the level of correspondence with the established key factors, for each item a score ranging from 0 to 2 has been proposed (see Fig. 2.10).

## 2.5 Conclusions

HBIM is a part of the wider processes related to the Heritage Building Information Modelling. Differently from conventional BIM, the HBIM, dealing with existing artefacts, must consider some additional issues connected with the knowledge of the building ‘as-it-was’ and ‘as-is’.

If capturing technologies do play a very relevant role in freezing the geometric shape of objects, nevertheless much effort has to be put in retrieving additional information to increase the level of knowledge. This information can be 1D or 2D.

On that basis, the Modeller becomes the main character in the construction of the HBIM model, as it is his /her responsibility to choose how to disassemble and reassemble the existing object in the digital space.

Furthermore, the parameters that internationally describe the HBIM process make some confusion between the Level of Development and the Level of Detail of any element. While the former can describe quite well the position of a digital object in the BIM progression in terms of both development and information, the latter seems only to refer to its geometric features.

Finally, we dealt with the problem of assessing the informative content of objects according to its reliability. In this framework, we proposed the introduction of the Level of Reliability for BIM objects as the necessary methodological premise to make BIM systems an actual tool also for knowledge enhancement.

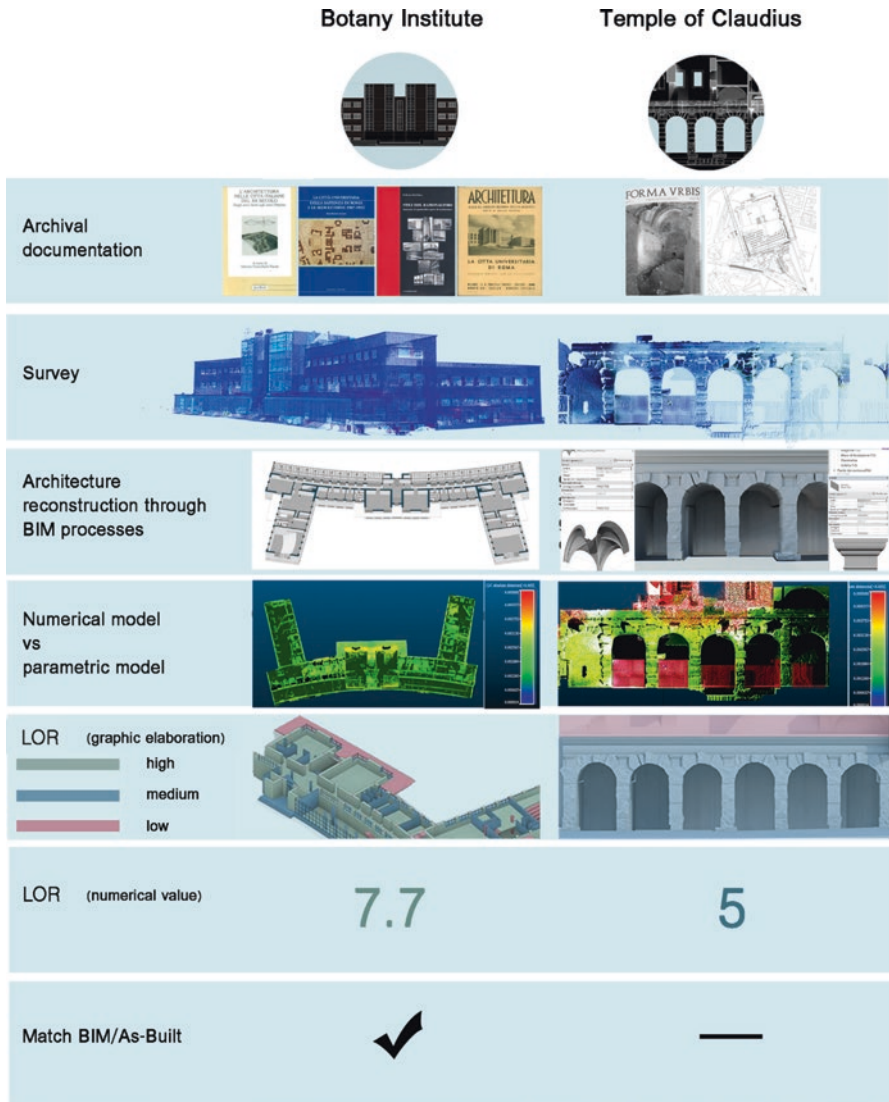


Fig. 2.10 The Botany Institute and the Temple of Claudius. Comparison of the processes and LoR

Knowledge is in fact a gradual process strongly related to the results of new investigations from which new information is generated and accumulated. This same rule seems to be applicable to the HBIM environment too, at least to its informative components. For this reason, specific protocols referring to investigation methods and objectives (as archival and bibliographic research, diagnostic and survey activities) could become themselves components of the HBIM workflow. Besides, thanks to the LOR diagrams, the information contained in the HBIM database will lead to more enhanced and reliable models (Table 2.1).

**Table 2.1** The Botany Institute and the Temple of Claudius, level of reliability in BIM processes

Level of reliability LOR			Botany Institute	Temple of Claudius	
Geometrical features	Free form	Symbol/simplification of geometry	0	<b>2</b>	<b>1</b>
	Geometric shape	Parametric modelling	1		
		Geometrical modelling	2		
Surveying data	No survey	Simplification of geometry	0	<b>2</b>	<b>2</b>
	Survey	Not integrated surveying	1		
		Integrated surveying	2		
Specialist investigations	Not available or no reliable data	Hypothetical information	0	<b>0</b>	<b>0</b>
	Available data	Generic information	1		
		Specific information	2		
Archival documents	Not available or no reliable data	Hypothetical information	0	<b>2</b>	<b>1</b>
	Available data	Generic information	1		
		Specific information	2		
Physical features	Free form	Hypothetical information	0	<b>2</b>	<b>1</b>
	Geometric shape	Generic information	1		
		Specific information	2		
Technological configuration	Uncertain or not definable	Symbolic or absent articulation	0	<b>1</b>	<b>1</b>
	Verified or definable	Generic articulation	1		
		Specific articulation	2		
Conservation status	Not analysed	Not definable	0	<b>1</b>	<b>1</b>
	Analysed	Defined through external links	1		
		Defined through digital objects	2		
Compliance or congruence checks	Not checked	Not verified	0	<b>2</b>	<b>1</b>
	Checked (comparison between model, model checking)	Verified/not relevant inconsistencies	1		
		Verified/relevant inconsistencies	2		
Operational or in-depth indications	Not provided Directions	Absent indication/low probability of profiting	0	<b>2</b>	<b>1</b>
	Provided directions	Generic indication/medium probability of profiting	1		
		Specific indication/high probability of profiting	2		
			<b>7.7</b>	<b>5</b>	

The HBIM models and environment discussed so far are to play a crucial role also in ‘regenerative’ projects. First, because the entire building sector is quickly embracing the BIM philosophy. Secondly because regenerative designs could benefit more than other approaches from the HBIM ability to merge heterogeneous information without losing the possibility of retrieving and combining it in a creative way. In this framework, the wide access to HBIM models and to their informative background will actually embody the so-called ‘digital operational archives’ envisaged by the *Carta del Rilievo Architettonico*, where a ‘rational synthesis of data’ would encourage the integration of skills and ‘the osmosis of disciplinary or professional knowledge’.

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# Chapter 3

## The Application of Urban Building Energy Modeling in Urban Planning



Shimeng Hao and Tianzhen Hong

**Abstract** Urban energy planning plays an essential role in guiding human settlements, from a neighborhood scale to a megacity scale, to a sustainable future. It is particularly challenging to integrate energy planning into the urban planning process, considering the urban system's complexity, multi-objective decision making, and multi-stakeholder involvement. In this context, recent years have witnessed a significant development of urban building energy modeling (UBEM). With a trend toward performance-based urban planning, there is a rising need to introduce proper UBEM tools into the different planning phases. The main objective of this chapter is to provide an overview of the UBEM tools across different urban planning phases, as well as to discuss to what extent these tools could provide decision-making support to stakeholders. The chapter starts with a brief discussion on emerging energy-related issues in urban development and why the conventional planning approach needs the integration of modeling tools to provide a quantitative evaluation to better respond to these new challenges. The state of the art of UBEM also is reviewed, followed by a description of the applications and limitations in different planning phases. Finally, several challenges and opportunities regarding energy-modeling-assistance urban planning are discussed.

**Keywords** Urban energy planning · Urban systems · Urban planning process · Energy efficiency · Sustainability

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### 3.1 Introduction

Contemporary cities are composed of complex and interrelated systems. With unprecedented rapid global urbanization and booming urban technologies, not to mention climate change and environmental issues, the enormous challenges faced by a modern urban planner are far beyond those of the ancient Greek urban planner Hippodamus's imagination (Burns, 1976). The United Nations (UN) predicts that by 2050, 6.4 billion people will be living in urban areas, making up 70% of the world population (UN, 2014). Today's cities are endeavoring to be sustainable, and energy is always an inevitable topic of prime importance.

Several positive and negative impacts are associated with urbanization from an energy perspective. On the one hand, a compact city form will promote energy efficiency and urban service quality compared with a low-density sprawling urban form. A growing number of researches have shown that the optimization of urban density, function allocation, building configuration, and morphology, as well as other urban form parameters, can positively influence energy demand and carbon dioxide emissions (Ratti, Baker, & Steemers, 2005; Rode, Keim, Robazza, et al., 2014; Salat, 2009). On the other hand, the increasingly densified metropolitan area suffers from the urban heat island (UHI) effect and is more vulnerable to extreme climatic events such as heat waves, rainstorm waterlogging, wildfires, and power outages.

The emerging next-generation urban energy technologies—such as district energy networks (DEN) (Rismanchi, 2017), smart grids, decentralized energy systems, and net-zero energy buildings (NZEB)—offer opportunities to tackle these problems. The district energy system is characterized by utilizing multi-energy sources and providing heating, cooling, and electricity to local neighborhoods with a combination of district energy plants, energy storage systems, and distribution systems. Compared with conventional heating and cooling systems, the benefits of district energy system include relatively higher overall efficiency, lower annual cost for customers, more flexibility in integrating locally available renewable energy resources (such as solar energy, biomass, and geothermal), and a significant potential for greenhouse gas (GHG) reductions (Rismanchi, 2017; Schweiger, Heimrath, Falay, et al., 2018). Correspondingly, for system design and optimization, challenges are arising: the drastic fluctuation from centralized and individual renewable energy generators, the complexity of user behavior from the building and transportation sectors, dynamic energy storage from daily to seasonal temporal scale, and more. The application of district energy modeling tools can bring considerable advantages to support design assessment, as well as operational optimization of the system (Schweiger et al., 2018).

Nonetheless, the traditional empirical evidence-based urban planning scheme often fails to support the effective integration of these technologies into urban (re) developments (Cajot, Peter, Bahu, et al., 2017; Markus, Avci, Girard, Keim, & Peter, 2009; Strasser, 2015). With the trend of performance-based and, more specifically, energy-based urban planning approaches, which seek to optimize or even

generate urban morphologies from an energy perspective, a strong need arises to introduce proper urban energy modeling and simulation tools into various planning phases (Van Beuzekom, Gibescu, & Slootweg, 2015). In this context, recent years have witnessed a significant development of urban building energy modeling (UBEM). This chapter provides an overview on how and to what extent these UBEM tools could support urban planning by addressing some key questions, including:

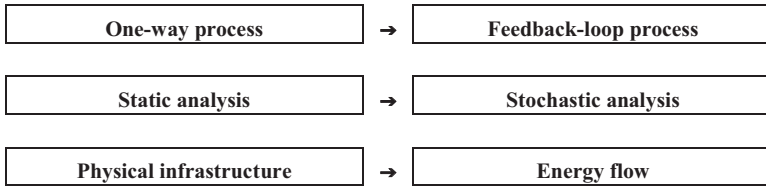
- What are the new requirements of urban planning from the energy perspective?
- What are the specific applications of UBEM tools across various urban planning phases and scales?
- How can stakeholders benefit from the integration of UBEM tools into urban planning process?
- What are the challenges and opportunities of energy modeling-assisted urban planning?

## 3.2 The Role of Energy Modeling in Urban Planning

### 3.2.1 *New Requirements of Urban Planning from the Energy Perspective*

Urban planning plays a vital role in guiding a human settlement, from the neighborhood scale to the megacity scale, to a better future (Peter & Yang, 2019). In line with the concept of sustainable development, the significance of energy planning reveals increasing coordination with master plans, either integrated with the general comprehensive plan or as an independent specialized plan. Although the specific planning approaches and components may be extremely varied from country to country, due to the different planning law frameworks and urban development stages, some common trends and barriers in urban planning have emerged (Geneletti, La Rosa, Spyra, & Cortinovis, 2017; Torabi, Delmastro, Corgnati, & Lombardi, 2017).

In recent years, the paradigm of energy system planning has shifted from the traditional, supply-side energy policy and management to a more demand-side approach, focusing on the district level (Keirstead, Jennings, & Sivakumar, 2012; Nageler, Koch, Mauthner, et al., 2018). The application of renewable energy sources within the smart grid and microgrids has increased the diversities in energy supply and its business models. Decentralized energy solutions such as on-site power generation can transform an individual building or household from an energy consumer to an energy producer. Consequently, the energy flows in this new-generation system are multi-directional and change dynamically, which brings tremendous challenges to energy planning (Ma, Ren, Zhao, et al., 2020). In line with the concepts of distributed energy resources and the District Energy System (DES), the task of developing more accurate energy load forecasting models with higher spatiotemporal resolutions becomes increasingly crucial.



**Fig. 3.1** Three main trends in urban energy planning

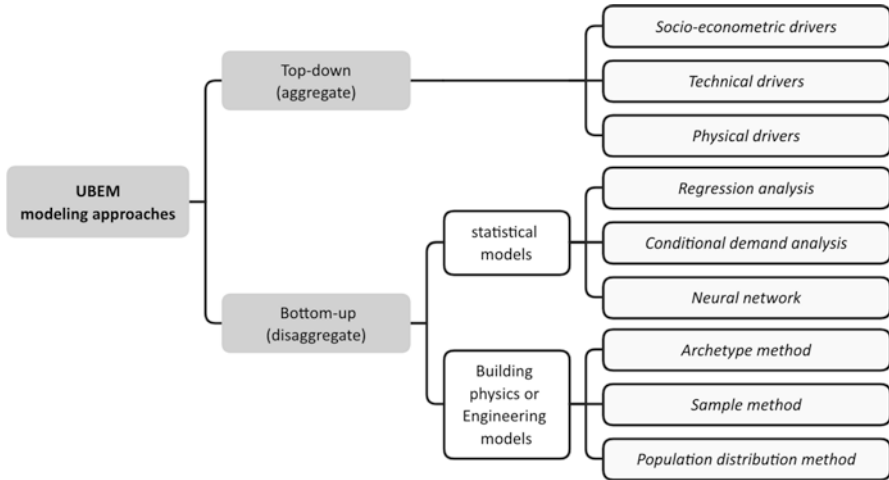
Furthermore, the energy concerns in sustainable urban planning are not solely addressable through the urban energy infrastructure alone (Li, Quan, & Yang, 2016; Madlener & Sunak, 2011). Urban building energy consumption is highly coupled with other urban systems and sectors, including but not limited to transportation, land-use patterns, and urban forms. However, conventional urban energy system planning is often conducted at the end of the planning phase, to select proper energy supply methods, when most of the decisions crucial to energy consumption have already been made. Under the traditional planning framework, the socioeconomic issues and quality of urban services are the main topics, while the role of energy planning is relegated to just supporting those “more important” issues (Cajot et al., 2017). Moreover, urban planners and other decision-makers typically rely on precedent projects and experience, which depends more on qualitative analyses than quantitative assessments (Ferreira, Lage, Doraiswamy, et al., 2015).

In general, three trends can be observed for urban energy planning (see Fig. 3.1): (1) from a one-way process to a feedback-loop process, which improves consideration of the interactive effects among urban systems and processes, (2) from static analysis to stochastic analysis, which enables robust design that considers uncertainty in weather and climate conditions as well as dynamic energy demand and supply, and (3) from physical infrastructure to energy flow, which abstracts and represents urban systems as urban metabolism in terms of materials and energy flows in urban areas.

### **3.2.2 Introduction to Urban Building Energy Modeling (UBEM)**

Urban building energy modeling (UBEM) tools have a high potential to strengthen the integration of the multidisciplinary aspects of energy issues in the urban planning process (Hong et al., 2020; Reinhart & Cerezo Davila, 2016). UBEM is widely used in the evaluation of energy consumption between alternative urban forms, optimization of energy management from both the energy supply and demand sides, and scenario analysis of energy-saving potentials of technologies (Lombardi, Abastante, Torabi, & Toniolo, 2017; Van Beuzekom et al., 2015; Zanon & Verones, 2013).

Based on modeling approaches (see Fig. 3.2), UBEM can be classified into “top-down” models and “bottom-up” models (Reinhart & Cerezo Davila, 2016; Swan &



**Fig. 3.2** Modeling approaches of UBEM

Ugursal, 2009; Kavgić et al., 2010). The top-down approach is characterized by aggregating input data and results at urban and regional levels without considering spatial or temporal details. It has been considered to be suitable in long-term and large-scale energy policy estimation; however, it has obvious limitations when performing energy analysis for a group of building in the urban context (Hong & Luo, 2018). Bottom-up models provide energy insights down to the individual building level, and these are subdivided into statistical-based models and physics-based models. The statistical models establish correlations between the actual energy use and driving drivers such as building stock characteristics, local climate, and occupant behavior at a building or district level, by adopting regression analysis, conditional demand analysis, and machine learning techniques (Torabi et al., 2017). In contrast, building physics models are based on thermodynamic simulations (Aydinalp-Koksal & Ugursal, 2008), which have been recognized as suitable for energy retrofit assessment and optimization across different spatiotemporal scales. Correspondingly, high-quality data and considerable computational efforts are essential to effectively support and generate high fidelity building physics models.

Building energy modeling at a larger scale is not simply scaling up the simulation results of individual buildings (Hong et al., 2020). Inter-building effects, including long-wave heat emission and shading, as well as heat exchange between buildings and the urban environment, can significantly influence building energy demand (Bourikas, 2016; Savić, Selakov, & Milošević, 2014). Consequently, UBEM should take microclimate effects and interactive effects among buildings into account. In this light, a physics-based dynamic simulation method shows its predominance compared to other approaches.

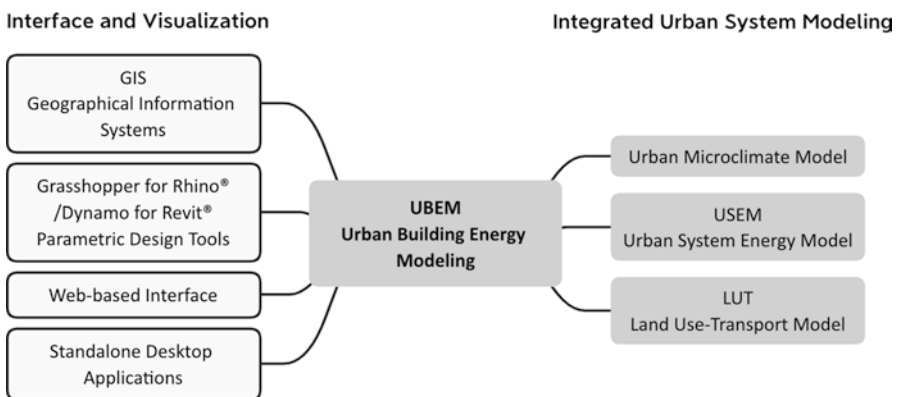
Some literature thoroughly reviewed the state of the art of UBEM tools in detail (Hong et al., 2020; Li, Zhou, Cetin, et al., 2017; Torabi et al., 2017), comparing the differences in calculation approach, spatiotemporal resolution, input/output data

format, and potential applications. Some tools, such as the Urban Modeling Interface (umi) and Grasshopper interface for CitySim (GHCitySim), were developed as plug-ins for prevailing planning and design platforms (Peronato, Kämpf, Rey, & Andersen, 2017) (see Fig. 3.3), benefitting the integration of energy systems with urban form generation and optimization at the early planning stage. These tools usually emphasize the correlations between urban design parameters (such as block density, building geometry, and land-use allocation) and urban performances (e.g., energy efficiency, outdoor thermal comfort, energy generation potential). The simulation requirements are often simplified, while the analysis target is to obtain the tendency rather than the specific data. Therefore, they are more user friendly to planners and are suitable for early-stage planning.

In contrast, other UBEM tools emphasize the accuracy and robustness of the models, and are more dependent on high-performance computing efforts and data availability. These tools have great application potential in operational optimization and energy retrofit estimation. However, such tools require operation by professional users with urban building energy simulation backgrounds. Whether this process is conducted by an independent consultant group or professional staff within the planning team, close collaboration with urban planners is undoubtedly necessary.

Apart from the conventional stand-alone desktop applications, web-based UBEM tools have been a growing trend in recent years. Web interfaces have shown satisfactory performance in data visualization, as well as in supporting cloud computation.

The planning and research communities are coping with increasing complexities in modeling interactions among different urban systems. Many efforts have been made to promote co-simulation of UBEM and various urban system models, including (1) urban microclimate models using computational fluid dynamics (CFD) and other numerical models (Mirzaei, 2015; Toparlar, Blocken, Maiheu, & van Heijst, 2017), (2) urban system energy models (USEM), and (3) land-use transport models (LUT), as shown in Fig. 3.3.



**Fig. 3.3** Integration of UBEM with other urban system models and design platforms

Energy consumption of an individual building is strongly affected by the local urban climate. Conversely, building geometry, thermal characteristics, and the operation of building equipment also influence the urban microclimate significantly (Sharmin, Steemers, & Matzarakis, 2017). Coupling the urban microclimate model with UBEM can improve the accuracy of simulation results for both sides. Urban system energy models are widely adopted in the field of designing and optimizing energy networks and systems. However, when it comes down to the district level, the application of USEM is limited due to its relatively low fidelity on demand-side estimation. UBEM and USEM approaches are combined in the latest tools to better support the planning and operation of the district energy system. Building energy models (BEM), an inherent and inseparable part of the physics-based simulation UBEM approach, also play an important role in the operation of the district energy system and building energy resilience. Dynamic BEM are capable of predicting real-time indoor environment variables and energy loads, giving control feedbacks to the district system, and providing early warnings of the most vulnerable urban areas or buildings under extreme weather events. Moreover, a great deal of energy can be saved by establishing a correlation between urban human mobility and building energy consumption. Several studies demonstrated a strong spatial dependency between energy use and location-based activities (de Casas Castro Marins & de Andrade Roméro, 2013; Shirgaokar, Deakin, & Duduta, 2013). In this sense, one can estimate building energy demand by using individual positional data.

The profundity of co-simulation may vary by adopting different coupling approaches. One approach is to combine the physical models and processes into one model hierarchy (Hong et al., 2020). This might be the most promising approach when the complexity of coupled physical processes is acceptable and sufficient computational resources are available. Otherwise, co-simulation frameworks could be used. By adopting such frameworks, coupled models are assigned as different simulation layers, which can be executed in parallel or series with data communication in run-time. A third approach is to run several predetermined scenarios across different models when the data quality or other conditions cannot meet the requirements.

### ***3.2.3 Application of UBEM in the Urban Planning Processes***

Before integrating energy considerations into the urban planning process, it is fundamental to understand that process. The urban development paradigm, as well as the urban planning scheme, undoubtedly varies from country to country, even case to case. Nevertheless, despite the different names assigned to certain planning schemes, the hierarchy and planning objectives of contemporary statutory planning systems in different countries have more in common with each other than differences (Wu, 1991; Hall & Tewdwr-Jones, 2019). Generally speaking, the most commonly adopted planning schemes can be summarized as five phases (Cajot & Schüller, 2018; Meskel & Weber, 2017) (see Fig. 3.4):

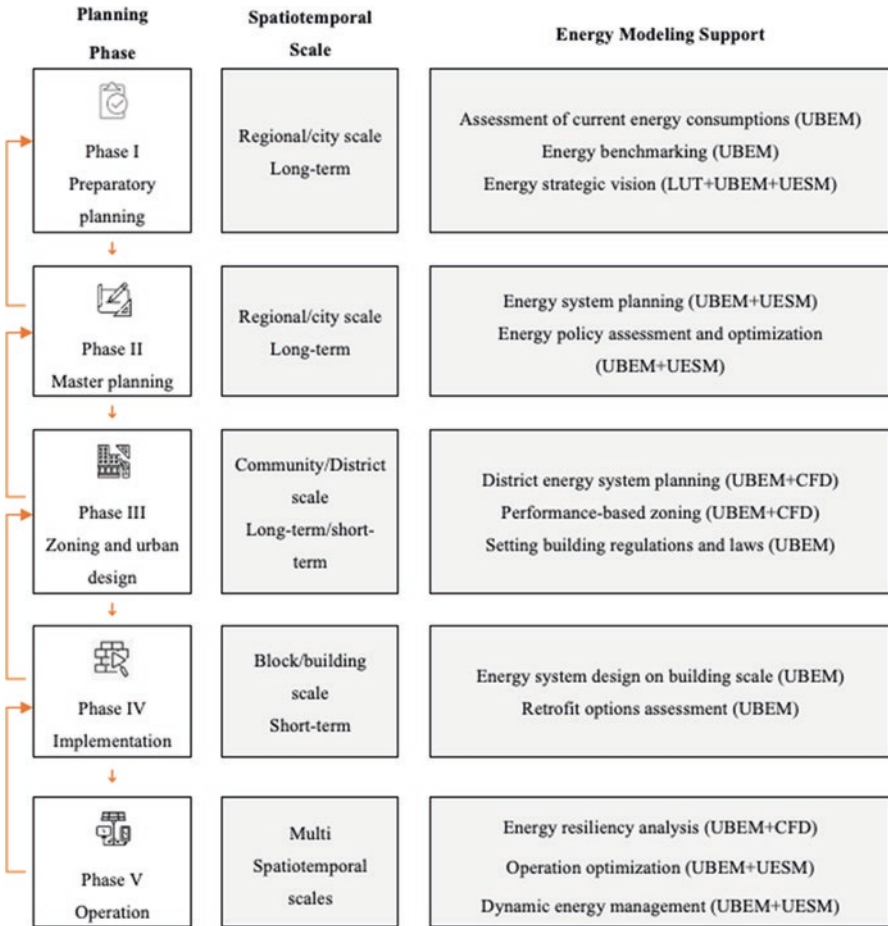


Fig. 3.4 UBEM support within a typical urban planning process

1. **Preparatory planning:** Identification of existing problems, definition of planning issues, and formulation of goals and visions
2. **Master planning:** Formulation of the evaluation framework based on the achievement of goals and objectives, generation, and assessment of alternative plans
3. **Zoning and urban design:** Elaboration of a comprehensive master planning at the district or community level, and formulation of a zoning plan and building regulation plan
4. **Implementation:** Building design and construction for the new development area or building retrofit for the transformation area in compliance with upper-level plans, and performance optimization at individual buildings or the block level

### 5. **Operational:** Operation of buildings, infrastructure, and services, and monitoring of energy generation and consumption

It should be noted that urban planning is not a one-way process; the outcomes of each phase should be carefully evaluated to see whether they are in full compliance with the planning objectives, and if not, adapting the present plan through a feedback loop (Schoenwandt, 2016). The planning deliverables of these phases play their roles on different temporal and spatial scales. A comprehensive general plan outlines the regional or metropolitan development vision in a relatively long term of 15–20 years (Yigitcanlar & Teriman, 2015), whereas detailed planning schemes such as zoning ordinance and redevelopment plans on the district level are formulated for the short-term or medium-term. UBEM has the capability to cover spatial scales from dozens of buildings in a block to hundreds of thousands of buildings in an entire city, and cross-temporal scales from an hour to multiple decades. It is essential to select scale-appropriate UBEM tools to ensure the efficiency and accuracy of the simulation.

The assessment of energy aspects in urban planning is executed by introducing proper planning instruments for different planning stages (Meskel & Weber, 2017). These instruments can be classified into two groups: specific energy planning instruments and general urban planning instruments. Specific energy planning instruments directly provide guidance on how to make decisions on energy infrastructure and management, including an urban climate and energy strategy, an energy road-map, building regulation for energy efficiency, and so on. Conversely, general urban planning instruments, such as zoning, land use plans, transportation plans, and urban design guidelines, have an indirect yet significant influence on energy issues by shaping urban form. Accordingly, UBEM tools should be carefully selected and applied to facilitate different instruments. In the following parts of this section, the planning instruments and matching UBEM tools will be discussed in detail for each planning phase, demonstrating their viability for supporting decisions by urban planners, policymakers, and other stakeholders.

#### 3.2.3.1 Phase I: Preparatory Planning

The pivotal tasks in the preparatory planning phase include assessment of current and forecast conditions, the development of goals and visions with full involvement of stakeholders, and the evaluation of policy and strategy feasibility by future scenario exploration analyses.

Data collection is one of the fundamental actions in Phase I (Mirakyan & De Guio, 2013). To set up a strong support for urban system modeling, numerous energy-related data of different formats and sources should be included into the dataset, including large-scale urban spatial and geometry data (mainly imported from CityGML, GeoJSON, and other open data sources), socioeconomic and demographic data (from a census database), and meteorological data (from historical weather data or imported from Urban Weather models). However, the lack of



high-quality and continuous data in the early planning phase has always been a major problem.

Another challenge for rational planning at this early stage is multi-objective decision making. Although planners and other decision-makers can get a clear overview of the current energy consumption level with UBEM simulation tools, more comprehensive evaluations that also account for other energy-related planning issues (such as urban growth, transportation dynamics, land use, and environmental quality) are essential for setting up future scenarios. However, in most cases, this does not seem viable, due to both the complexity and unclear mechanisms of urban systems and the limitation of the prevailing tools (Van Beuzekom et al., 2015). Nevertheless, simplified models seem to be acceptable for scenario comparisons at this early stage, for the decision making is more reliant on tendencies rather than specific data (Wilson, Danforth, Davila, & Harvey, 2019). To enhance the collaboration of multiple stakeholders and experts in decision making, data visualization is an important feature (; Pelzer, Arciniegas, Geertman, & Lenferink, 2015). Interfaces based on the web or planning software such as geographic information systems (GIS) and parametric design platforms have advantages in this respect.

### 3.2.3.2 Phase II: Master Planning

For the master planning phase, general planning objectives and strategies are further developed into a more operational and implemental design criteria. UBEM plays an important role in generating and evaluating alternative urban forms according to design criteria and objectives. Compared with Phase I, more detailed analyses with higher fidelity are required for formulating comprehensive master planning and energy system planning at a city scale. The urban form (characterized by the typology of urban blocks, land use-transportation structures, urban density, open space structures, and other factors) will be determined at this phase. Those factors highly influence demand-side energy use, as well as the potential for decentralized energy generation. Accordingly, the proper energy system aimed at securing a reliable and affordable energy supply will be established, addressing the dynamic energy demand, through coupling with urban comprehensive energy system modeling tools. By incorporating UBEM with generative design tools, it is possible to obtain tens of thousands of alternative master plans automatically, by manipulating urban form-related parameters (Wilson et al., 2019). The performance of these alternative plans can then be evaluated and clustered by machine learning methods.

In this phase, once the best alternative planning is selected, it should loop back to see whether it is compliant with the energy planning objectives and criteria defined in the former phase. If it can fulfill the evaluation requirements, the plan goes to the next process.

### 3.2.3.3 Phase III: Zoning and Urban Design

At this mesoscale district level, there is significant potential in energy optimization of both the district energy system and the impact of district morphology on energy consumption (Rismanchi, 2017; Wilson et al., 2019; Wilson, Danforth, Harvey, & Licalzi, 2018).

Advanced district energy systems, which can be composed of shared energy infrastructures, smart microgrids, and decentralized energy sources, can achieve much higher energy efficiency. A wide variety of USEM tools have been developed for planning district energy systems. The key point of a well-designed district energy system lies in the accurate forecasts of energy loads and supplies (Lake, Rezaie, & Beyerlein, 2017), which can be achieved by coupling UBEM with USEM.

Although most research efforts have focused on the district energy system in this planning phase, performance-based zoning has attracted more attention. There is substantial evidence that building typology and urban morphology influence building energy consumption and GHG emissions (Li et al., 2016). Considering the unprecedented growth rate and high increasing density of cities, traditional standards and workflows cannot adequately facilitate the timely updating of zoning regulations (Wilson et al., 2019). For new development of urban areas, the overall energy consumption of urban neighborhoods can be greatly reduced by applying the optimization of street walkability, accessibility, building function, geometry, and orientation. Detailed building characterization, including physical properties, geometry information, and energy use data, either should be used as inputs for UBEM by establishing archetypes or can be integrated and represented with CityGML Energy Application Domain Extension (Energy ADE) (Agugiaro, Benner, Cipriano, & Nouvel, 2018). Furthermore, the productivity and economic efficiency of on-site renewable energy generation can be promoted with UBEM tools. Another strategy is to improve building energy codes and standards by considering the effect of microclimates at the district level, by co-simulation with UBEM and urban microclimate models (Abdolhossein Qomi, Noshadravan, Sobstyl, et al., 2016; Hong, Chen, Lee, & Piette, 2016).

### 3.2.3.4 Phase IV: Implementation

The implementation for urban planning is by urban (re)development or energy retrofit projects in units of parcels or blocks, in compliance with zoning plan, urban design guidance, and building regulations.

For the design of new energy-efficient buildings, established simulation-aided design workflows have already been widely used in practice (Hong et al., 2018). ASHRAE Standard 209 proposed a framework of applying BEM across a building life cycle (Scott, 2019). To improve energy efficiency of a group of buildings planners can further engage UBEM into this framework, taking dynamic heat transfer between building bulks, shading effects, and outdoor thermal comfort into consideration.

For the retrofit of existing buildings, UBEM is a powerful tool to conduct retrofit option assessment. By executing energy retrofit simulation in multiple scenarios, efficient refurbishment solutions can be promoted. Long-term energy saving potentials can be estimated along with the market aspects and economies of scale associated with the selected retrofit measures. The energy retrofit assessment can also be performed at an urban scale to improve the energy performance of agglomerate building stocks and associated service provisions (Keirstead et al., 2012). Top-down UBEMs are only capable of processing simple scenario estimations like adding or replacing a group of buildings with the same attributes. In contrast, bottom-up UBEMs are more flexible in setting energy conservation measure (ECM) scenarios with deeper complexity (Reinhart & Cerezo Davila, 2016).

### 3.2.3.5 Phase V: Operation and Management

Load forecasting is critical for urban energy supply designers to estimate the energy demand and to optimize operations on a dynamic basis at a district or city scale. The empirically data-driven method, such as a nonlinear regressive model, is commonly adopted to make future load predictions using measured loads as a reference point (Powell, Sri Prasad, Cole, & Edgar, 2014). However, its application is generally limited to specific building types and locations, with an excessive reliance on data training (Hong et al., 2020). To address this gap, there is a growing interest in using UBEM as a dynamic representation of building systems imposing constraints on the control and distribution systems (Molitor, Gross, Zeitz, & Monti, 2014). With the application of UBEM in a real-time mode, there will be large energy-saving potential and trade-offs supported by optimal control feedback, along with continuous data monitoring of energy use and supply.

Under global climate change, urban areas suffer from increasingly frequent extreme weather events, such as heat waves, wildfires, snowstorms, and urban waterlogging. Extreme weather conditions will dramatically raise building energy demand, and an accompanying power outage could soon develop into a colossal disaster. The vulnerability degree is related to building thermal characteristics, building equipment, local microclimate, and economic conditions of the occupants. The identification of vulnerable buildings, which is vital to improving urban resiliency and safety, can be accomplished with CFD modeling and UBEM (Katal, Mortezaazadeh, & Wang, 2019). With energy resiliency analysis and building retrofit analysis, local government decision-makers can identify vulnerable buildings and prioritize high-risk populations that need to be rescued.

### **3.3 Challenges and Opportunities of Energy-Modeling-Assistance Urban Development**

#### **3.3.1 Challenges**

##### **3.3.1.1 Complexity of Urban Energy Systems**

Addressing energy issues at a city scale is much more challenging than at a building scale, because an urban system is composed of ill-defined, multifaceted, and dynamic problems (Cajot et al., 2017). Viewing the energy problem in a holistic and comprehensive perspective with other urban systems is crucial because it allows for both direct and indirect promotion of urban energy efficiency. Nonetheless, establishing a comprehensive integrated urban energy model is undoubtedly a challenging task because it is necessary to consider the interactions between multiple and diverse urban systems in a nonlinear way (Reinhart & Cerezo Davila, 2016).

Apart from the technical challenges presented by the coupling and co-simulating of multi-physics urban system models (such as architecting simulation layers, runtime data exchange, and synchronization control), the main obstacle is the lack of fundamental studies on urban system interdependencies. There are future research opportunities in urban science studies. The research community should not only focus on narrowly defined urban system components but also put more effort into the interconnected influencing mechanisms among them.

##### **3.3.1.2 Multi-objective Decision Making**

Urban planning is a multi-objective decision-making process that needs the strong intellectual engagement of planners, policymakers, community and utility representatives, and related professions. The stakeholders involved and their conflict of interests are much more than a building design process. Participatory planning can be a lengthy process, requiring considerable human and financial resources. Most of the time and effort is spent on identifying shared benefits, reaching agreement on development goals, and evaluating the future influences of a specific policy. A successful, collaborative decision-making process should be based on communication of extensive information and sufficient data support. Aiming at facilitating effective stakeholder engagement and providing actionable insights from a mass volume of data, especially for non-specialist participants, there is a strong need of development of decision-making tools integrated with simulation and visualization techniques.

### 3.3.1.3 Limitations of the Modeling Approaches

To avoid the “garbage-in, garbage-out” problem, a well-performing model relies on a high-quality dataset; however, that such a dataset is not always available in every case. Oversimplified archetypes and decade-old weather datasets, for instance, inevitably result in a large inaccuracy of simulation results. On the other hand, a comprehensive model with high fidelity on an urban scale is prohibitively resource- and time-consuming. In this light, it is critical to find the balance between the necessary level of detail and the computability of the model. Adapting proper spatial and temporal resolutions according to distinctive modeling purposes is essential. Further challenges exist in model calibration and result-validation work, which are limited by the lack of large-scale measurements of urban energy data.

## 3.3.2 Opportunities

### 3.3.2.1 District-Level Energy Technologies

District energy networks offer many economic and environmental benefits with excellent system flexibility (Powell et al., 2014). In addition to the high efficiency of district-level energy generators, such as combined heat and power (CHP) plants and heat recovery steam generators (HRSGs), they also take advantage of supply and demand diversities on a dynamic basis (Powell et al., 2014). An intelligent operation can be achieved through dynamic optimization with UBEM by providing more accurate electric, cooling, and heating load forecasting to the control system than an empirical black-box approach to forecasting (Rismanchi, 2017).

### 3.3.2.2 Economies of Scale

Economies of scale exist in urban development and redevelopment activities. There is a “minimum efficient scale” for construction and retrofit projects (such as a small-scale power plant, photovoltaic panel installation, or thermal energy storage), which refers to the scale point of maximum investment efficiency. Take building energy conservation projects, for instance: the evaluation of building retrofit opportunities is not limited to the energy-saving potential of certain energy-efficiency upgrades; it is also necessary to include cost-effectiveness, payback year, project scale, business model, and socioeconomic affordabilities. Applying UBEM coupling with a microeconomics model can maximize system efficiency while minimizing socioeconomic and environmental costs.

### 3.3.2.3 Computational Technology and Big Data

The advancement of computational and data technologies, including artificial intelligence, machine learning algorithms, urban sensing technologies, cloud computing, and Internet of Things (IoT), offers promising opportunities to introduce UBEM into the urban planning practice. Data streams from urban energy utilities, smart power grids, transportation infrastructures, and buildings are obtained by continuous monitoring, providing data sources for model setups and model calibration. Large-scale data centers and internet technology make cloud computing more feasible as an affordable and accessible service. Equipped by this substantial improvement of computational efforts, modeling approaches not only can support decision making for urban planning but also can be used for urban management by making minute-to-minute operational decisions, contributing to shape a digital twin for a smart city.

## 3.4 Concluding Remarks

A rational urban planning process needs the support of evidence-based and quantitative decision-making tools. It is a necessary step to embrace energy modeling and analyses in the early planning stages and consistently provide feedback to keep up with evolving energy challenges (Salat, 2009). Urban building energy modeling (UBEM) is a powerful tool with great application potential in the five general urban planning phases, namely: preparatory planning, master planning, zoning and urban design, implementation, and operational. UBEM coupled with other urban system models can inform decision-makers and stakeholders for energy policy formulation, urban (re)development projects, and the intelligent operation of cities. It can provide informative and well-visualized results of end-use energy auditing and benchmarking, energy demand forecasting, building retrofit assessment, urban thermal resiliency analysis, and district energy system operation and optimization. Following a deepening understanding of the correlation between urban form and energy consumption, the energy-performance-driven planning approach is emerging, and is expected to be adopted for broad application in the future (Li et al., 2016; Naboni, Natanian, Brizzi, et al., 2019).

Corresponding to the complexity of the urban system, a promising application of UBEM is enabled by high-quality data feeding and synergism with other urban system models, such as urban system energy models, urban climate models, and land use and transportation models, as well as decision-making models and micro-economics models. Balancing the model fidelity and complexity according to the purpose of different planning stages is essential. The explosive development of big data and cloud computing technologies provides opportunities to solve data availability and computing resources problems. Promoting the standardization of data formats, terminologies, and modeling approaches among modeling and planning communities will benefit UBEM development.

Last but not least, new planning approaches that support the integration of energy issues should be developed in practice. Ideally, a supportive planning framework should involve energy concerns from a very early planning stage and form a feedback loop. A UBEM tool developed with an interface or as a plug-in of prevailing design tools, such as GIS and parametric design tools, would be beneficial to facilitate a broad application of models by planners and designers in practice. An optimal data visualization will further enhance stakeholder involvement in the planning process. Altogether, it can be imagined that digital twins of urban systems, powered by real-time sensing, artificial intelligence, big data and analytics, modeling and simulation, and 3D GIS integrated visualization will address many challenges of urban planning, design, and operation, and unlock the potential for holistic integration of multisector dynamics to achieve optimal energy efficiency, demand flexibility, and resilience of the urban environment.

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# Chapter 4

## Adaptation to Climate Change as a Key Dimension of Urban Regeneration in Europe: The Cases of Copenhagen, Vienna, and Madrid



Sonia De Gregorio Hurtado

**Abstract** Urban regeneration emerged during the 1990s as a policy area aimed at addressing urban decay through a novel approach to overcoming the limitations rooted in physical sectoral transformation. From that point on, a number of integrating mechanisms and relevant topics have emerged in this field, aimed at resolving current urban problems. At this juncture, when climate change has now been recognized as one of the most pressing urban challenges, urban regeneration needs to integrate adaptation to climate change as a crucial basis for action toward resilient urban transformation. This study springs from the recognition of the relevance of this policy approach, the analysis of which is undertaken focusing on three European cities – Copenhagen, Vienna, and Madrid – to understand whether and how the three municipalities are currently integrating adaptation to climate change within their urban regeneration programs. This objective is addressed through a mixed qualitative methodology that uses the case study approach to analyze the policy process, drivers, and obstacles that are fostering or limiting that vision in each local context. The research responds to the questions posed, showing the transformative capacity of integrating adaptation explicitly in the “common” regeneration practice of municipalities, the relevance of the development of local capacity as a crucial element for that, and other main factors that enable cities to advance or keep rooted in “traditional practices.”

**Keywords** Urban regeneration · Adaptation to climate change · Adaptive urban regeneration · Local capacity

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## 4.1 Introduction

Demographic urban stabilization in Europe, unsustainable land use for urban expansion, and the increasing vulnerability of specific neighborhoods over the last three decades are three of the main reasons that explain why cities are focusing their urban planning and policy on the improvement of the existing city. This trend has its roots in the 1980s, when structural changes in the economy and society pointed out to the necessity of giving a meaning and a future to existing urban areas (Secchi, 1984). The transformation of specific neighborhoods of European cities during the 1980s and the early 1990s resulted in the search for a new way to address urban decay, capable of overcoming the limitations identified so far. At that moment, urban regeneration emerged as a concept aimed at introducing a different approach to solving the main problems of deprived urban areas, adopting a vision significantly influenced by the so-called “collaborative turn” and transformation in local governance (Healey, 1996), along with the adoption of a holistic view toward sustainable development, enshrined in the Rio Summit of the United Nations in 1992 and its Declaration.

As urban regeneration is a policy field strongly, and essentially characterized by an integrated holistic approach (Informal Ministerial Meeting for Urban Development of the EU, 2010), it adopts a vision that comprehensively takes into account the relations between the different aspects of degradation in urban areas (Roberts & Sykes, 2000). This vision has pointed to urban regeneration as an opportunity to solve the problems that lead to decline and vulnerability in deprived neighborhoods (Alpoppi & Manole, 2013; Lehmann, 2019).

The main drivers that result in negative impacts in urban areas are profoundly related to global trends that have local consequences. Observing this framework, Roberts and Sykes (2000) argued that the “new” challenge for urban regeneration, at that moment, was to contribute to the achievement of sustainable development. At this juncture, there is no doubt that sustainability embraces new factors related with all the relevant aspects of climate change and energy in urban environments (Bulkeley, 2012; Lehmann, 2019). Consequently, it can be argued that adaptation to climate changes is today a new challenge to urban regeneration, a new dimension that requires to be fully integrated within urban regeneration policies.

Urban regeneration can address many of the challenges posed by climate change (Lehmann, 2019; UNU-Institute of Advance Studies, 2010) as it can provide essential and effective solutions toward making our cities more resilient (Ncube, 2011; Pearson, Newton, & Roberts, 2014) acting in the four key dimensions of urban sustainable development through its integrated approach: the physical, social, economic, and governance dimensions. In this regard, the literature points out that urban regeneration projects can facilitate the implementation of spatial policy responses to adapt to the consequences of climate change in cities (Puppim de Oliveira & Balaban, 2013). It can also act on the social, cultural, and economic dimensions of adaptation to climate change and contribute to reviewing the

mechanisms of governance that determine this, for example, through the creation of local partnerships (Harman, Taylor, & Lane, 2015; Taylor & Harman, 2016).

Moreover, the very essence of urban regeneration leads us to consider that, due to its comprehensive nature, urban regeneration strategies need to integrate adaptation to climate change. Otherwise – and because of the relevance of this challenge – those strategies would be biased and not able to give a place to comprehensive responses toward enduring positive transformation.

The review of the literature on urban regeneration and climate change for this study reveals that contributions addressing this topic have been insufficient so far. This confirms the relevance of focusing attention on integrating adaptation to climate change within the “common” practice of urban regeneration from an academic standpoint. It can contribute to filling relevant research and policy gaps, as well as giving visibility to this issue.

This study has found that most of the analysis undertaken by the literature on local adaptation focus mainly on planning issues and the necessity to integrate adaptation to climate change in urban planning instruments (Zucaro & Morosini, 2018). Other studies focus on different physical dimensions of urban regeneration: urban design and its capacity to adapt to climate change (Palazzo & Wan Mohd Rani, 2017); adaptation in urban regeneration as a way to manage flood risks and deliver water sensitive cities (Chelleri, Schuetze, & Salvati, 2015; Radhakrishnan, Pathiran, Ashley, Gersoniur, & Zevenbergen, 2018); the capacity of urban green spaces or urban agriculture as elements to adapt cities to climate change (García Sánchez, Solecki, & Ribalaygua Batalla, 2018; Mancebo, 2018); and how greening the built environment can accelerate an urban transition (Boeri, Gaspari, Gianfrate, & Longo, 2017; Wilkinson, James, & Reed, 2009). Some studies address the collaborative dimension of urban regeneration, in particular, the capacity of local partnerships to advance toward adaptive scenarios (Harman et al., 2015; Taylor & Harman, 2016). Finally, there are relevant studies that have examined initiatives where urban regeneration includes adaptation to climate change as a key dimension (Ncube, 2011; Puppim de Oliveira & Balaban, 2013). These are aligned with this study, but make a different contribution.

The fact that urban regeneration constitutes a specific policy field recognized by theory (Jones & Evans, 2008; Roberts, Sykes, & Granger, 2016) and practice (Couch, Fraser, & Percy, 2003; Jones & Evans, 2008) contrasts with the low attention paid to it by the literature and the practice from a climatic perspective. Nevertheless, it can play a key role in this regard because most big and medium EU cities implement instruments of urban regeneration.

The identification of this lack of attention to the issue has led to the research objectives of this chapter: (i) to understand if and how cities in Europe are integrating adaptation to climate change within their urban regeneration instruments and (ii) to analyze the main factors that explain this integration (or lack of).

In order to achieve these objectives, the research has developed a mixed qualitative methodology. In the first phase, the study focused on the identification of currently operating programs of urban regeneration in capital cities in Europe, while in the second phase the work focused on the development of three case studies for the

cities of Copenhagen, Vienna, and Madrid. The study is structured as follows: Sect. 2 presents the conceptual framework in which the theoretical and practical interrelations between urban regeneration and adaptation to climate change are highlighted; Sect. 3 explains the methodology; Sect. 4 introduces and develops the case studies, summarizing the results and their discussion; and Sect. 5 presents the conclusions.

## 4.2 Conceptual Framework

### 4.2.1 *Urban Regeneration*

From the 1990s, urban transformation has been undertaken by municipalities, along with other stakeholders, in two main ways:

1. Through the designing of policies and instruments that fall within the domain of “urban regeneration.” Often, in these cases, cities place urban regeneration at the heart of their holistic approach to sustainable urban development. Relevant action in this regard, in Europe, over the last decades enables us to state that: the most important interventions targeting urban areas have not only considered sustainable urban development, but have also focused on regeneration (Alpoppi & Manole, 2013: 179).
2. Through transformative actions implemented with the use of sectoral instruments that are intended to overcome specific existing problems.

Commonly, cities take public action to improve their existing neighborhoods by combining both approaches. This study focuses on the first of these.

As mentioned earlier, the concept of urban regeneration emerged in the framework of a structural transformation of the economy and society that was leading to major negative effects on cities (Hall, 1987). The term and meaning, it concealed, signaled in the shaping of a new area of public policy that aimed to differentiate itself from other approaches to urban transformation that were specifically focused on physical renewal (Roberts & Sykes, 2000). Against this backdrop, urban regeneration has been proposed as an alternative to the existing sectoral instruments with low participation of municipalities and local communities. This also featured an area-based approach, and the necessity to base concerted action on an integrated diagnosis.

As a strategic approach, urban regeneration sets the objective to be achieved and designs strategies that require to be formalized through concrete measures. In 2000, after relevant experience from 1989 onward, this vision became embedded in the framework of the urban dimension of EU Cohesion Policy. It was from that context that, in 2007, the term “integrated urban regeneration” was formalized. This concept is now widely used. Its conceptualization was made definitively explicit and disseminated through the Toledo Declaration (Informal Ministerial Meeting on Urban Development of the EU, 2010). The literature provides

definitions of urban regeneration that are importantly aligned with the Toledo Declaration (even if presenting significant differences). For example, a definition widely disseminated, accepted, and referenced is the one proposed by Roberts et al. (2016):

Comprehensive and integrated vision and action which seeks to resolve urban problems and bring about a lasting improvement in the economic, physical, social and environmental condition of an area that has been subject to change or offers opportunities for improvement. (Roberts et al., 2016: n.a.)

These authors also consider that urban regeneration is characterized by an integrated approach and adopts an area-based vision. All these elements are also present in other definitions with slight differences (e.g., Aparicio Mourelo & di Nanni, 2011; Couch et al., 2003; Moya & Díez, 2012). The definitions by Aparicio Mourelo and di Nanni (2011) and Moya and Díez (2012) put specific attention to acting in vulnerable/deprived areas. This is also a relevant feature of the Toledo Declaration that highlights the fact that deprived urban areas:

[...] are not to be seen as a problem, but as a source of untapped human talent and physical capital whose potential has to be unlocked [...] (Informal Ministerial Meeting on Urban Development, 2010: 7).

through urban regeneration processes. As a result, the document conceptualizes an approach to urban regeneration that clearly considers the relevance of focusing on the most vulnerable areas of cities in the EU. These are also the areas that are the most vulnerable to climate change (Sánchez & Guerrero Lemus, 2017), those that have a greater need of a vision leading to a higher level of climate adaptation capacity.

A relevant feature of urban regeneration that emerges implicitly from all the definitions mentioned, particularly important in the framework of this work, is that it aims to create local capacity through the implementation of a participative process in which public authorities, practitioners, and technicians interact with the local community. All these stakeholders develop new skills, knowledge, and experience, allowing them to continuing the beneficial effect of the urban regeneration program (beyond its life span), and to facing future negative trends. Because of this, urban regeneration is a public policy with strategic potential to improve the adaptive capacity of local communities.

#### ***4.2.2 Adaptation to Climate Change in the Framework of Urban Regeneration***

In the last decades, climate change has been recognized as one of the most pressing challenges of humanity with relevant consequences for cities. It is now widely recognized that cities need to face its effects, particularly those related with the extreme weather events, but also those that are transforming climatic conditions in urban areas in a slower and lower degree. The literature recognizes that:

local authorities are intensifying efforts to design climate policy that includes effective climate change adaptation [but at the same time points out that the] translation of policy into effective actions [...] faces barriers, and is proving to be a true challenge. (Simonet & Leseur, 2018: 1)

This is also reported in the case of specific adaptation plans (Reckien, Salvia, Heidrich, Church, et al., 2018). The literature shows that while many cities in Europe are already working on mitigation, adapting to climate risks is a novel challenge for most of them (EEA, 2016; Reckien et al., 2018).

In any case, the negative socioeconomic and ecologic consequences of climate change are leading cities to face adaptation from different areas of action. Cities are addressing adaptation to climate change in different ways: (i) The most explicit one is the development of local plans for climate adaptation (Reckien et al., 2018); (ii) Many cities are also trying to mainstream the adaptation to climate change in urban planning. This is because urban planning and design are considered key determinants to limit the impacts of climate change (Jabareen, 2015) by acting on the physical dimension of vulnerability and exposure to risks. Municipalities are also trying to integrate the adaptation to climate change in other sectoral policies (mobility, social cohesion, housing, etc.).

In the framework of this work, it is relevant to note that when it comes to urban regeneration it is possible to see that, even if this is a domain in which generally big and medium European cities are active, there is a lack of explicit integration of the adaptation to climate change in their regeneration strategies. For example, in the work conducted by Reckien, Flacke, Dawson, Olazabal, et al. (2013), looking to the thematic areas of action included in the adaptation local plans in 200 European cities, urban regeneration did not arise as a policy field in which municipal authorities aimed to integrate adaptation to climate change. This fact limits the delivery of urban regeneration programs. On the contrary, the advancement toward programs of regeneration that integrate climate adaptation has a long-term transformative capacity. This is because this vision integrates into urban regeneration the adaptive capacity to climate change as an explicit objective, mobilizing technical, economic, and relational resources for that.

Smit et al. (2001: 881) define adaptive capacity as “the potential or ability of a system, region, or community to adapt to the effects or impacts of climate change.” Urban regeneration, because of its integrated vision and its participative approach, has a real potential to increase the adaptive capacity of the area in which it operates, building capacity for urban adaptation, in the sense pointed out by Carter et al. (2015) in the framework of scenarios characterized by climate change and uncertainty (Lampis, 2013). The potential of integrating adaptation to climate change in urban regeneration is not limited to physical transformation. As it is a holistic practice, it is a fertile and coherent policy ground to understand and integrate the complex nature of climate adaptation, avoiding the fragmented vision that “overlooks the multidisciplinary nature of the issue” (Jabareen, 2015: 40).

As mentioned earlier, the literature has addressed this topic in a limited way. Some visions on the issue recommend a different approach to the one adopted by this



study. They ask for a change of focus from urban regeneration to adaptation. In contrast, this study departs from the relevance of maintaining and enhancing urban regeneration as a relevant policy field, in which adaptation to climate change is integrated into an overall vision to advance toward the improvement of deprived neighborhoods. For that, building on the definitions mentioned (see Sect. 2.1), this work proposes the following definition of urban regeneration:

Integrated action, characterized by a multi-agent collaborative process, whose objective is the lasting improvement of the economic, physical, social, climate, and governance dimensions of a vulnerable urban area adopting an area-based approach and through the construction of local capacity.

This definition is proposed to municipalities and stakeholders that operate in urban regeneration to integrate the climate dimension (not only adaptation but also mitigation) explicitly in their urban regeneration practice.

### 4.3 Methodology

In order to achieve the objectives mentioned, the work has adopted a mixed qualitative methodology that has been structured into two phases:

In the first phase, the study aimed to identify currently running programs of urban regeneration. The research focused the analysis at this stage on the cities that have more capacity to integrate adaptation to climate change in urban regeneration. These are the cities with more potential to innovate and with more financial, technical, and institutional capacity and experience in running complex urban policies and instruments. This decision led to selecting a sample of capital or economic capital cities of European countries.

The search mapped urban regeneration initiatives in nine EU capital or economic capital cities of the EU (see Table 4.1). They were analyzed to understand the level of introduction of adaptation to climate change.

The programs' analysis identified three different levels of adaptation to climate change in urban regeneration (see Sect. 4). It was then decided to run case studies focusing on each of these levels. The selection of cities was based on the following criteria: (1) focusing on one city for each level of integration of adaptation to climate change in urban regeneration; (2) sufficient secondary sources to develop the analysis; (3) availability to develop interviews to public servants and/or technicians in the three municipalities. The cities selected for the development of the case studies were finally Copenhagen, Madrid, and Vienna.

In the second phase, the research designed the protocol for the development of the case studies and applied it to the three cities mentioned. The case study was selected as the method to undertake this part of the work as it allows to investigating the phenomenon under study in relation with its urban context using different sources of evidence. The objective was to understand the level of integration of adaptation to climate change in urban regeneration programs, and the policy and

**Table 4.1** Urban regeneration programs in the cities addressed in the first phase of the study

City	Country	Name of the urban regeneration initiative/program	Government level
Brussels	Belgium	Zone de Revitalisation Urbaine (ZRU)	Regional
Berlin	Germany	Transformation areas	Municipal
Copenhagen	Denmark	Integrated Urban Renewal Projects	Municipal
Lisbon	Portugal	Estratégia de Reabilitação Urbana de Lisboa 2011/2024	Municipal
Madrid	Spain	Plan Madrid Regenera. Estrategia de Regeneración Urbana	Municipal
Milan	Italy	Bando alle Periferie	Municipal
Paris	France	Les Projects de Renouvellement Urbain: GPRU, NPNRU	Municipal
Vienna	Austria	Gründerzeit Action Plans	Municipal
Warsaw	Poland	Rewitalizacja w Warszawie	Municipal

implementation process for this, as well as drivers and limitations. In order to achieve this, the development of the case studies was based on the storyline analysis, as it “identifies assumptions and logics underlying the choice of particular policy directions over others” (MacCallum, Babb, & Curtis, 2019: 194) building on an inductive work based on the analysis of policy documents. The gaps of information identified in the policy documents were filled through semiopen interviews to public servants (see Acknowledgments).

The summary of the results and the discussion of the case studies are reported in Sect. 4. Each case has been structured in two main parts that allow understanding if and how the practice of urban regeneration has evolved from a “traditional” approach to the integration of climate adaptation:

3. Contextualization of the city’s urban regeneration policy. Plan of urban regeneration and its characterization (with a specific focus on adaptation).
4. Understanding if adaptation to climate change has been integrated (or not) into the urban regeneration plan of the city and how, with a specific attention to drivers and limitations. This part of the analysis focused on a specific area-based urban regeneration project in order to understand the level of embeddedness of the policy discourse developed in the policy documents in the transformation of concrete neighborhoods.

This work shows the results of the first stage of a wider study that will develop more case studies and will also focus on medium and small cities. The results achieved will determine important next steps, and are proposed as the basis for a reflection of a policy issue that is relevant in the current framework of climate emergence.

## **4.4 Adaptation to Climate Change in Urban Regeneration: The Cases of Copenhagen, Madrid, and Vienna**

As already mentioned, the research reviewed the action that was undertaken in the field of urban regeneration in nine cities (see Table 4.1). In most of them, the urban regeneration initiatives are launched by the local level (only in Brussels it was launched at the regional level). Cities develop urban strategies based on different temporal horizons (2030, 2050), as well as climate plans that include sectoral adaptive action. Predominantly, urban regeneration is not pointed out as a field to be taken into account in the adaptation to climate change.

The first insight into the cities' strategies, and their programs for urban regeneration, identified the fact that while Copenhagen introduced adaptation to climate change explicitly in its urban regeneration practice, the cases of Milan, Madrid, Brussels, Warsaw, and Lisbon presented measures that contributed indirectly to the adaptation to climate change without mentioning this dimension. These measures can be considered as part of a "traditional" view of urban regeneration, where physical transformation is prioritized. The cases of Berlin, Vienna, and Paris showed an intermediate position, where the vision analyzed in this study has been embedded within the discourse of policy documents, but has not been fully integrated within urban regeneration programs.

The research has developed the case studies of Copenhagen, Vienna, and Madrid in order to focus on the three levels of adaptation to climate change in urban regeneration identified by the study.

### ***4.4.1 The Case of Copenhagen***

#### **4.4.1.1 Contextualization of the City's Urban Regeneration Policy**

The municipality of Copenhagen has a tradition of urban regeneration that has operated over time under different names. In 2010, this public policy was unified under the term "integrated urban renewal" (Copenhagen Technical and Environmental Administration Urban Design Department, 2012: 4). The initiative was taken under a national law that allocated national funding to this objective. This policy action was aimed to act on the most vulnerable districts and was characterized by a clear area-based (Copenhagen Technical and Environmental Administration Urban Design Department, 2012: 7) and integrated approach.

The current integrated urban regeneration vision of the city can be considered as the evolution of the previous experience. The municipality has recognized and built on it, considering the integrated urban renewal projects as a sort of second generation of regeneration instruments. Each regeneration project sets up a local office (located in the area where the measures are being implemented) and a steering committee including local people among the other relevant stakeholders. Beyond this,

the interdepartmental governance dimension of the strategy is addressed and a participation process is developed. All this effort is aimed at “empowering people. The partnership must become strong enough to cope with the future” (interview to Municipality of Copenhagen officer, 2019), as a path to construct local capacity.

Another important characteristic of this approach is the interest in involving different funding sources. Before the development of the strategy takes place, there is a preliminary task aimed at identifying potential investors (public and private). As a result, an investment statement is drawn up, covering the possibility for investment from the different stakeholders (Copenhagen Technical and Environmental Administration Urban Design Department, 2012).

The projects are structured in three different phases: (i) the start-up phase, in which participative working groups are created. It comprises the preparation of the district plan (strategy for regeneration of the area) and its approval; (ii) implementation, at this point, the ideas for the projects are planned in detail and implemented wherever possible; (iii) the anchoring phase, in which the future of the various activities and physical projects implemented is determined. In the framework of this study, it is relevant to note that the anchoring phase is extremely important in projects that aim to improve the adaptive capacity of urban areas to climate change to create local capacity.

The analysis of the regeneration practice of Copenhagen shows that it has built a sound method to improve vulnerable neighborhoods over time. In that experience, adaptation to climate change had been integrated indirectly through measures that aimed to improve urban spaces and the energy performance of buildings. This changed in 2011, as explained in the following section.

#### **4.4.1.2 Understanding if Adaptation to Climate Change Has Been Integrated (or Not) Into the Urban Regeneration Plan and How**

The explicit integration of the climate issue in urban regeneration took place from 2011 onward. The main reason mentioned in the gray literature and the interview (interview to Municipality of Copenhagen officer, 2019; Werner, 2014) was that, in July 2011, sudden torrential rain resulted in floods that affected large areas of the city. The neighborhood of Skt. Kjøeld’s was particularly affected. At that time, the city was implementing an integrated urban renewal project in that area. Due to the damages incurred by the flood, the municipality “changed the agenda and direction of the initiative,” causing a “snowball effect” that resulted in the identification of Skt. Kjøeld’s as a “Klimakvarter” (climate resilient neighborhood) (interview to Municipality of Copenhagen officer, 2019) (see Fig. 4.1).

The planning expert for the municipality interviewed and the review of policy documents confirm that the climate pilot project of Skt. Kjøeld’s has evolved the previous experience of urban regeneration by integrating a climate adaptive concern and content. This is because the climate agenda has become a priority for the city (interview to Municipality of Copenhagen officer, 2019). Due to the importance of the project for the development of Copenhagen’s urban approach toward including



**Fig. 4.1** The implementation area of the integrated urban renewal project for Skt. Kjeld's. (Source: The City of Copenhagen, *The Integrated Urban Renewal in Skt. Kjeld's*, 2011: 2)

adaptation to climate change as a crucial facet, and because it has been recognized as the initiator of this vision, it is relevant here to draw a comparison between the approach and measures of the initial project and the project that has finally been implemented under the “Klimakvarter” framework and that has complemented the measures originally planned: the initial project (that began in 2010) assumed that there was a need to overcome the “rundown” perception of Skt. Kjeld's district by making comprehensive physical improvements “to lead the way for additional moves designed to give the area a social lift” (Copenhagen Technical and Environmental Administration Urban Design Department, 2012: 51). The main measures showed an integrated approach, in which the physical and the social dimensions were prominent:

5. Improvement of the Skt. Kjeld's Plads and surrounding streets.
6. Provision of “activity and exercise belts which create better conditions for play, social interaction, and activity” (Copenhagen Technical and Environmental

Administration Urban Design Department, 2012: 54). The many small open spaces were binding together.

7. Places for young people.
8. Project and media workshop (local volunteers helped to create projects for the development of the area).
9. Cultural laboratory.
10. Integration of the project with other municipal strategies. For example, regarding traffic and a cyclist route, the strategy was related to the traffic reduction planned by the Municipality for local streets and the extension of the Copenhagen Green Cycle Route through the district (Copenhagen Technical and Environmental Administration Urban Design Department, 2012).

As mentioned earlier, the regeneration approach embedded in this set of measures was complemented with new actions developed from the perspective of adaptation to “green climate” (Werner, 2014) under the “Klimakvarter” vision. This evolved urban regeneration approach was expressed in the words of the head of Technical and Environmental Affairs for the municipality:

We need to make Copenhagen more resilient to future cloudburst. This will require new ideas and solutions so that we can use rainwater to create new recreational urban spaces. (City of Copenhagen, 2011: 2)

The actions included were as follows:

11. 20% of the asphalted areas in the neighborhood to become green spaces that can be used for storm water management. Objective: 30% of everyday rain “managed locally on the surface in order to prevent pressure on the sewers” (City of Copenhagen, 2011: 5).
12. Transformation of Tasinge Plads (first climate change-adapted urban space) and Skt. Kjeld’s Plads.
13. Creation of the green corridor of Bryggervangen.
14. Cloudburst roads defined as roads that in heavy rain events act as channels, diverting rainwater away from the buildings.
15. Creation of green courtyards.
16. Construction of a “climate resilient block” as a demonstration project for innovative scalable solutions aimed to find sustainable energy and climate solutions for buildings.
17. Citizens’ own climate projects: taking advantage of the participatory process initiated in 2010, the initiative also builds on the involvement of the residents, so that they become jointly responsible for the initiative. For that purpose, the urban renewal office of the climate resilient neighborhood provides financial support and technical knowledge for projects initiated by residents (City of Copenhagen, 2011). Projects include city gardens and transformation of asphalted areas into green spaces.

The comparison of the measures of the two programs confirms the evolution of the urban regeneration concept for the city through the integration of climate change adaptation measures. Within this framework, particularly interesting was the

intention to create local capacity through the involvement of citizens and the private sector in the design and delivery of adaptive measures. This is fully consistent with the vision for the city detailed within the 2015 municipal plan:

Together with the people [...] we will develop good, climate-adapted solutions that improve both everyday life and quality of life in the city as much as possible. It is important that all the city's projects focus on climate adaptation, especially those relating to regeneration [...] (City of Copenhagen, 2015: 40)

As a result of the action described in Skt. Kjeld's, the municipality reported that "the identity of the area is changing" due to the effect of the project (City of Copenhagen, 2015: 25). Interestingly, climate adaptation emerges in this case as an innovative driver capable to reverse the stigmatization of the area by redefining its identity. Beyond this, the initiative is creating an experience and knowledge that are starting to be transposed to other areas of Copenhagen. The project "has won several international awards" (The Climate Resilient Neighbourhood, 2016: 9) and has been recognized by other cities as an inspirational pathway (e.g., New York is currently implementing a similar concept, and C40 included the initiative in the list of the 100 best sustainable urban solutions [The Climate Resilient Neighbourhood, 2016]).

## 4.4.2 *The Case of Vienna*

### 4.4.2.1 Contextualization of the City's Urban Regeneration Policy

The city of Vienna based its approach toward urban regeneration on a vision described as "soft urban renewal" (City of Munich, 2014: 2) that had been developed over the previous four decades. It consists of an approach implemented by the Urban Renewal Offices through the Fund for Housing and Urban Renewal, with the aim of promoting rehabilitation programs, and focused originally on the improvement of relevant social housing stocks owned by the municipality (City of Munich, 2014; Stadt Wien, 2014).

Over time it has implemented interrelated actions aimed at the comprehensive improvement of entire residential blocks by combining housing redevelopment with other measures to improve living conditions more generally (Bretschneider, 2010). The "soft" vision of urban regeneration is based on a strong partnership principle that considers that all players have to be integrated within the process of transformation, moderate redensification, and strong social responsibility (City of Munich, 2014). It aims to preserve the existing population (preventing gentrification) and existing buildings and infrastructure.

The review of the literature on the issue confirms that the vision of urban regeneration in the city of Vienna has evolved from a sectoral one, focused on the physical dimension, and consisting of refurbishment of residential buildings, to an approach that aims to upgrade urban areas where initiatives form part of a more comprehensive vision. An example is the initiative "Together for Floridsdorf" that was launched in 2014 (Stadt Wien, 2014). In 2014, the municipality pointed out that

“this action will decisively shape Vienna’s urban renewal programme in the coming years” (Stadt Wien, 2014: 29). It was based on an approach that aimed to make the city districts “sustainably fit for the future” (Stadt Wien, 2014: 29) and was implemented in two areas: “Am Spitz Süd” and “Am Spitz Nord,” in the district of Floridsdorf. The strategy of transformation consisted of the improvement of 11 buildings through a “socially orientated upgrade of the district” (Stadt Wien, 2014: 28). The action undertaken included structural refurbishment; enhancement of public space; reuse of ground floor premises; the achievement of social equilibrium in the district; and participation of the residents (Stadt Wien, 2014: 28). The regeneration strategy was integrated but did not explicitly address adaptation to climate change. It is relevant to note that the same approach can be found in the policy discourse embedded in the description of the urban regeneration vision of the city, explained in the Stadt Wien (City of Vienna) report in 2014 and 2015.

#### **4.4.2.2 Understanding if Adaptation to Climate Change Has Been Integrated (or Not) Into the Urban Regeneration Plan and How**

A subsequent Stadt Wien (City of Vienna) report (2016) adopted a more holistic view toward urban regeneration than the previous ones. In this report, the integration of environmental and sustainability dimensions turned its attention to climate change. The document mentions the relevance of the Paris Agreement of 2015. It is pointed to as a factor that influenced the urban policy agenda of Vienna significantly, by increasing awareness in local policymakers, and also in other stakeholders (interview to Municipality of Vienna officer, 2019). The conducted interview confirms this development, pointing out that “Since 2016 the topic of climate protection has gained a lot more attention and has become a higher priority” (interview to Municipality of Vienna officer, 2019).

In line with this, the 2016 document *Housing in Vienna* included the concept of “climate-friendly urban renewal” (Stadt Wien, 2016: 42) for the first time. This refers to measures taken on community heating, open spaces, e-mobility, and information and communications technology (ICT) solutions through clear liaisons with the Vienna’s Smart City Framework Strategy (Stadt Wien, 2016) focused on standards of living, societal dimensions, and technological aspects.

The most relevant area-based project developed in this regard is that of *Simmering* (interview to Municipality of Vienna officer, 2019) (see Fig. 4.2).

It is particularly relevant to compare the action being undertaken under this initiative to the one for Floridsdorf. The project for *Simmering* shows a development toward a greater concern with climate issues, in which adaptation is not explicitly mentioned but rather given a more relevant presence. It comprises the following actions:

18. “Smart refurbishment” of three housing blocks with alternative energy generation, and implementation of e-car and e-bike sharing for residents.





**Fig. 4.2** Location of the different actions being implemented in the Simmering project. (Source: Adapted from City of Vienna, [n.d.](#): 9)

19. Densification of district heating, including the local production of energy (photovoltaic and solar systems).
20. New secondary schools (with a new zero-energy gym complex).
21. City data platform contributing to Vienna's IT infrastructure.
22. Modernization of e-logistics and installation of charging infrastructure for e-cars and e-bikes.
23. Modern "mobility points" being prepared for use in public spaces to interlink local mobility services that suit users' needs.
24. Street lighting changed to LED lights.
25. "Landmarks" in the form of innovative street equipment with photovoltaic use (that allow people to charge their phones in public spaces) and aimed to draw attention to the project, making it more "visible."

26. Implementation of the “mobile information lab SIMmobil” as a communication platform to offer comprehensive information and the chance for residents to be involved in the project.
27. “The lessons of knowledge and innovation will be put to use on a city-wide and international basis” (Stadt Wien, 2016: 42). This is because this project is integrated within the Smarter Together project (funded under Horizon 2020), the largest urban renewal project funded by the EU, and in which Vienna is exchanging knowledge and experience with other EU cities, such as Munich and Lyon.

The project has a clear “smart city” profile, in which the integration of new technologies is at the core of the solutions envisaged, showing that this is also a sector from where cities can propose to advance toward urban regeneration processes that integrate adaptation to climate change. In any case, adaptation to climate change has not been explicitly integrated, or made visible. Significantly, the document that reports on the action undertaken in this framework up to 2019 is entitled “Simmering. Smart Urban Renewal” (City of Vienna, 2019). The project partnership consists of 12 partners (the municipality, research institutions, private technology companies, etc.) that work together to design and implement the mentioned measures.

The analysis of the urban regeneration policy discourse in Vienna reveals the major influence of growing climate concerns and international agreements achieved on this issue. It can also be noted that this new urban regeneration approach has evolved through the years toward a vision in which the climate dimension in urban regeneration has been increasingly recognized and fostered through advancement in environmental (interview to Municipality of Vienna officer, 2019) and smart solutions. This vision appears nowadays as fully embedded in the policy discourse of the municipality. At the present moment, the city is undertaking a policy of adaptation to climate change on the basis of its 2010–2020 Climate Protection Plan II (Klimaschutzprogramm, KliP II). A relevant element that will contribute to it is the city, recently approved, Urban Heat Island Strategy (City of Vienna, 2018), an instrument that aims to “show planners, architects and the relevant administrative departments which actions can be implemented within their sphere of influence” (City of Vienna, 2018: 9). The philosophy of the plan is that action to reduce the Urban Heat Island effect can be selected and implemented “early” on, in different planning and urban development processes (City of Vienna, 2018), where urban regeneration can play a crucial role. The plan states that “climate change adaptation must be integral to planning, to increase the amenity of public spaces and improve the urban climate” (City of Vienna, 2018: 18), underlining its coherence with the Urban Development Plan 2025 (STEP 2025), where it is also mentioned that the city’s aim is that climate protection and adaptation to climate change should become an integral part of the planning, implementation, and development of city neighborhoods and open spaces (City of Vienna, n.d.). In line with this intention, and fully integrated within the political discourse, the city is advancing toward adaptation to climate change in the practice of urban regeneration, a move described as “completely necessary” (interview to Municipality of Vienna officer, 2019).

Nevertheless, there are some limitations to meet this horizon with regard to governance and implementation issues. The most relevant are the necessary involvement of a number of government departments that have traditionally worked independently and the division of the budget available, which requires a cross-funding vision to implement adaptive actions that come under the jurisdiction of different stakeholders (e.g., energy rehabilitation for housing, improvement of public areas, etc.) (interview to Municipality of Vienna officer, 2019). This is pointed to as an “internal challenge for Vienna” at the current moment, together with the necessary advancement in technical capacity within local public institutions (interview to Municipality of Vienna officer, 2019). It is pointed out that the benefits of integrating adaptation to climate change in urban regeneration are only visible in the medium term. Consequently, it is considered that climate awareness raising among technical staff, society at large, and other relevant stakeholders, in the context of urban regeneration, is also a transformative and key target to be achieved (interview to Municipality of Vienna officer, 2019).

### ***4.4.3 The Case of Madrid***

#### **4.4.3.1 Contextualization of the City’s Urban Regeneration Policy**

The city of Madrid does not have a tradition of urban regeneration. Public action toward urban transformation has gone ahead over time on the basis of sectoral instruments to improve the quality of public spaces, to construct or refurbish buildings, to offset the shortfall in facilities and public services, and to improve the standards of the housing stock, along with social and economic policies. This scenario changed in 2018, when the Government Area of Sustainable Urban Development (AGDUS) launched the strategy for urban regeneration integrated in the Madrid Recupera Plan (Plan MAD-RE), an instrument aimed to improve the existing neighborhoods, in line with the New Urban Agenda and the UN Sustainable Development Goals (SDGs) (Ayuntamiento de Madrid, 2018) and in pursuit of the main objective of overcoming the traditional urban policy based on urban expansion (Ayuntamiento de Madrid, 2018). The instrument adopts the concept of “integrated urban regeneration.”

Seeking explicit alignment with the UN’s New Urban Agenda, the Plan MAD-RE focuses on the area of the city located between the city center and the new urban developments, where it is considered that vulnerability is concentrated. The initiatives proposed are spread across the different districts of the capital, under different categories and form. Only few of them adopt an area-based approach.

The Plan MAD-RE, which sets down the main goals for action over the years to follow, does not explicitly consider adaptation to climate change as a specific facet within urban regeneration projects (Ayuntamiento de Madrid 2018; interview to Municipality of Madrid officer, 2019). It sets the following elements as its main focus in its proposals for urban regeneration: (1) rehabilitation of buildings and

neighborhoods; (2) the creation of central areas in the peripheries; (3) a new mobility culture; (4) the requalification of public space; and (5) the reinforcement of a green areas network. As a result, it can be said that it adopts a strong physical approach, far from a real integrated vision.

#### **4.4.3.2 Understanding if Adaptation to Climate Change Has Been Integrated (or Not) Into the Urban Regeneration Plan and How**

The introduction of the adaptive view is implicit in the Plan MAD-RE, as it funds energy rehabilitation in buildings, the improvement of public space, and the reinforcement of the green areas network under a renaturalization approach (interview to Municipality of Madrid officer, 2019). The implicit vision mentioned is also embedded in the fact that the plan's strategy has a global intention, aiming to achieve the integrated regeneration of deprived or vulnerable neighborhoods. Consequently, it is expected that the action within the Plan MAD-RE will be added to with other sectoral strategies developed by other municipal departments. To achieve this objective, the plan needs to be coordinated with the plan on air quality and climate change for the city and the plan Madrid + natural (both of them coming within the scope of the Government Area of Environment). While the first is aimed at mitigating carbon emissions, the second has a specific focus on adaptation to climate change through the development of nature-based solutions (NBS). In fact, the plan Madrid + natural is considered by the municipality as a vision of innovation and urban regeneration through NBS. The complementarity of the plan Madrid + natural with the strategy of urban regeneration has resulted in one pilot project entitled "Del Río a Pradolongo" (from the river to the Pradolongo park), an itinerary that links up two green areas, and that will be transformed through the improvement of public spaces, with a specific focus toward adaptation to climate change. It involves the collaboration between two government areas of the municipality, something that is difficult to implement at a general scale (interview to Municipality of Madrid officer, 2019).

The review of the plan has set the focus of this study on one of the few area-based initiatives with sufficient level of implementation to be considered of interest to this analysis: the transformation foreseen for the area located close to Madrid's airport, the Barrio del Aeropuerto. The area is located in the north-east of Madrid. Because of the physical problems of the level of conservation and lack of universal accessibility to the buildings, the state of public spaces, and recurrent flooding (due to the presence of an underground stream), this area has been subject of an urban regeneration strategy that focuses on the buildings, public spaces, and the existing social fabric (interview to Municipality of Madrid officer, 2019) in the framework of the Plan MAD-RE (see Fig. 4.3).

The strategy is a participated project importantly based on the physical transformation, in which the social and the economic dimensions are not explicitly addressed (because of the lack of competences of AGDUS on social and environmental issues) [interview to Municipality of Madrid officer, 2019]). Because of this, the transformation foresaw cannot be labeled strictly as "integrated" urban regeneration under



**Fig. 4.3** The area of implementation of the urban regeneration project of Barrio del Aeropuerto. (Source: Adapted from Ayuntamiento de Madrid, 2017)

the lens of this study. The main measures included in the project are the following: elevators installation, refurbishment and energy rehabilitation of the residential buildings, improvement of the public space, creation of a new green area to avoid flooding, and creation of new public facilities. The project foresees also the construction of two new housing buildings that will generate capital gains to face the planned transformation.

The project to regenerate the Barrio del Aeropuerto does not integrate adaptation to climate change as a specific area of action. The issue is not mentioned in any of the documents that define or summarize the proposals, approach, and outcomes of the participatory sessions, or in the gray literature. As a result, and in line to what emerges from the approach of the Plan MAD-RE, it could be said that the project only addresses adaptation to climate change through the indirect effect of certain physical measures that will contribute to better adapting it to more extreme hot temperatures and flooding.

While there is no doubt about the contribution that the project will make in this regard, the program's lack of specific integration of adaptation to climate change limits importantly the potential of the solution. In this sense, opportunity to give a place to public awareness raising with regard to adaptation to climate change through participation-based sessions has been lost. The lack of participative and integrated approach arises in this case as a factor importantly related with the limited transformative capacity of the project from an adaptive point of view. This contrast with the view expressed by the technician interviewed, who pointed out that explicit integration of adaptation to climate change should be present in urban regeneration programs in the future (interview to Municipality of Madrid officer, 2019). Nevertheless, to achieve this vision the municipality will need to overcome

relevant limitations related with path dependence: (i) the policy silos and the division of competences among different areas of the local government that need to work together and (ii) the division of the budgets to implement integrated urban regeneration projects (interview to Municipality of Madrid officer, 2019).

## 4.5 Conclusions

In the group of nine main cities addressed in first phase of the research, the study identified three different levels of integration of adaptation to climate change in urban regeneration:

- Cities that have integrated adaptation to climate change as a specific axis in their strategy for urban regeneration. This dimension acts as a relevant innovation driver of the strategies.
- Cities that have integrated adaptation to climate change as a specific issue in its strategy for urban regeneration from a discursive point of view, and that is evolving toward full integration of this vision in the practice of urban regeneration.
- Cities that have not explicitly integrated adaptation to climate change, either in their policy discourse on urban regeneration or as a specific angle to be addressed in the practice of urban regeneration.

These three different levels of integration of the policy issue addressed are represented, respectively, by the cities of Copenhagen, Vienna, and Madrid, the three case studies in which this research focused on. It is worth noting that the technical experts from the three cities interviewed point to the necessity of making adaptation to climate change explicit and visible in urban regeneration projects, as this can deliver a transformative adaptive local capacity in communities and institutions (interviews to Copenhagen, Vienna, and Madrid officers, 2019). They all underlined the urban regeneration potential of taking into account the physical, social, and economic dimensions of adaptation to climate change. This study identified that this vision has been fully embedded only in the case of Copenhagen. This case shows the relevance of identifying climate vulnerability at district level, and demonstrates the potential of involving the residents and the private sector in the design and implementation of adaptive measures (Harman et al., 2015) from the beginning in the context of regeneration programs. As a result, this case highlights the relevance of complementing traditional vulnerability indicators for the identification of the neighborhoods in which urban regeneration is more necessary, with climate change vulnerability indicators. It also shows that regeneration instruments based on a sound participative methodology and with a longer tradition on the implementation of the integrated approach (acting in the social, economic, physical, and governance dimensions) have the capacity to integrate adaptation to climate change as a new dimension.

In the case of Vienna, the municipality has undertaken a gradual commitment to adaptation to climate change that has been fostered by an awareness raising process

resulting from the Paris Agreement reached at COP21, in December 2015, and the participation in EU research/implementation projects. It has also been given momentum from the urban planning, environmental and smart city dimensions of local policy. The issue is not explicitly addressed in the practice of integrated urban regeneration showing governance and budget limitations, but it can be considered that the relevance of this vision has been fully integrated within the urban regeneration policy discourse of decision makers. This fact, along with the existence of a solid climate policy, shows a trend to fully integrate adaptation to climate change in urban regeneration in the medium term.

In the case of Madrid, the international urban agendas, and particularly those of the United Nations, have introduced local action on urban regeneration to a great extent, but this has not resulted so far in embedding adaptation within the policy discourse developed by the city plan for urban regeneration. The city has not developed, so far, a really integrated urban regeneration experience, as the plan focuses mainly on physical transformation. The lack of an integrated and participative approach in urban regeneration is acting as an obstacle to transfer adaptive solutions tested in pilot projects to the general urban regeneration practice, and to embed adaptive awareness in the area-based interventions addressed by this study.

The analysis shows that two are the main problems arising when integrating adaptation to climate change as an explicit approach in urban regeneration projects: (1) the traditional policy silos determined by the organization of local administrations (that limits powers of government departments that manage urban regeneration strategies) and (2) the division of budget allocations. These facts are pointed out as relevant obstacles, in the cases of Vienna and Madrid, over the lack of institutional or local capacity. These facts have been also identified by the literature as limitations to implement local adaptation in general (Measham, Preston, Smith, Brooke, et al., 2011).

Taking all this into account, and because this study has identified that the nine programs of urban regeneration addressed include implicit adaptive measures based on physical transformation (even in the cases that show more limitations to the integration of adaptation to climate change), this work proposes to adopt a strategic approach in urban regeneration to advance to more adaptive urban futures in policy contexts that present an important inertia to change, and are highly determined by path dependence. It departs from the definition of urban regeneration proposed in Sect. 2.2. From the adoption of that vision, cities can define adaptation to climate change as an explicit dimension of their regeneration programs (even if they do not include specific measures tackling that challenge in the first stage). The proposal consists in integrating adaptation to climate change in two main ways at the beginning: (i) as a specific topic for reflection, discussion, and awareness raising within the participative processes that characterize urban regeneration projects and (ii) as a dimension to be taken into account in the definition of all the actions proposed within the projects, making explicit how “traditional measures” (as the energetic rehabilitation of buildings, or the planting of trees) contribute to adapt the city to climate change. This approach can allow cities to start an important policy transformation with regard to their climate action without requiring extra budget and

without being limited by the policy silos. The proposal aims to activate the potential of urban regeneration to fully embed climate adaptation in future steps, developing local capacity gradually through an incremental transformation of the “traditional” urban regeneration vision.

Finally, the study shows that the integration of adaptation to climate change can act as a driver of innovation in urban regeneration (as identified in the case of Copenhagen and also, partially, in the case of Vienna). Jabareen’s (2015: 39) argument regarding the broader practice of urban planning is also pertinent and valid for urban regeneration: “climate change and its resulting uncertainties challenge the practices and concepts” of urban regeneration, resulting in a need to rethink and revise it. This study confirms that the integration of adaptation to climate change in urban regeneration can make evolve this policy area, so that it is capable to give a response to one of the main urban challenges of our time.

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# Chapter 5

## Water Runoff and Catchment Improvement by Nature-Based Solution (NBS) Promotion in Private Household Gardens: An Agent-Based Model



Rembrandt Koppelaar, Antonino Marvuglia, and Benedetto Rugani

**Abstract** Nature-based solutions (NBS) such as rainwater gardens and permeable paving can be deployed as an alternative to conventional urban gardens to improve cities' resilience against increasing rainfall. This study describes the application of an agent-based model (ABM) to assess the role of private gardens toward the enhancement of water management by households. The ABM simulates the process of switching from "gray" (i.e., paved) to green gardens, taking into account the effect of "soft" (garden networks and gardening workshops) and "hard" (monetary) incentives. The ABM is supported by a water balance model to consider the effect of rainfall on soil water retention. Four different cities in Europe were analyzed: Szeged (Hungary), Alcalá de Henares (Spain), Metropolitan city of Milan (Italy), and Çankaya Municipality (Turkey). The results demonstrate that greening private gardens can generate impact on water run-off and catchment in cities in the order of 5–10%, reaching peaks up to 20% in certain cases. While the proposed model is not devoid of limitations, the results provide useful insights in the ways different instruments (e.g., municipal subsidies and knowledge support) could assist with the greening of private gardens for NBS promotion to respond to cities' water management challenges.

**Keywords** Green gardens · Urban green solutions · Individual-based simulation · Water retention · Netlogo · Gardens management

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## 5.1 Introduction

Heavy rain showers cause serious water management problems in urban areas, when sewage systems overflow, streets are submerged and lower-lying buildings and basements face the risk of nuisance or even damage resulting from flooding (Atta-ur-Rahman, Parvin, Shaw, & Surjan, 2016; Eldho, Zope, & Kulkarni, 2018; Shepherd, 2013). An increase in soil sealing in urban areas has been acknowledged as an important factor in these urban water management problems (Ferreira et al., 2019). Increased soil-sealing is the result of increasing land use for urbanization not only due to population growth and urban sprawl but also of a trend to pave private gardens.

Urban water management is not only just a public issue but also increasingly one in which a variety of private actors have a role. Due to the share of privately owned land through homeownership, households can play an important role in preventing these water management problems. Homeowners could reduce soil sealing by changing their “gray” (i.e., paved) garden into a permeable, green garden with plants and grass that allows for better absorption of rainwater. This raises the question on how private households that have a yard in the back or in front of their homes could be encouraged to green their paved garden.

Based on the literature, three important conditions informed by social practice theory (Reckwitz, 2002) can be distinguished as relevant to the practice of garden transformation: (i) *Willingness to change*, that is, people’s proneness to change and how it is affected by social, physical, institutional, and economic conditions); (ii) *Competences*, that is, ability to change (what people need in order to be able to change, in terms of knowledge, relational and financial resources, time, and physical skills); and (iii) *Meaning*, that is, what motivations drive people to adopt this change, such as environmental values, financial values, comfort-related values, social or even religious values, and social status. Such dynamics of behavioral change are not straightforward. The value that a private garden represents varies substantially across people, and different types of behavioral change need different supportive measures to enhance the likelihood of successful and lasting transformation. Firstly, a need exists to consider the (symbolic) meanings, uses, and values of the yard and related practices to the householders. Secondly, the extent should be considered to which those meanings are maintained when (part of) the yard is greened, and perhaps complemented or replaced by new meanings over time, through supportive interventions. These factors affect the willingness to change; for example, if people are keen on gardening and they spend considerable time doing so, this is the best guarantee for them having a green garden (Beumer, 2018; Kullberg, 2016).

Changing one’s gray backyard into a (partially) green garden, involves both one-shot behaviors (the conscious decision to take out tiles and plant vegetation, often asking for an investment of money, effort, or time) and routine behaviors (adopting new routines of watering and maintaining this vegetation, or even gardening practices, which often need to be supported by the social, institutional, and physical

environment). It then becomes important that peers also adopt these routines, that norms and rules do not work against these routines and that the physical environment is not discouraging. The theoretical background concerning those hypothetical values, solutions, and behavioral changes is described in a deliverable of the project Nature4Cities (<https://www.nature4cities.eu/>), a European H2020 project that funded the present research (Nature4Cities, 2019). The aim of this work is analyzing them quantitatively, thus enabling comparisons of decisional impacts in terms of their social, environmental, and economic aspects. An agent-based modelling approach was deployed to accomplish this objective.

## 5.2 Methodology

In general, an agent-based model (ABM) allows for a fine representation of real world based on its object-oriented approach, where individuals can be simulated with their individual characteristics, as well as with their group behaviors arising from interactions among individuals (Marvuglia, Navarrete Gutiérrez, Baustert, & Benetto, 2018). As such, ABMs make it possible simulating heterogeneity among societal groups, due to socioeconomic factors such as age, lifestyle, preferences, and motivational factors. This renders ABMs a suitable methodology to study a wide range of behavioral and socioeconomic factors relevant for nature-based solutions (NBS) decisions, such as health, quality of life, social cohesion, environmental justice, economic value, and so forth. Another advantage of ABM is that spatial information of the urban environment and its relationship to people can be readily incorporated based on Geographical Information Systems (GIS) collated data, which is meaningful for purposes of evaluating heterogeneity between NBS spaces, buildings with NBS, and other structures associated with urban NBS networks.

This study is based on an ABM built in the popular Netlogo platform (version 6.0.4: <https://ccl.northwestern.edu/netlogo/>). Private garden owners are represented as a set of individual objects (called “agents”) enforcing a set of decision mechanisms directing them toward the enhancement of water management at the household level. NBS such as rainwater gardens, infiltration gardens, and permeable paving are seen as an intervention that transforms gardens covered with impermeable tiles, bricks, or other paved infrastructure into those that can absorb and retain water that is put to use for plant growth, for urban water and nature management purposes. The scenario focus is on gardens privately owned by households living in four use case cities of the Nature4Cities project: Szeged (Hungary), Alcalá de Henares (Spain), Metropolitan city of Milan (Italy), and Çankaya Municipality (Turkey). A water balance model is built to incorporate rainfall to soil dynamics in the model (see Sect. 5.2.1.1).

The modeling approach we adopt is based on the concept of causal chain layering, where a sequence of events that are assumed to have a causal relationship are modeled, leading to a particular outcome (in our case changes in the make-up of private gardens affecting water balances). The relationships are drawn from both

social-psychological perspectives and elements of social practice theory. We focus on factors by which a transformation can take place and affect a larger share of NBS-based gardens for water management on private property. The type of NBS is not specified in the absence of specific water balance impacts data, but generalized into green gardens, partially green gardens, and paved gardens. The adoption or absence of green gardens over time, based on different potential policy instruments by the municipality and other stakeholders is examined. Three instruments are assessed: (i) a subsidy that affects financial incentives, (ii) the organization of gardening workshops facilitated by the municipality, and (iii) the establishment of gardening networks including garden space provisioning, garden sharing, and knowledge exchange.

### 5.2.1 Model Setup: Change in Garden Type

The model simulates agent decisions to change their gardens based on the *motivation*, *ability to change*, and *willingness to change* concepts, as formerly introduced in Sect. 5.1. These pillars are used to derive a probability by which change happens, which varies depending on segments of the population as defined by motivation and ability to change. The framework is depicted in Fig. 5.1.

#### 5.2.1.1 Simulation of Garden Change Behavior

The simulation is limited to agents that own gardens and starts with the identification of the baseline situation for their private gardens, distinguishing among the following options (based on their land use type): (a) fully paved gardens, (b) partially green gardens (50% surface area), or (c) fully green gardens (100% surface area).

The change in a person's garden is not a trivial and fast decision. As such, it is not implemented in the simulation as a binary 0/1 switch. Instead, each agent will have a bar measuring the "effort made to make a change" in the simulation, which goes from 0 to 100%, and only once 100% is reached a garden is transformed. This allows simulating the presence of inertia in such an important decision. A step toward the 100% is simulated depending on a successful probability exceedance roll that is carried out per time step (in the simulation set to 3 months). Such a roll establishes an instantiation of the *probability of change* for an agent. If the draw is below 0.9 (90%) no "change step" occurs, but if it is 0.9 or higher a "change step" occurs in the simulation, adding a set percentage increase to the change bar.

The *probability of change* is formed by the linkage between motivations, ability to change, and willingness to change segments, described below. All qualitative elements are thereby combined to represent a likelihood (between 0 and 1) by which a change will happen.

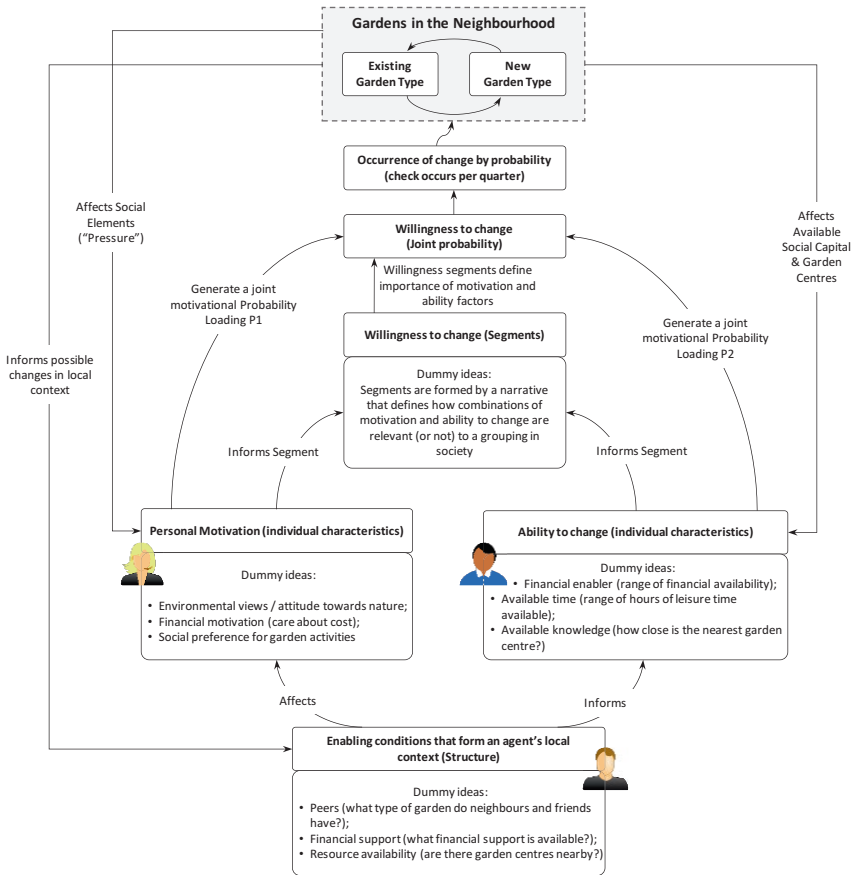


Fig. 5.1 Relational model used to build the simulation

To set heterogeneity in the simulation, the increase in the “effort to make a change” bar is further varied between two types of agents called “transformative decision” and “incremental decision” agents. An *incremental decision agent* needs four successful probability exceedance rolls ( $4 \times 25\%$ ) to change their garden, while a *transformative agent* needs two successful probability rolls ( $2 \times 25\%$ ) to enact the change. The rationale behind the transformative vs. incremental setting is that some people will make changes in their lives swiftly, while others gradually, with large variations between people on the pace of change.

Thereby, multiple steps are required before the 100% value is reached, indicating successive efforts required before a garden change occurs. Such efforts can also partially vanish in the simulation, representing the idea that plans for making change can be deprioritized or cancelled as other events happen in life. This “decay” or “erosion” is simulated with a decline in the “effort made to make a change” bar, which can occur every 3 months and can be varied.



The additional rationale for introducing the process of “decay” or “erosion” is also that if the simulation is run for a very long time span, say 1000+ years, it will not lead to all gardens becoming green. This is because without such a “decay rate” all gardens would become green, given enough time at positive probabilities of change, even at very low levels, unless these probabilities are zero. This is deemed unrealistic, since even with large scale support not all people will want to have a green garden.

Each agent is initialized with motivational characteristics, which define their motivation to create change. In the simulation, these motivations are related to the following environmental, financial and social aspects:

- M1—Environmental values, that is, those responding to the question: What is my attitude toward nature?
- M2—Financial values, that is, those that determine whether or not I am financially motivated when greening my garden.
- M3—Social preference, that is, the answer to the question: Do you consider gardening a pleasure?
- M4—Social network, expressed by the answer to the question: Are my friends interested in gardening?

The motivational characteristics are set based on theoretical reasoning informed by the literature, and not informed by detailed surveys, as this was outside of the scope of the study. The descriptions below should therefore not be interpreted as real-life characterizations. The agents in the simulation are categorized into two groups that identify the variety in their motivation and abilities. “Proud Gardeners” forming a group of people who see gardening as a favorable past-time and “Backyard Barbeques” who favor using gardens for barbequing and family purposes. In reality, more groups can likely be identified in relation to household typologies (e.g., single person, multiple people, and families). The motivational characteristic influences the agents using the Likert scale from 1 to 5 (indicating very low to very high motivation) presented in Table 5.1.

For example, for the question “what is my attitude toward nature?” a value of 1 means that the agent gives a very low importance to the natural environment, and vice versa for a ranking of 5. To simplify the simulation, it is assumed that motivations are fixed, except for the influence of the municipality interventions that the user can set: a subsidy that affects financial incentives, the organization of gardening workshops facilitated by the municipality, and the establishment of gardening networks including garden space provisioning, garden sharing, and knowledge

**Table 5.1** Motivation and Ability Likert scale rating for segments in the simulation

Segments	Motivations				Abilities			
	M1	M2	M3	M4	A1	A2	A3	A4
Proud gardeners	5	1	3	1	2	4	2	3
Backyard barbeques	1	2	1	1	3	3	1	3

exchange. Each of these interventions' forms enabling conditions that either affect motivational factors or ability to change factors or both, as follows:

- Organization of garden workshops: when the agent is connected to a garden workshop influencer, this increases the A3 knowledge available by 2, up to a maximum of 5.
- Establishment of gardening networks: when the agent is connected to a garden networking influencer, this increases the score for motivation M4 related to social network to 5.
- Gardening subsidies: improves the score for ability finances available to 5 and increases the score for motivation A1-finances-available by 1, up to a maximum of 5.

The model could be extended to further address changes in motivation. For example, "are my friends interested in gardening?" will change depending on the friendships of the agent with other agents and the gardens that these agents own, and this can affect the social network motivation of the agent. Such changes are informed by enabling conditions and barriers that form an agent's local context. In this case, an enabling condition is the type of gardens that friends have, which informs on whether friends are interested in gardening.

Each agent is also initialized with characteristics that sum up their ability to change, in terms of what (physically, socially, economically, external to their mental perceptions) will help them in the process of change. In the simulation, this relates to the following financial, timing, knowledge, and resource abilities:

- A1: Do I have the finances available to change my garden?
- A2: Do I have the time available in my schedule to change my garden?
- A3: Do I have the knowledge or is there knowledge support in my network to change my garden?
- A4: Is there a garden center nearby where I can obtain the items needed for my garden's change?

Each agent always has a ranking for an ability to change on a Likert scale, similar to motivation, from 1 to 5 (indicating very low to very high ability) (see Table 5.1). In reality, abilities to change are never fixed but always vary depending on the agent's circumstances as simulated (such as for time available), friends' network with levels of gardening knowledge, and the existence of garden centers. To simplify this, however, aspects in the simulation will be fixed as otherwise each individual ability will need to be simulated (such as income level variation), and this is not the purpose of our model.

An agent is part of a population segment that defines their willingness to change that is expressed as a probability for being driven by a certain purpose. Before expressing this, a qualitative description of the segment is made, as informed by the three aspects:

- People in a segment will either carry out change rapidly (called transformative), or carry out the change slowly (called incremental) as defined above.

- A segment is assumed homogenous in how important particular motivations are.
- A segment is assumed homogenous in how they score on particular abilities to change.

An example of a dummy segment is an “Incremental Pioneering Gardener,” which is described as a person who “cares substantially about nature, is willing to take incremental steps to change his/her garden if he/she has time available and will fit the garden to what means are available to him/her; he/she is thus not reliant on financial resources, considers gardening a pleasure, and the social influence of friends does not matter substantially.”

In terms of motivation this hypothetical segment ranks high (value 4) on attitude toward nature, very high on the absence of financial motivation when greening the garden (value 5), high (value 4) on considering gardening a pleasure, and finally the interest of friends in gardening is not an important motivation (no ranking).

In terms of ability to change, this segment is typically initialized based on a low ranking (value 2) for financial resources available, a high ranking (value 4) for time available, a ranking of 5 for knowledge/support available (very high), and a medium ranking (value 3) for a garden center nearby. The rationale for such initializations relates to different segments. In the simulation, this will be done by a normalized initial distribution of the preferences, with the mean being the typical ranking. A dummy logic fitting the dummy example above could be that pioneering gardeners are likely younger people that are environmentally conscious and as such live in areas where gardening resources are available. The willingness to change of this type of people is thus defined by the combination of their motivational attitude toward nature and pleasure in gardening, and their ability is usually underlined by seeking out conditions to have the ability to fulfill these motivations.

### 5.2.1.2 Transformation to Probability of Change per Segment

A single value of the probability of change ( $P^c$ ) is formulated for each segment. This is done starting from separate probabilities for motivation  $P^M$  and ability  $P^a$  and multiplying these:

$$P^c = P^M \cdot P^a, \quad 0 < P^c, P^M, P^a < 1 \quad (5.1)$$

The probability values are multiplied such that all probabilities fall between 0 and 1. The probabilities are set based on a sigmoid function that relates to the Likert score ( $L$ ), which ranges between 0 and 1. A sigmoid function is often used to represent a growth process. The standard logistics function (a version of the sigmoid function) is chosen here for its simplicity, ease of interpretation, and proven applicability for statistical analysis:

$$P = \frac{1}{1 + e^{-(\beta_0 + \beta_1 L)}} \quad (5.2)$$

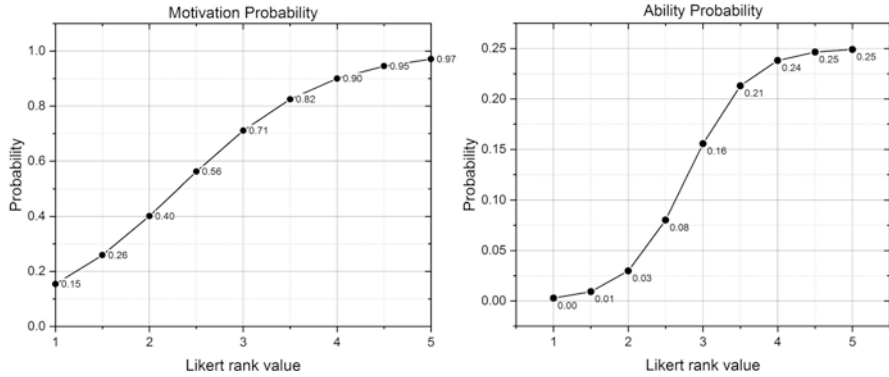


Fig. 5.2 Motivation probability curve example (left) and ability probability curve example (right)

The selection of the parameters  $\beta_0$  and  $\beta_1$  defines the result of the Likert ranking translation into a probability value.

In the case of motivation, the function given by Eq. (5.2) is utilized as is. It is also assumed that motivation probabilities are multiplicative, such that if all motivations are high, the probabilities are high, and if one motivation is very low, the probability will drop significantly, thus forming a constraint. In other words, different motivations influence each other, and having just a single very high motivation is insufficient for change. Choosing  $\beta_0 = -3$  and  $\beta_1 = 1.3$  we obtained the probability curve for motivation shown in Fig. 5.2 (left).

The joint motivational probability for the “Incremental Pioneering Gardener” using these parameters would then be:

$$P^M = 0.9 * 0.97 * 0.9 = 0.786 \tag{5.3}$$

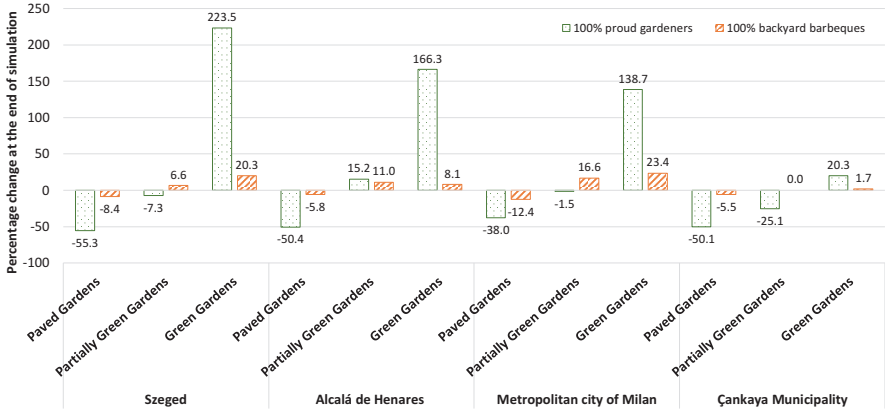
In case of ability to change, we used an adjusted version of Eq. (5.2), based on the idea that abilities to change are not multiplicative, but additive. One can score low on one ability to change but this does not affect other abilities to change. As such, in order to make the total joint probability of the ability to change sum to one, an adjustment factor is needed, based on the number of ability factors  $f$  that are summed. The adjusted function becomes:

$$P = \frac{1/f}{1 + e^{-(\beta_0 + \beta_1 L)}} \tag{5.4}$$

If we choose  $\beta_0 = -7$  and  $\beta_1 = 2.5$  we obtain the probability curve for motivation shown in Fig. 5.3 (right).

The joint motivational plus ability probability for the “Incremental Pioneering Gardener” would then be:

$$P^a = 0.03 + 0.238 + 0.03 + 0.03 = 0.328 \tag{5.5}$$



**Fig. 5.3** Percentage variations in the numbers of each type of garden between the beginning and the end of the simulations in each of the four cities

The final joint probability obtained by Eq. (5.1) for this example would be:

$$P^c = 0.787 \cdot 0.328 = 0.25 \tag{5.6}$$

Therefore, for this segment, based on the conditions set in the example, there is a 25% chance to make a stepwise effort of change in the change bar. Given that four steps are required to reach 100% and a probability check is done four times per year (once every 3 months), ignoring “effort decay,” on average the “Incremental Pioneering Gardener” will change their garden within a 1 to 2 years’ time, assuming a stable motivation and a stable ability to change.

The importance of motivation becomes clear if we adjust the values to show how low motivations influence the outcomes. If the interest of friends in gardening was important and the scoring here was very low, the motivation probability outcome would translate into:

$$P^M = 0.9 \cdot 0.97 \cdot 0.9 \cdot 0.154 = 0.122 \tag{5.7}$$

The joint probability would then change to:

$$P^c = 0.122 \cdot 0.328 = 0.040 \tag{5.8}$$

This would mean that for this segment there is a 4% chance to make a stepwise effort of change in the change bar. Given that four steps are required to reach 100% and a probability check is done four times per year (ignoring “effort decay”), this implies that this agent segment would change their garden within 6–7 years; unless a growing number of friends become interested in gardening and motivate the agent to change their garden, thereby improving the motivational score for the “social network” motivational factor.

### 5.2.2 Model Setup: Water Balance Model

A key purpose of the simulation is understanding the impact that private gardens without and with NBS can have on water management across the city. To this end, a water balance model was introduced in the simulation to assess how different types of private gardens affect the soil water balance and water run-off following rainfall events, as an indicator for potential flooding.

The water balance simulation is linked with the change in garden type by taking into account the type of garden, including paved gardens, partially paved/green gardens, and green gardens. For each of these garden types, different parameter values are introduced due to which soil moisture content and runoff vary. As such, a picture for individual gardens and the entire city emerges over time as rainfall affects runoff and soil moisture over time, along with changes in garden types.

The soil water balance model takes into account four processes: rainfall, plant transpiration, soil evaporation, and net runoff. For the sake of simplicity, water transfer processes between soil layers, including percolation and lateral water exchanges, were not considered. The main water balance equation used was taken from (Sheikh, 2006; Sheikh, Visser, & Stroosnijder, 2009):

$$\Delta s_t = \frac{P_t - R_t - E_t - T_t}{d * 1000} \quad (5.9)$$

where  $\Delta s_t$  is the change in soil moisture (in  $\text{m}^3$  per soil layer volume in  $\text{m}^3$ ),  $d$  is the depth of the soil layer in meters,  $P_t$  is precipitation rate in mm,  $R_t$  is net runoff in mm,  $E_t$  is evaporation in mm, and  $T_t$  is transpiration in mm. The factor 1000 at the denominator is used to convert from 1 mm to 1 meter, in order to translate to a  $\text{m}^3$  of water per  $\text{m}^2$  of soil surface area (being 1 mm of rainfall equivalent to 1 liter of water per  $\text{m}^2$ ). Thereby the water content in the soil  $s_t$  changes every time step as:

$$s_{t+1} = s_t + \Delta s_t \quad (5.10)$$

Precipitation was incorporated as an exogenous variable using daily rainfall data from 2007 to 2017 taken from the European Climate Assessment Dataset project (<https://www.ecad.eu/>). Runoff was simulated based on the SCS Curve Number Procedure developed in the US (Neitsch, Arnold, Kiniry, & Williams, 2011), which was also adopted by (Sheikh et al., 2009). The value calculates the runoff in mm based on the amount that is “abstracted” before it reaches the soil (in plants, puddles) and the amount that is “retained” by the soil. The general equation is:

$$R_t = \frac{(P_t - I_t)^2}{(P_t - I_t + S_t)} \quad (5.11)$$

where  $I_t$  is the abstraction of precipitation  $P_t$  before it reaches the soil as a combined variable for surface storage (puddles), interception by plants, and root infiltration, and  $S_t$  is the retention of precipitation water in the soil. Thereby, the higher the

soil retention of precipitation and the abstraction of precipitation, the lower the runoff, inclusive of interaction between these elements. To simplify the equations, the value of  $I_t$  is typically assumed to be 0.2 times the soil retention, resulting in the following equation:

$$R_t = \frac{(P_t - 0.2S_t)^2}{(P_t + 0.8S_t)} \quad (5.12)$$

The values of soil retention are calculated from so-called curve number (CN) values, which indicate the share of imperviousness of an area, based on a parameterized equation (Sheikh, 2006; Sheikh et al., 2009):

$$S_t = 25.4 \left( \frac{100}{CN} - 1 \right) \quad (5.13)$$

The values for the CN or share of imperviousness are described in (Neitsch et al., 2011) varying by hydrological soil group (A: sandy soils, B: loam soils, C: sandy clay loam soils, D: clay soils) and type of land use (agricultural lands and urban areas). The values used in our simulation are 98 for paved gardens (based on being nearly impervious), 75 for partially green gardens (being somewhat permeable), and 50 for green gardens (indicating a permeable soil). Soil evaporation is calculated based on the calibrated crop water balance model in (Tribouillois et al., 2018), based on 7 years of observation of evapotranspiration for several different soil covers. The empirical equation is based on first calculating the total potential evapotranspiration (PET), and subsequently adjusting this with crop specific coverage, soil water content, and capacity impacts. The equation was adopted as:

$$E_t = PET_t \cdot \left( 1 - \frac{k}{k_{max}} \right) \cdot \left( \frac{S_t}{S_{max}} \cdot E_{min} + 1 - E_{min} \right)^b \quad (5.14)$$

Where  $PET_t$  is the potential evapotranspiration (PET) of the soil layer which is first adjusted by the crop foliage. This is done by the coefficient  $k$ , which is a crop- or foliage-specific evaporation coefficient divided by  $k_{max}$ , a boundary parameter such that there is no evaporation if  $k$  equals  $k_{max}$ . Subsequently, potential evapotranspiration is adjusted by the soil water situation, where  $S_t$  is the soil moisture content. The closer the soil moisture content to the maximum soil moisture  $S_{max}$ , the higher the evaporation. The adjustment parameter  $E_{min}$  is introduced as a minimum evaporation rate that varies per soil type, regardless of soil moisture content. Finally, the soil water situation component is adjusted by a power factor parameter  $b$  which is empirically estimated, and was introduced to add a weighting on the soil moisture effect versus the crop effect in the equation.

Several calculations for PET are possible, of which the ‘‘Thorntwaite formula’’ approach was used because of its parsimoniousness (Thornwaite, 1948) and validity in providing a reasonable approximation of PET (Pereira & Paes De Camargo, 1989) based solely on daily and monthly temperature values for a location. The formula is empirically established as follows:

$$PET_t = 1.6 \cdot \left( \frac{10 \cdot T_t}{I} \right)^e \quad (5.15)$$

where  $I$  is a heat index that captures the relative warmth for the location across the year,  $T_t$  is the daily temperature in Celsius degrees, and  $e$  is an empirically fitted parameter that adjusts the result based on the heat index. The heat index is calculated as:

$$I = \sum_{m=1}^{12} \left( \frac{T_m}{5} \right)^{1.514} \quad (5.16)$$

where  $T_m$  is the mean monthly temperature.

The value of the parameter  $e$  can be calculated using the polynomial:

$$e = (6.75 * 10^{-7}) I^3 - (7.71 * 10^{-5}) I^2 + (1.792 * 10^{-2}) I + 0.49239 \quad (5.17)$$

The calculation of transpiration,  $T_t$ , is based on the DREAM model (Distributed model for Runoff Evapotranspiration, and antecedent Soil Moisture Simulation) described in (Manfreda, Fiorentino, & Iacobellis, 2005). The model utilizes the potential evapotranspiration (PET) that is adjusted with soil moisture content and a canopy fraction-specific parameter. The equation is formulated as:

$$T_t = m \cdot \min \left( 1, \frac{1}{3} \frac{S_t}{S_{max}} \right) \cdot PET_t \quad (5.18)$$

where, similarly to Eq. (5.12), the potential evapotranspiration  $PET_t$  is adjusted by the soil water situation.  $S_t$  is the soil moisture content; the closer it is to the maximum soil moisture  $S_{max}$ , the higher the evaporation. Subsequently, the resulting value is adjusted by a canopy specific parameter value  $m$  (fraction of soil covered by vegetation). The value has been estimated as 0.35 for grass, 0.45 for crops, and 0.5–0.77 for trees. In our simulation, a value of 0 was chosen for paved gardens, a value of 0.25 for partially open gardens, and a value of 0.5 for open gardens, assuming an urban setting with limited coverage.

### 5.3 Model Results

The simulation provides two key outputs. First, changes in the number of gardens based on paved, partially green, and green NBS-based garden types. Second, the runoff across the city at a cumulative level based on local rainfall patterns and soil types associated with the garden types.

Each of the three models was run for four use case cities: Szeged (Hungary), Alcalá de Henares (Spain), Metropolitan city of Milan (Italy), and Çankaya Municipality (Turkey). The spatial and population data for the case studies are more extensively described in (Nature4Cities, 2019). The models were run with the same



input data variations. Twelve model runs were established for each city, based on variation in two population segments with either 100% of the population allocated as “Proud Gardeners” or 100% of the population allocated as “Backyard Barbeques.” Furthermore, variation was added for each of these two groups. Firstly, the results were simulated twice for both groups with no interventions. Subsequently, four interventions’ combinations were simulated for each group: (1) only 80 municipal agents organizing gardening workshop; (2) only 100 gardening municipal agents organizers’ network groups; (3) only 1000 annual financial subsidies per year for garden transformation; and (4) a combination of all three interventions occurring at the same time.

A summary of the results for the case studies is reported in Fig. 5.3, which shows the percentage variation of the number of each type of gardens in each city, between the beginning and the end of the simulation, distinguishing the two population agents. The values for each population are calculated as the average of the simulation runs. One can observe relevant percentage increases in the number of green gardens and decrease in the number of paved gardens among the members of the 100% “Proud gardeners” community. As expectable, much more modest increases in the numbers of green gardens are observed among the agents belonging to the community of 100% “Backyard Barbeques.” Çankaya is the city with the lowest increases of green garden in both communities.

In the following sections, the results for each simulated city are described in more detail.

### 5.3.1 Szeged Case Study

The simulation area was selected to cover the center of Szeged with surrounding areas and satellite peri-urban areas.

The simulation shows a substantial difference between the “Proud Gardeners” and “Backyard Barbeques” segments in terms of transitions from paved to NBS-based green gardens, due to differences in gardening-related motivation and ability between these segments. In both cases, at the start of the simulation, the number of paved gardens ranges from about 350 to 380. In case of “Proud Gardeners,” 120 to 150 paved gardens are transformed into partially green and green NBS-based gardens, whereas in case of “Backyard Barbeques” only about 30 paved gardens are transformed. In addition, the majority of transformed gardens become green NBS-based gardens for “Proud Gardeners,” whereas the majority of transformed gardens for “Backyard Barbeques” become partially green gardens (see Table 5.2).

The effect of gardening knowledge workshops and gardening network group organizers, and subsidies as individual measures, is nonexistent for “Backyard Barbeques.” In case of “Proud Gardeners,” the effect is nonexistent for gardening knowledge influencers, small for gardening group organizers, with 35 more transformed paved to green gardens over the modeled period, and large for subsidies with close to 130 additional gardens transformed from paved to green gardens (see

**Table 5.2.** Szegeid simulation model results for water runoff and catchment improvement by NBS promotion in private gardens

Run set	Household mix	# Gardening knowledge workshop influencers	# Gardening group organizer influencers	# Financial subsidies per year for garden transformation	# Paved gardens		# Partially green gardens		# Green gardens		Cumulative runoff 10 years (m <sup>3</sup> )	Cumulative runoff final year (m <sup>3</sup> )
					Start	End	Start	End	Start	End		
1	100% proud gardeners	0	0	0	354	216	165	207	119	215	253,300,000	25,725,000
2	100% proud gardeners	0	0	0	383	230	184	243	91	185	259,000,000	26,220,000
3	100% backyard barbeques	0	0	0	380	353	162	181	104	112	265,200,000	27,860,000
4	100% backyard barbeques	0	0	0	359	338	174	187	104	112	265,110,000	27,943,000
5	100% proud gardeners	80	0	0	367	219	172	200	92	212	243,900,000	24,567,000
6	100% proud gardeners	0	100	0	367	188	168	193	91	245	248,770,000	25,100,900
7	100% proud gardeners	0	0	1000	385	94	178	65	97	501	245,500,000	24,769,000
8	100% proud gardeners	80	100	1000	367	47	170	53	94	531	226,900,000	22,750,000
9	100% backyard barbeques	80	0	0	368	346	155	161	106	122	270,000,000	28,460,000
10	100% backyard barbeques	0	100	0	405	369	150	168	108	126	273,000,000	28,630,000
11	100% backyard barbeques	0	0	1000	388	365	173	184	91	103	269,200,000	28,310,000
12	100% backyard barbeques	80	100	1000	366	304	198	198	97	159	267,090,000	27,810,000

Table 5.2). Interestingly, in case of combined interventions, there is a medium-sized effect on “Backyard Barbeques,” with an additional 50 gardens transformed from paved to green, demonstrating that combining measures can be more effective for particular segments than others.

The garden transformation has a non-measurable impact on total private garden water runoff for “Backyard Barbeques” segment model runs. In case of “Proud Gardeners,” the growth in green NBS-based gardens reduces water runoff by over 10% in the case where close to 300 paved gardens are transformed into partially green and green gardens. The estimated order of magnitude is thereby 5–10% of the water runoff that can be reduced by private garden-based NBS promotion.

### ***5.3.2 Alcalá de Henares Case Study***

The simulation area was selected to include the city center of Alcalá de Henares with surrounding areas and satellite peri-urban areas. The whole area includes the edible forest NBS use case proposed as a green space in the Nature4Cities project (Nature4Cities, 2019). The simulation shows limited changes for “Backyard Barbeque” segments and substantial changes for “Proud Gardeners” in terms of transitions from paved to NBS-based green gardens, due to differences in gardening-related motivation and ability between these segments. At the start of the simulation, the number of paved gardens range between 670 and 800. In case of “Proud Gardeners,” 240 to 300 paved gardens are transformed into partially green and green NBS-based gardens, whereas in case of “Backyard Barbeques” only about 30 to 40 paved gardens are transformed. In addition, about half of transformed gardens become green NBS-based gardens for “Proud Gardeners” and the other half partially green gardens. The majority of transformed gardens for “Backyard Barbeques” become partially green gardens (see Table 5.3).

### ***5.3.3 Metropolitan City of Milan Case Study***

The simulation area was based on a portion of the North of the Milan Metropolitan Area centered on the quarry restoration site in Parco Lago Nord (about 15 km north of Milan city center) selected with surrounding neighborhoods.

The simulation shows a transformation of about 80 to 90 paved gardens into partially green and green gardens for “Backyard Barbeques” segment, relative to a transformation of close to 500 paved gardens into both partially green and green gardens for “Proud Gardeners.” In both cases at the start of the simulation, the number of paved gardens ranges from 1350 to 1400 (see Table 5.4).

The influence of gardening knowledge workshops, gardening network group organizers, and subsidies does not lead to additionally transformed gardens for “Backyard Barbeques,” showing the lack of influence of additional motivational and ability factors. In case of “Proud Gardeners,” the effect is not measurable for

**Table 5.3.** Alcalá de Henares simulation model results for water runoff and catchment improvement by NBS promotion in private gardens

Run set	Household mix	# Gardening knowledge workshop influencers	# Gardening group organizer influencers	# Financial subsidies per year for garden transformation	# Paved gardens		# Partially green gardens		# Green gardens		Cumulative runoff 10 years (m <sup>3</sup> )	Cumulative runoff final year (m <sup>3</sup> )
					Start	End	Start	End	Start	End		
1	100% proud gardeners	0	0	0	801	516	211	337	177	336	122,443,876	13,157,346
2	100% proud gardeners	0	0	0	709	461	222	334	223	359	126,219,000	13,724,784
3	100% backyard barbeques	0	0	0	673	632	205	236	198	208	131,859,470	15,318,105
4	100% backyard barbeques	0	0	0	709	679	230	249	223	234	139,723,138	16,319,339
5	100% proud gardeners	80	0	0	694	413	223	327	146	323	117,229,700	12,578,218
6	100% proud gardeners	0	100	0	756	465	217	321	224	411	128,962,056	13,916,964
7	100% proud gardeners	0	0	1000	672	135	233	118	238	890	112,762,481	12,364,437
8	100% proud gardeners	80	100	1000	668	141	223	94	175	831	100,678,370	11,151,138
9	100% backyard barbeques	80	0	0	719	685	246	265	175	190	135,234,450	15,678,575
10	100% backyard barbeques	0	100	0	771	734	225	246	191	207	136,389,930	15,857,002
11	100% backyard barbeques	0	0	1000	690	654	205	226	210	225	136,660,000	15,921,648
12	100% backyard barbeques	80	100	1000	726	654	249	288	226	258	136,421,300	15,609,300

**Table 5.4** Metropolitan city of Milan simulation model results for water runoff and catchment improvement by NBS promotion in private gardens

Run set	Household mix	# Gardening knowledge workshop influencers	# Gardening group organizer influencers	# Financial subsidies per year for garden transformation	# Paved gardens		# Partially green gardens		# Green gardens		Cumulative runoff 10 years (m <sup>3</sup> )	Cumulative runoff final year (m <sup>3</sup> )
					Start	End	Start	End	Start	End		
1	100% proud gardeners	0	0	0	1373	874	502	711	373	663	1,153,782,700	118,912,091
2	100% proud gardeners	0	0	0	1390	917	488	656	385	690	1,191,479,000	122,381,000
3	100% backyard barbeques	0	0	0	1404	1322	463	502	380	423	1,217,212,257	128,300,480
4	100% backyard barbeques	0	0	0	1410	1334	491	540	396	423	1,206,933,500	127,273,740
5	100% proud gardeners	80	0	0	1356	828	448	653	373	696	1,167,484,600	119,423,008
6	100% proud gardeners	0	100	0	1344	887	514	665	401	707	1,155,100,000	118,499,250
7	100% proud gardeners	0	0	1000	1405	393	459	262	355	1564	1,122,606,470	113,974,702
8	100% proud gardeners	80	100	1000	1355	300	490	268	403	1680	1,119,285,721	113,404,603
9	100% backyard barbeques	80	0	0	1355	1299	503	520	368	407	1,201,793,500	126,945,900
10	100% backyard barbeques	0	100	0	1312	1251	491	531	376	397	1,204,644,599	127,176,382
11	100% backyard barbeques	0	0	1000	1371	1293	508	560	364	390	1,246,314,209	131,399,937
12	100% backyard barbeques	80	100	1000	1393	1290	495	552	388	434	1,210,696,790	127,365,850

gardening knowledge influencers and small for gardening group organizers, and large for subsidies with close to 500 additional gardens transformed from paved to green gardens (see Table 5.4). Interestingly, in case of combined interventions there is a medium-sized effect on “Proud Gardeners” with an additional 100 gardens transformed from paved to green versus only providing subsidies, showing that combining measures can lead to better results.

The garden transformation has a non-measurable impact on total private garden water runoff for “Backyard Barbeques” segment model runs as there is a limited transformation from paved to green gardens. In case of “Proud Gardeners,” the growth in green NBS-based gardens reduces water runoff by about 5% in the case where close to 1000 paved gardens are transformed into partially green and green gardens. The order of magnitude as estimated is thereby up to 5% of water runoff that can be reduced by private garden-based NBS promotion.

### 5.3.4 Çankaya Municipality Case Study

The simulation area was based on the southeast portion of Ankara where Çankaya municipality is located. The simulation shows a substantial difference between the “Proud Gardeners” and “Backyard Barbeques” segments in terms of transitions from paved to NBS-based green gardens, due to differences in gardening-related motivation and ability between these segments. The number of paved gardens at the start of the simulation ranges from 190 to 270, while the number of initial partially green gardens ranges from 160 to 220, and the number of NBS green gardens from 700 to 800. Thereby the households in the municipality already have mostly green gardens as opposed to paved gardens. During the simulations, in case of “Proud Gardeners,” close to 70÷100 paved gardens are transformed into green NBS-based gardens. In case of “Backyard Barbeques” segments, only about 15 paved gardens are transformed. Of the transformed gardens, nearly all become green NBS-based gardens for “Proud Gardeners” (see Table 5.5).

## 5.4 Limitations of the Model

Some simplifications and assumptions were necessary to make the model operational using the information available. Firstly, a number of assumptions were necessary when local data were not available (e.g., on exact number and location of gardens, soil type) and conducting local surveys for these particular model parameters was not possible in the context of this work. Secondly, given the absence of specific data for particular buildings or built areas, generalized assumptions based on land use data were made. If more spatially explicit and survey-based data had been available, deeper and more location-specific insights could have been gained. For example, data on the actual instead of inferred type of garden privately owned

**Table 5.5** Çankaya municipality simulation model results for water runoff and catchment improvement by NBS promotion in private gardens

Run set		# Gardening knowledge workshop influencers	# Gardening group organizer influencers	# Financial subsidies per year for garden transformation	# Paved gardens		# Partially green gardens		# Green gardens		Cumulative runoff 10 years (m <sup>3</sup> )	Cumulative runoff final year (m <sup>3</sup> )
					Start	End	Start	End	Start	End		
1	100% proud gardeners	0	0	0	241	147	159	147	787	893	278,875,680	28,806,589
2	100% proud gardeners	0	0	0	198	125	170	167	787	863	282,621,000	29,182,840
3	100% backyard barbeques	0	0	0	233	218	201	208	752	760	293,545,000	30,865,200
4	100% backyard barbeques	0	0	0	234	226	181	177	796	808	294,414,000	31,043,860
5	100% proud gardeners	80	0	0	213	135	173	160	751	842	279,634,000	28,922,090
6	100% proud gardeners	0	100	0	258	179	187	176	795	885	287,024,000	29,654,200
7	100% proud gardeners	0	0	1000	225	57	179	64	795	1078	270,198,000	27,816,820
8	100% proud gardeners	80	100	1000	252	49	163	58	792	1100	271,416,800	27,963,900
9	100% backyard barbeques	80	0	0	255	244	197	195	765	778	297,173,290	31,319,940
10	100% backyard barbeques	0	100	0	249	229	216	221	761	776	294,381,057	30,916,457
11	100% backyard barbeques	0	0	1000	270	259	171	173	718	727	297,249,331	31,278,000
12	100% backyard barbeques	80	100	1000	193	179	158	150	791	813	294,819,370	31,039,300

by citizens could allow a more accurate assessment of the potential for rainwater management through NBS transformation of paved gardens. As such, in case of further developing the existing models for purposes of supporting decision making on NBS development, a data collection exercise would need to be programmed to combine local surveys with observational data.

In the applied ABM, generic garden types are chosen to make the model parsimonious for displays purposes, in order to establish a valid relationship between private garden transitions and city water management. NBS-specific water management data would be required for a real-world usable model, ideally tailored to different soil types on which the NBS are placed within an urban context. Similarly, to assess the transition from one garden type to another, the population is segmented with different start values for motivation and abilities. In a real world usable model, these segments would need to be investigated based on location-specific statistical survey work, inclusive of motivational and ability-related questions from which different segments can be deduced, for example, through exploratory data analysis (EDA) or cluster analysis (CA). To make the model more concretely usable, historical patterns of garden change and the causes of change would need to be studied in more detail, so as to provide boundary conditions on how these changes occur, for example, distinguishing the real cases of event-based changes, such as when moving to a new house, or changes happening on an on-going basis, or both. In the present model, the possibility of a garden type change occurring is set to be *in itinere*, with decision moments happening on a weekly basis. A further limitation lays in the fact that the effect of the interventions has not been evaluated with real world data related to the situation with no interventions. In the model, three interventions are currently available as inputs, setting the number of subsidies, the number of influencer agents that organize local gardening workshops, and influencer agents that facilitate the setup of gardening networks. Finally, the tool used for developing the showcase models, that is, Netlogo, was found to be highly suitable for rapid model development and testing of the conceptual ideas. In fact, Netlogo allows quick adjustments, and provides a visual interface with no additional coding required to obtain results in a versatile manner including spatial maps. However, the main limitation was found in two aspects. Firstly, the limited ability of the platform to carry out many simulations in a sequential and automated manner, as opposed to having to manually log the results of every run, and start every new run manually. Secondly, the limited ability of the platform to link with web and data streaming architecture, which is possible in case of other ABM packages such as MESA (<https://mesa.readthedocs.io/en/master/>), MASON (<https://cs.gmu.edu/~eclab/projects/mason/>) and Repast-Simphony (<https://repast.github.io/index.html>) as these utilize cross-platform programming languages including Java and Python, that can be readily linked to web and data platform architecture. When developing such models for replicability purposes within simulation platforms for recurring use, one of these different platforms would thereby be selected for programming. The downside is that these languages have more complexity and do not come with similar in-built visualization automation, thereby requiring substantially more coding time to provide a working model.



Based on the assumption simplifications listed above, the results cannot be interpreted on an absolute basis of the number of gardens transformed to green NBS-based garden, or on the absolute size of run-off in cubic meters of water. In other words, the results cannot be taken as a direct transition pathway, where the interventions can be used to evaluate the impact a municipality has on the number of private gardens in the city. Instead, the values should be interpreted on a comparative basis between model runs, where changes and the different speed of changes occurrences can suggest whether one solution is better than another.

The results inform whether this type of assessment modeling can be useful from a planning perspective, especially in terms of providing insights in the ways municipal incentives could assist with the greening of private gardens for NBS promotion in order to address potential city water management issues.

## **5.5 Conclusions and Recommendations for Future NBS Agent-Based Modeling Assessments**

The purpose of this work is gaining an improved understanding of the extent to which substantial rainfall in short periods can be mitigated by increasing the number of green private gardens in a city. Within this context, the model allows to assess how “soft” (garden networks and gardening workshops) and “hard” (monetary) incentives can help to further the adoption of NBS on private property. Several scenarios were tested to create a tool to empower further discussions on the approaches that could be implemented in order to improve the success for NBS adoption by households through facilitation at a municipal level.

The ABM approach was applied to the cases of four different towns in Europe: Szeged (Hungary), Alcalá de Henares (Spain), Metropolitan city of Milan (Italy), and Çankaya Municipality (Turkey). The simulation results demonstrated that changing the make-up of private gardens could have up to a 20% impact on water run-off and catchment in cities with mostly paved gardens and large private garden areas, but that the typical impact of such changes is in the order of 5–10%. However, these results are not representative for peak flows that may result in flash floods.

In the simulation, two different opposing segments of the population were simulated: “Proud Gardeners” and “Backyard Barbeques.” The former with high motivation on environmental values and social preferences, high ability in time but lower in finances, and the latter with low motivation for gardening on all motivational factors, but with higher financial means. A substantial variation between the two different segments emerged, primarily due to the low motivations of the “Backyard Barbeques” segment. While very few (5%) “Backyard Barbeques” activated garden transformations in the base case scenarios, in the case of “Proud Gardeners” up to 40% of paved gardens were transformed into fully green NBS gardens.

The simulations also highlighted how different qualitative and quantitative policy and social programs that could be setup by a municipality can be simulated, in

terms of their potential impact on people's socioeconomic factors, such as motivation and the ability to implement green NBS gardens. Three types of such interventions were simulated: (i) organization of garden workshops that increases knowledge available, (ii) establishment of gardening networks that increased motivation, and (iii) gardening subsidies that increased finances available as an ability. The simulations established that based on the loadings that were included, limited improvements were established due to garden workshops and gardening networks, but that making gardening subsidies available had a significant impact in the order of an additional 20–40% of gardens transformed from paved to green gardens. The results also showed that combinations of interventions could have an impact even if individual interventions do not, because they can lift multiple barriers. The reason is that it is assumed that motivational factors relate to probabilities that are multiplicative, such that when increasing motivation for multiple factors, the overall probability of transforming a garden grows. In other words, if there is more environmental motivation and social motivation, the combined effect is greater than the effect of these motivations alone. The results indicate that by using such simulations to evaluate actual segments based on local surveys, insights can be gained into how combined facilitation of NBS changes can work best together.

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# Chapter 6

## Carbon Accounting for Regenerative Cities



Jukka Heinonen and Juudit Ottelin

**Abstract** The carbon budget for limiting global warming to the targeted 1.5 ° is running out. Cities have a central role in climate change mitigation, as the vast majority of all greenhouse gas emissions occur to satisfy the energy and material needs of cities and their residents. However, cities typically only account for their direct local emissions from transportation, industry, and energy production. This may lead to the so-called low-carbon illusion of cities following from producing little and reporting low emissions, while extensively relying on imported material and energy flows. Consumption-based accounting, or carbon footprinting, enables overcoming this problem by assigning the emissions to the end user regardless of the place of production. However, currently the carbon footprinting methods only capture the harm side, and not the potential positive effects, the restorative or regenerative impacts, caused by green infrastructure, reforestation, and carbon capture and storage, for example. These positive impacts are sometimes called “carbon handprint”. In this chapter, we create a handprint-extended carbon footprinting method to illustrate how restorative and regenerative impacts can be incorporated consistently in the carbon accounting of cities and carbon footprints of consumers. We also link the discussion on regenerative cities with the remaining carbon budgets.

**Keywords** City · Carbon budget · Carbon footprint · Carbon handprint · Regenerative · Restorative

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## 6.1 Introduction

World is continuously becoming more urbanized as population concentrates to growing cities. However, the current type of urbanization, linked to economic growth and increasing consumption, requires a vast amount of natural resources and causes increasing levels of greenhouse gas (GHG) emissions and waste (Rees & Wackernagel, 2008). In order to break this destructive pattern, urbanization needs to be reinvented. Ecologically regenerative urbanization aims to do this by finding new regenerative ways of production, consumption, and urban living (Girardet, 2014). While “regenerative” by definition means going beyond “sustainable”, i.e., improving or restoring the state of environment instead of neutral environmental impacts (du Plessis, 2012; Pedersen Zari, 2018; Reed, 2007), it should be realized that, at the global scale, even sustainability is a far target regarding most planetary boundaries (O’Neill, Fanning, Lamb, & Steinberger, 2018). However, local regenerative actions can help to achieve global sustainability.

Reaching regenerative urbanization calls for a systemic approach. Individual solutions cannot be labeled “regenerative” unless their impact is regenerative at the global system level, including life cycle perspective and rebound effects caused by changes in the economic activities, technology, and human behavior. For example, creating and maintaining green infrastructure requires energy and resources, but may also reduce energy and resource consumption of other activities, such as the construction and maintenance of grey infrastructure. At the city level, these environmental spillover effects are most easily captured by using environmentally extended economic input-output (EE IO) models (Ottelin, 2016; Wiedmann, Chen, & Barrett, 2015). In this chapter, we focus on one aspect of regenerative cities: climate change mitigation. We propose a conceptual model for incorporating regenerative actions to the existing comprehensive carbon accounting tools.

Despite the fact that numerous national and international level commitments have been made to address climate change, the global GHG emissions are still rising (aside from times of global recession) (IPCC, 2018). Thus, many cities have recognized their responsibility in taking strong climate action (e.g., C40 CitiesXE “Cities” , 2018; Covenant of Mayors, 2020; ICLEI, 2020). However, the tools that cities have for carbon accounting may limit these actions and sometimes lead to unintended consequences. In particular, cities typically only account for their territorial emissions, meaning the direct local emissions from transportation, industry, and energy production. This may lead to the so-called low-carbon illusion of cities following from producing little and reporting low emissions, but extensively relying on imported material and energy flows (Heinonen & Jóhannesson, 2019). When regenerative actions are added in the equation, cities may even claim to be “carbon neutral” or “carbon negative”, but this usually only holds true if the imported emissions are ignored. C40 Cities have made pioneering work by assessing their consumption-based emissions (C40 Cities XE “Cities” , 2018), meaning the life-cycle emissions caused by the consumption of goods and services within a city regardless of the location of production. Consumption-based accounting can be a powerful tool in

designing GHG mitigation policies on a city-level, as it accounts for the trans-boundary flows (Ottelin et al., 2019) which tend to become more and more important as the geographic unit of analysis gets smaller (Heinonen et al., 2020). Combined, the two approaches, territorial and consumption-based, give a comprehensive overview of the overall impact of a city (Afionis, Sakai, Scott, Barrett, & Gouldson, 2017). The above-mentioned EE IO models provide these two perspectives simultaneously and coherently.

Consumption-based GHG accounting, also called carbon footprinting, provides unique insights into the climate impacts of global trade. Regardless of where the emissions originate, they are allocated to the final consumer. This accounting approach is becoming increasingly important as the share of global emissions embodied in international trade has increased significantly over the last decades, reaching soon one third of the gross annual emissions (Kanemoto, Moran, Lenzen, & Geschke, 2014; Sato, 2014; Wiedmann & Lenzen, 2018). Moreover, when it comes to cities and their territorial boundaries, the trans-boundary share is significantly higher (Heinonen et al., 2020).

While the inclusion of consumption-based accounting to a city's toolbox indisputably opens up new avenues for GHG mitigation policies, the method also carries along a significant limitation. It inherently only captures the harm side, the gross amounts of emissions caused in the production and delivery chain, and the use phase of a good or a service (see the review of consumption-based carbon footprint literature of Heinonen et al., 2020). Currently, consumption-based carbon footprint models don't take into account the potential improvements in the state of the environment, the restorative or regenerative impacts, and therefore don't incentivize creation of regenerative solutions.

These restorative and regenerative impacts, meaning e.g. increases of carbon sinks and stocks, are sometimes called "carbon handprint" (Grönman et al., 2019; Horváth, 2019). For example, wooden construction, green infrastructure, reforestation, and carbon capture and storage can have positive impacts that are not taken into account by the current consumption-based carbon accounting methods. On the other hand, the negative impacts of land use change are often excluded from the models as well, although not always (Heinonen et al., 2020). It is easy to argue that similarly as in the case of emissions, the positive impacts should also be taken into account either locally (like territorial emissions) or globally by using a life-cycle method (like consumption-based emissions). These can also be combined into a matrix-like city carbon map, as proposed by Wiedmann et al. (2015).

In this chapter, we open the discussion on how to incorporate the regenerative impacts consistently in the consumption-based carbon accounting methods. We create a visualization of such a handprint-extended carbon accounting of cities and consumers. We also link the discussion on regenerative cities with the actual state of annual global GHG emissions and remaining carbon budgets in order to discuss the scale of the needed change.

In the following sections, we first explain the concept of carbon budgets and how it relates to city and consumer carbon footprints, and to the importance of looking at the balance between emissions and stocks and sinks instead of the harm-side

only. Next, in Sect. 6.2, we present the various carbon accounting methods for cities, and discuss the current limitations of carbon accounting from the perspective of regenerative actions. In Sect. 6.3, we illustrate how restorative and regenerative impacts, i.e., carbon handprint, could be integrated into the carbon accounting of cities and consumer carbon footprints. In the last section, we provide some final conclusions and policy implications.

## 6.2 Theoretical Context

### 6.2.1 *The 1.5° Warming Target and Carbon Budgets*

Global warming has reached the one-degree milestone (above the pre-industrial level) and is quickly approaching the Paris Agreement's target mitigation level of 1.5 °C (UNFCCC, 2018). Yet the annual anthropogenic GHG emissions are still on an upwards pathway (IPCC, 2018). Reaching the 1.5° halting target, or even staying below two degrees, thus requires massive emission reductions rapidly, or going below zero in the near future (Minx et al., 2017).

Carbon budgets make the reduction requirements tangible, showing how much emissions can still be emitted without exceeding a certain warming target (IPCC, 2018; Le Quéré et al., 2012). The budget estimations are not exact, but subject to uncertainty and vary by source, and also depend on the assumed peak year and zero year (Rogelj et al., 2015). However, they still give a good idea of the magnitude of change required to reach a certain target. IPCC (2018) reports 420 GtCO<sub>2</sub> until 2100 as the remaining carbon budget for staying below the 1.5 °C target at 67% confidence level. Budget for 2 °C is estimated at 1170 GtCO<sub>2</sub> at the same confidence level. Currently the anthropogenic GHG emissions are around 40–45 GtCO<sub>2</sub> per year (Le Quéré et al., 2018; IPCC, 2018). Thus, with annual emissions at this level, the 1.5 °C carbon budget would be used in 10 to 15 years.

The carbon budget only shows the gross allowance over time for meeting a selected warming target. In order to operationalize it for decision making, the budget needs to be divided for countries, cities, companies, individuals, or other meaningful units. One such operationalization is the division of the carbon budget to per capita pathways from the current situation to zero without exceeding the budget (Raupach et al., 2014). The pathways work so that the later the emission reductions begin, the steeper the curve becomes requiring faster and faster reductions (Raupach et al., 2014). According to Raupach et al. (2014)'s work, even reaching the 2° target would already now require annual reductions of 10% until reaching zero around 2080 (Fig. 6.1). Postponing the mitigation for another 5–10 years would lead to a 30% annual reduction requirement and reaching zero already around 2050.

O'Neill et al. (2018) have calculated that the same 2° target would mean global per capita emissions of 1.6 tons annually over the period between 2011 and 2100. The current global average carbon footprint is around 6 tons per capita, and, in the

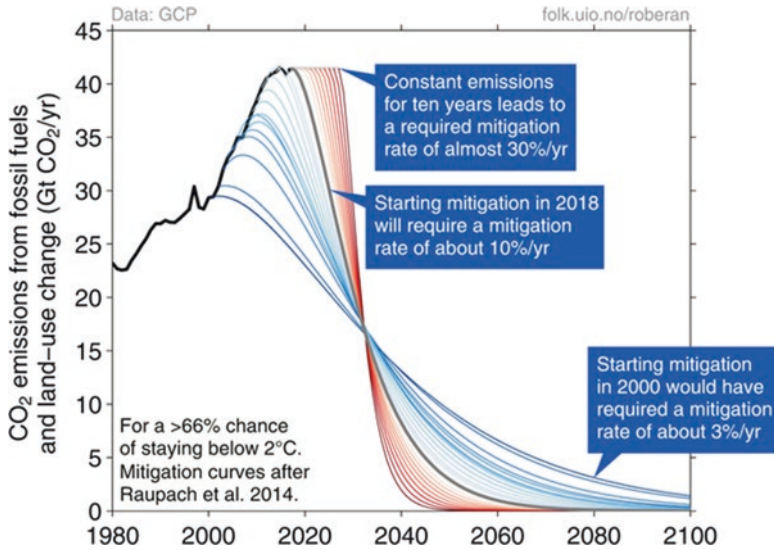


Fig. 6.1 The GHG emissions mitigation curves for 2° warming. (Drawn from Andrew, 2020)

more affluent countries, the current carbon footprints are well above 10 tons per capita on average (Clarke, Heinonen, & Ottelin, 2017; Hertwich & Peters, 2009), and particularly high in affluent cities (Heinonen et al., 2020; Moran et al., 2018). These numbers give benchmarks for mitigation targets and policies at different scales from international bodies to nations, cities, organizations, and even individuals. They also tell how the pace of mitigation in any of the more affluent locations, if considered that all should reach zero at the same time, would need to be tremendous.

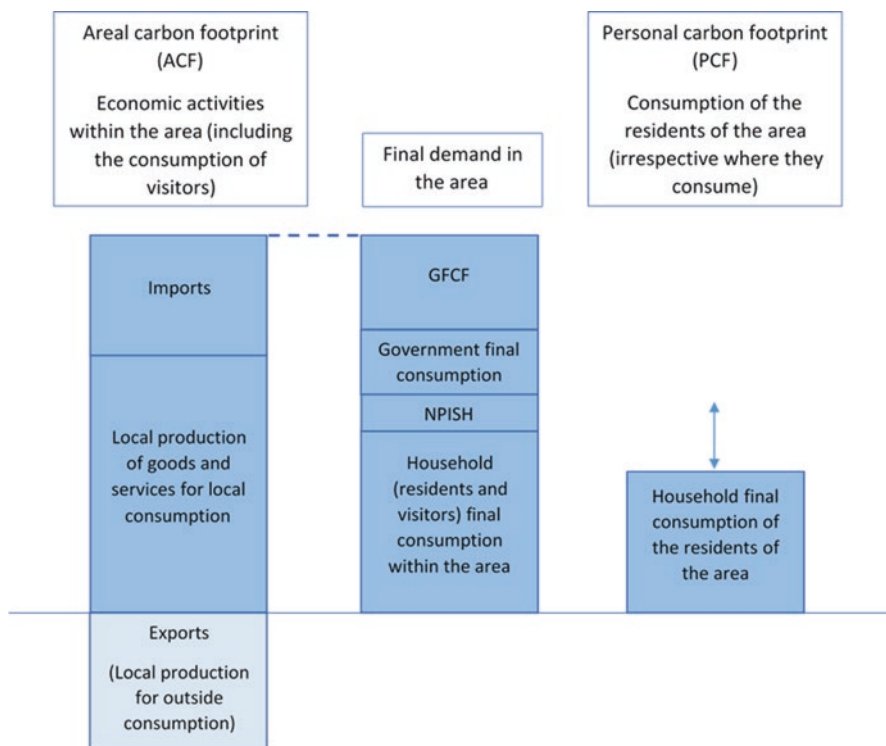
## 6.2.2 Carbon Accounting for Cities

Current climate change mitigation targets and policies, including the Paris Agreement, rely on territorial carbon accounting, which allocates GHG emissions according to the place where the emissions take place. However, many countries, and particularly cities, outsource a large share of the industry, agriculture, and transportation that serves their citizens (Clarke et al., 2017; Heinonen & Jóhannesson, 2019), and even energy production. Thus, alternative system boundaries for carbon accounting of cities have been suggested. For example, community-wide infrastructure carbon footprint includes the life-cycle GHG emissions embodied in the cities' infrastructure (Ramaswami & Chavez, 2013), whereas wide production-based carbon footprints include the direct and life-cycle emissions caused by the industrial production in the area in question (Chen, Long, Chen, Feng, & Hubacek, 2019).



Consumption-based carbon footprints, as an opposite to territorial, assign the emissions to those causing them by their consumption of resources, energy, goods, and services, regardless of the geographic location of the emissions (Baynes & Wiedmann, 2012). They cover the emissions through the whole production and delivery chain to the final consumer, including trans-boundary flows. Thus, consumption-based carbon footprints are compatible with life cycle thinking. According to Wiedmann (2016, p. 163), consumption-based carbon footprints include the “impacts of local production minus impacts embodied in exports plus impacts embodied in imports”. Heinonen (2012) describes that the method assigns “to a consumer the GHG emissions caused by his/her consumption regardless of the geographic location of the occurrence of the emissions”.

Consumption-based carbon footprints are therefore demand-focused assessments. Typically, they are based on EE IO models, although a few alternative attempts have been presented (Heinonen et al., 2020). Following from the dominance of input-output basis, the footprints are also usually presented and explained in terms of national accounts for areal demand, in which the areal demand consists of private consumption, governmental consumption, capital formation, and non-profit institutions (Fig. 6.2). Since the residents of an area can consume within



**Fig. 6.2** The composition of the two main types of consumption-based carbon footprints (ACF and PCF). (Drawn from Heinonen et al., 2020). *GFCF* gross-fixed capital formation, *NPISH* non-profit organizations serving households

it, or outside, and visitors can purchase goods and services as well, the private consumption component can be different from the consumption of the residents. Figure 6.2, drawn from Heinonen et al., 2020, shows schematically the different definitions of consumption-based carbon footprints given above, and their relation to the gross final demand of an area.

Due to the extensive outsourcing in developed countries and in wealthy cities, consumption-based emissions are typically much higher than territorial emissions, since their consumption relies on imports from other regions. In other words, the imports component in Fig. 6.2 is much larger than the exports component, often even larger than the local production for local consumption-component (Heinonen et al., 2020). Similarly, in growing cities, the GHG emissions embodied in buildings and infrastructure play a major role.

Unfortunately, the usability of consumption-based carbon footprints as policy tools has remained limited, mainly because of methodological issues and perhaps also because of political will (Afionis et al., 2017; Ottelin, Ala-Mantila, et al., 2019). While territorial emissions are rather straightforward to report and examine, the other accounting methods with broader system boundaries require somewhat different know-how. Nonetheless, some cities around the world, for example C40 Cities, have made efforts to include the consumption-based carbon footprints in policy-making (C40 Cities XE "Cities" , 2018). Yet, the efforts to connect the footprints to the remaining carbon budgets are still rare. It should be noted that the total global territorial and consumption-based emissions are equal. The two approaches simply allocate the same global emissions differently to nations, cities, companies, and individuals. Consequently, the same carbon budget limits both.

### 6.2.3 *Regenerative Impacts in Carbon Accounting*

Regenerative actions are in general actions that improve or restore the state of the environment. Circularity of resources and energy has been highlighted as an important part of regenerative urbanization (Girardet, 2014) and buildings (Gou & Xie, 2017). Circular economy aims at slowing, narrowing, and closing material and energy loops, which lead to a more regenerative economy with lower environmental impacts (Geissdoerfer, Savaget, Bocken, & Hultink, 2017). However, the strict definition of regeneration states that it goes beyond reducing environmental impacts to actually restore or improve the state of the environment (Pedersen Zari, 2018; Reed, 2007). In the case of climate change, this means that emissions are not only reduced, but carbon is absorbed from the atmosphere, leading to so-called “negative emissions”.

Currently, there is a significant weakness in the otherwise comprehensive consumption-based carbon accounting of cities: it focuses only on the harm-side. Any positive actions leading to carbon negative impacts are not taken into account as is evident also from the definitions of carbon footprints given above. On a

city-level, this may have harmful consequences. Sink and storage creation is not incentivized, and where these are anyway created, the carbon footprint comparisons show false outcomes. Though some steps have been taken to include the land-use and land-use change (LULUCF) sector in the underlying databases (e.g., Eora, <https://worldmrio.com/>), a broader discussion and conceptualization on negative emissions is missing from the literature of spatial carbon footprints (Heinonen et al., 2020).

Solutions to create negative emissions are generally called negative emission technologies (NETs), although many of the solutions are more natural than technological. NETs include for example afforestation and reforestation, bioenergy with carbon capture and sequestration, biochar (e.g., in agriculture and green infrastructure), enhanced weathering (spreading of minerals that naturally absorb carbon), and direct air capture of CO<sub>2</sub> (Minx, Lamb, Callaghan, Bornmann, & Fuss, 2017). Since NETs have been suggested as an important component in the pathway to 1.5 or 2.0° targets (Minx et al., 2018), it is becoming essential to develop carbon accounting methods that can cover these. For example, looking at Fig. 6.1, it becomes obvious that the mitigation curves quickly become steep beyond reach if radical reductions don't start taking place very soon. NETs will then become the hope that remains, allowing for going beyond zero later, and restoring the earth system to a lower level of warming, for example to 1.5° (IPCC, 2018). It should be also noted that the existing annual carbon uptake by mainly forests and oceans is already taken into account in the IPCC's carbon budgets, and thus the NETs have to come on the top of these to have a real impact.

While negative emissions have not yet been incorporated into EE IO models, many other aspects of regenerative cities are captured by them. For example, the environmental impacts of increased recycling rates, up-cycling, and *servitization* (shifting from consumption of products to consumption of services) can be studied with the current models (Aguilar-Hernandez, Sigüenza-Sanchez, Donati, Rodrigues, & Tukker, 2018; Greenford, Crownshaw, Lesk, Stadler, & Matthews, 2020). However, it should be more clearly defined when these activities actually are regenerative instead of just reducing the emissions, wastes, and virgin material consumption. In this chapter, we use the term “carbon handprint” to denote the negative emissions. Any reductions of carbon footprint are captured by the existing carbon footprint models and should not be included in the handprint, in order to avoid double counting.

### 6.3 Proposed Model

#### 6.3.1 Incorporating Regenerative Impacts into the Carbon Accounting of Cities

The regenerative impacts of cities could be integrated into the current carbon accounting methods by assessing carbon handprint, meaning negative emissions, alongside carbon footprint and territorial emissions, as illustrated in Fig. 6.3. The figure is applied from the concept of city carbon map introduced by Wiedmann et al. (2015).

The columns in the figure stand for the place of consumption and the rows the place of production. Thus, the emissions are classified as follows:

- E1 = Global life cycle emissions caused by products produced and consumed in the city
- E3 = Global life cycle emissions caused by products produced outside but consumed in the city (imported emissions)
- E1d = Local direct emissions (from the burning of fossil fuels and industrial processes) caused by products produced and consumed in the city
- E2d = Local direct emissions caused by the products produced in the city but consumed outside the city (exported emissions).

	Consumption in the city	Consumption in the RoW	
Production in the city	$E_1$ / $H_1$	$E_{2d}$	<b>Territorial carbon balance of the city = <math>E_{1d} + E_{2d} - H_4 - H_5</math></b>
Production outside the city	$E_3$ / $H_3$		
	<i>Regenerative actions of the city and city residents</i>	<i>Regenerative actions of the RoW</i>	
In the city	$H_4$	$H_5$	
Outside the city	$H_6$		
	<b>Consumption-based carbon balance of the city = <math>(E_1 - H_1) + (E_3 - H_3) - H_4 - H_6</math></b>		

Fig. 6.3 City carbon balance. (Applied from Wiedmann et al., 2015, “City carbon map”). *E* emissions, *H* restorative impacts (handprint), *d* direct emissions, *RoW* Rest of the World

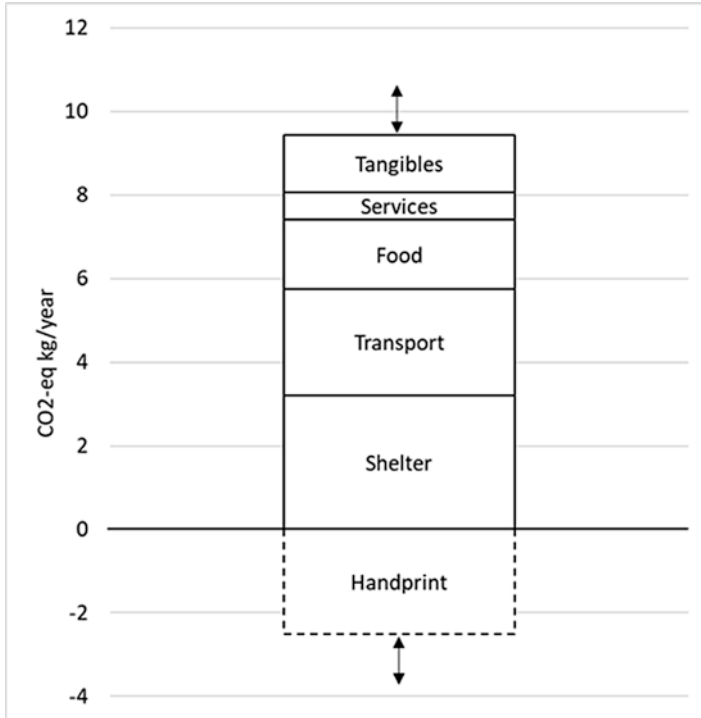
Following the same logic, we have added the negative emissions (handprints) to the model as follows:

- H1 = Global life cycle handprint of products produced and consumed in the city
- H3 = Global life cycle handprint of products produced outside but consumed in the city
- H4 = Local handprint of the city and city residents in the city
- H5 = Local handprint of other actors in the city
- H6 = Global handprint of the city and city residents outside the city (e.g., via carbon offsets).

The consumption-based column (E1, E3, H1, H3, H4, H5) represents life cycle perspective and focuses on the city residents and the city as a public actor, whereas the territorial perspective includes only the direct emissions originating from local production (E1d, E2d) and direct negative emissions created within the city borders (H4, H5). In practice, the life-cycle regenerative impacts of the production chains (H1 and H3) might be impossible to take into account, unless they are integrated into the global input-output models used for consumption-based accounting, or accounted for case-by-case following the production and delivery chains of, e.g., major industrial producers. However, adding the local restorative actions (H4 and H5) to the accounting is fully possible without any sophisticated tools. In addition, carbon offsetting, meaning that cities, companies, or consumers pay for offsetting their emissions and the money is used for, e.g., reforestation or emission reductions elsewhere, can be included relatively easily. However, there are several risks related to this. First, emission reductions of global industries are already covered by the footprint models, thus leading to a double counting problem. Second, in the case of afforestation and reforestation, it is difficult to ensure that the impact is real and permanent, meaning that the forest is not destroyed later, or the cuttings just shift from one area to another. Thus, in the future, it would be important to develop the global input-output models to cover the overall positive and negative changes in carbon balance due to land-use change.

Following this presentation (Fig. 6.3), there are actually some emissions and negative emissions included in both accounting methods: direct emissions produced and consumed inside the city (E1d) and handprint created by the city and city residents within the city borders (H5). However, if the whole map is used for the assessment, double counting is avoided. If just one of the two approaches is chosen, territorial or consumption-based, one should be careful not to mix territorial emissions and global handprint, or consumption-based carbon footprint and local handprint by outside actors, because this leads to an ambiguous interpretation of the carbon balance. This mistake is often made when cities or companies declare to be “carbon neutral”: only direct local emissions are included, but international compensation mechanisms are used.

In any case, the introduction of these regenerative and restorative components opens new policy options and encourages cities to work towards sink and storage creation, instead of just searching for ways to reduce the harm-side. Next, we



**Fig. 6.4** Consumer carbon balance. The figure is illustrative: the sizes of footprints, handprints, and their components, vary in reality. The footprint components can also be categorized differently, but the division of overall household consumption into Tangibles, Services, Food, Transport, and Shelter is common

demonstrate how the handprint component could be integrated into the carbon footprints of individual consumers, or groups of consumers, such as city residents.

### 6.3.2 Consumer Carbon Footprint and Handprint

The consumer carbon footprint is dominated by emissions related to housing, transport, and food (Fig. 6.4, see also, e.g., Ottelin, Heinonen, Nässén, & Junnila, 2019). The carbon footprints include the life-cycle emissions caused by purchasing of goods and services, but also the direct emissions caused by the burning of fossil fuels in everyday activities, such as driving and heating (Heinonen et al., 2020). The regenerative actions of consumers, i.e., carbon handprint, can be added to the carbon footprint assessments as illustrated in Fig. 6.4. These actions could include, for example, products storing more carbon than caused by their manufacture, sustainable gardening and forestry, purchasing of carbon offsets, and wooden construction materials.

It should be noted the annual carbon footprint and handprint, presented in Fig. 6.4, cumulate into the emissions in the atmosphere and carbon stocks, respectively. Carbon stocks can be destroyed as well (e.g., by burning wooden products at the end of their life cycle), which releases the embodied emissions back into the atmosphere. Thus, the carbon handprint in one year can transform into carbon footprint some year in the future. Similarly, sometimes burning of wood and biofuels are considered causing zero emissions in carbon footprint models (Heinonen & Junnila, 2014). However, if the carbon handprint of using renewable biofuels is separately taken into account, these emissions should be added to the carbon footprint in order to avoid double counting of the negative emissions.

## 6.4 Discussion and Conclusions

The aim of this chapter was to open the discussion on adding regenerative impacts to the consumption-based carbon accounting of cities and consumers, and to illustrate how this can be done coherently and consistently. In other words, we brought together two research fields: regenerative urbanization and consumption-based carbon accounting.

Previous literature has highlighted that the environmental impacts of cities go far beyond the territorial environmental impacts taking place within the city borders. Consumption-based accounting reveals the life cycle environmental impacts of the final consumption of cities and city residents, including the trans-boundary flows. However, the existing consumption-based carbon footprint literature has largely ignored the regenerative impacts that nations, cities, and individuals may have (see the review by Heinonen et al., 2020). Sink capacity creation, natural carbon storages, and even more high-tech end NETs could already be in an important role in the quest for low-impact living, and even more so in the future along with the development of these technologies. Thus, it is essential to incorporate these aspects to the accounting methods as well.

Similarly, as emissions, regenerative impacts can also be assessed either locally (territorial accounting) or globally by using a life-cycle method (consumption-based accounting). The most comprehensive picture is achieved by examining both of these at the same time, as shown by Wiedmann et al. (2015) regarding emissions, and as presented in this chapter with the handprint addition. However, if just one of these two approaches is chosen, one should not mix territorial emissions and global handprint, or consumption-based carbon footprint and local handprint by outside actors, since this leads to a false picture on the carbon balance of a city. In fact, instead of seeking “carbon neutrality” by choosing convenient system boundaries that allow for such balance, it would, in many cases, be more beneficial if cities would take responsibility for their consumption-based emissions and aim to reduce them. Regenerative actions may help to achieve carbon neutrality, but looking from the consumption-based perspective, the cities and consumers of the developed world are very far from having a zero carbon balance.

In the context of climate change, we defined regenerative impacts here as “negative emissions”, meaning that GHG emissions are not only reduced but carbon is absorbed from the atmosphere. This is a more stringent definition than some previously presented. For example, increased circularity of resources and energy has been described as regenerative by previous literature, but, from the perspective of climate change, it only reduces emissions instead of absorbing them. These sorts of impacts are already covered by the current “harm-side” accounting methods. In general, regenerative impacts should be more clearly defined. Some solutions may be regenerative in one environmental impact category, but harmful in another. Broad life cycle methods, including several environmental impact categories, have been created specifically to address these types of dilemmas and should be applied to assess the overall environmental impacts of potentially regenerative solutions.

To conclude, regenerative impacts should be incorporated into city carbon accounts to incentivize and support the creation and use of regenerative solutions. However, this should be done consistently and, at the same time, cities should take responsibility for the imported emissions that serve the consumption of the city and city residents. Otherwise, cities may create a “low-carbon” or even “carbon neutral” illusion that does not tell the whole truth of their climate impacts. Although thinking through the positive side is important, it should be grounded on the real planetary limits and, in the case of climate change, the remaining carbon budgets.

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# Chapter 7

## How Rating Systems Support Regenerative Change in the Built Environment



Melinda Orova and András Reith

**Abstract** Urban development principles have evolved from sustainability, where the focus was on limiting the negative impact of urban environment, to restorative and regenerative sustainability, where positive impact is needed on global social and ecological systems. This recent paradigm shift requires the development of new tools for practitioners, like design methodologies, new technologies, and assessment methods.

To measure the impact of sustainability on the built environment, several building-scale assessment tools exist. The question is how these widespread rating systems support restorative change in the built environment.

The main question of the research is answered in three methodological steps. First, the goals of restorative sustainability are summarized from the available extensive literature, including the topics of Place, Energy, Water, Well-being, Carbon, Resources, Equity, Education, and Economics. Then different rating tools (Living Building Challenge, WELL, LEED, BREEAM, DGNB) are analysed how the considered issues and indicators in these rating tools are connected to restorative goals. Then these indicators are assessed how they serve that goal.

The result of this study shows the main strengths and gaps in current wide-spread international rating tools regarding their support of restorative sustainability.

**Keywords** Sustainability rating tools · Indicators · LEED · WELL · Living building challenge

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## 7.1 Introduction

Regenerative and restorative architecture are emerging approaches for addressing the shortcomings of the current sustainability paradigm, as numerous segments of society have begun to accept that merely limiting the negative effects of human interventions into nature is no longer sufficient (Sonetti, Brown, & Naboni, 2019).

Most of the current literature (Attia, 2016; Bayulken & Huisingsh, 2015; Du Plessis & Brandon, 2015; Hes & Du Plessis, 2015) define regenerative sustainability alongside two key points (Akturk, 2016): the principle of not conserving the status quo but to effect net positive impact on the built environment and the concept of integrating positive human processes and creating natural environment that can continue regenerating itself.

To support this change toward a regenerative worldview, experts on the field are developing new design and construction support tools as well as new technological solutions for the implementation of regenerative principles. There is also a need to measure the regenerative performance of building projects so as to be able to compare them to the industry state of the art and to communicate the regenerative sustainability objectives effectively.

For sustainability projects, extensive literature covers these performance metrics grouped into sustainability indicator sets (Haapio & Viitaniemi, 2008; Illankoon et al., 2017; Lazar & Chithra, 2020). The sustainability indicator sets that are used as rating tools on the construction market are to be considered as a benchmark for quality.

Regarding regenerative architecture, limited literature exists on dedicated indicator sets in this field. For example, the Living Building Challenge (ILFI, 2019) assessment is promoted as a system providing a comprehensive set of regenerative performance metrics. Other design-support tools have also been developed that reference performance metrics, such as REGEN (Svec, Berkebile, & Todd, 2012) and the LENSES (Living Environments in Natural, Social and Economic Systems) framework (Akturk, 2016). Also, Naboni et al. (Naboni et al., 2019) define urban scale regenerative criteria, including Key Performance Indicators (KPIs) for Urban Heat Island, outdoor comfort, energy efficiency, daylighting, and biophilia. The paper mainly focuses on KPIs that can be integrated into the digital design workflow. Some literature about regenerative indicator sets only covers some specific aspects of regenerative sustainability. COST-RESTORE (European Cooperation in Science & Technology – Rethinking Sustainability Towards a Regenerative Economy) WG 4.1a developed an indicator set for regenerative indoor environmental quality (EURESTORE, 2020) by relying on existing metrics, but redefining their thresholds to reflect the regenerative principles. Jiang et al. (2020) propose to include the restorative benefits of biophilia in assessment tools. McArthur and Powell (2020) investigated the inclusion of health and well-being criteria in eight key topics related to health and productivity in 11 international rating tools.

In literature, regenerative sustainability principle is considered as the next step in the evolution of sustainability (Bayulken & Huisingsh, 2015). Therefore, the

question arises whether the development of sustainability indicator sets can also take the next step to cover the newly identified regenerative goals and raise their benchmarks towards requiring positive impact on humanity and the global environment. To get the answer for this question, it is at first necessary to investigate the status of currently used indicator sets. Therefore, the main objective of this research is to assess how existing indicator sets cover the main regenerative goals by cataloguing the existing indicator sets, then evaluating their utility towards regenerative sustainability.

In the following chapters, first, the most influential indicator sets to be investigated will be identified, then a quantitative and qualitative assessment will be described to define the existing gaps and to recommend the route to evolve towards reaching the regenerative goals.

## 7.2 Rating Systems

Based on the Brundtland report (UN 1987), the necessity of sustainable development was first recognized. Since then, several sustainability indicator sets were developed in the construction industry and the related academic fields. By today, this field has grown such that the organization and definition of the topology of these indicator sets have become necessary. The indicator sets that are used as building sustainability assessment systems can be defined as tools that assess the level of sustainability of a building, as well as classifying and certifying the building based on a series of predefined sustainability parameters or categories. (Díaz López et al., 2019: 7)

The typical structure of indicator sets that are used as building sustainability assessment systems has a three-level hierarchy: the topic, index, and indicator levels. Topics group indexes into diverse areas with the purpose of general guidance. Indexes (or credits/features/imperatives) target different sustainability issues and usually the compliance with index requirements generate points in the rating system. The indexes contain an indicator or a combination of indicators, which are the quantifiable measures of sustainability parameters.

Five main aspects were identified to differentiate between indicator sets: their usage, the targeted scale of assessment, applicability, goals, and evolutionary stage.

Regarding their usage, sustainability indicator sets have been developed by different types of organizations for different purposes. Three main types are identified:

- Research – numerous literatures exist on indicator sets that are not in active use, but mainly exist in theoretical work
- Governmental – metrics that mainly exist of support financial incentive programs for construction projects
- Commercial – third party-developed rating tools that are available on the construction market, the obtainment of a commercial certification provides added market value.

These three types of indicator sets are not independent from each other. The ones existing in research usually represent the newest indicators that are developed in relation to new ideas and solutions. These then influence the development of commercial and governmental systems. Commercial and governmental systems usually exist in parallel to each other, with some exceptions. For example, the Japanese CASBEE rating tool is adopted as the official local rating tool, but is also used as a commercial international tool as well.

Based on their targeted scale of assessment, building, neighbourhood, and city scale indicator sets are recognized. The general consensus is that, for an effective sustainable strategy, all scales of intervention should be targeted, and their synergies to be utilized. For example, the U.S. Green Building Council (USGBC) has certifications for all three urban scales: LEED v4 Building Design and Construction, LEED v4 for Urban Development, and LEED for Cities.

Based on their applicability, indicator sets can be developed for use by certain countries or in a specific region, but there are also metrics for international usage (that can be limitedly tailored for regional priorities).

Based on their goals, McArthur and Powell (2020) differentiate between sustainability rating systems (those developed to promote environmental sustainability), wellness rating systems (that promote occupant health and wellness), and regenerative design rating systems as the primary motivator for building-scale indicator sets. On city scale, other goals are also present, such as smart- or resilient-city indicator sets.

Chew and Das (2008) identified four generations of building assessment systems:

- First generation: nominal type pass or fail certification system
- Second generation: simple additive systems
- Third generation: weighted additive systems
- Fourth generation: tools which operate based on advanced concepts like building environment efficiency or life cycle impact and cost.

Hundreds of sustainability indicator sets exist today (Lazar & Chithra, 2020), with similar goals and metrics. This study focuses on the most universally recognized and topically diverse indicator sets. Therefore, from the pool of indicator sets, the following typology was selected:

- International tools – to include the ones with the largest global influence
- Building scale tools – as the building scale systems have been developed the earliest, and have been implemented the longest
- At least second-generation assessment tools – to include the most widely used generation of systems
- Most diverse systems regarding their main principles – to cover the widest range of topics already considered.

Based on the above-listed criterion, five of the most popular and widespread rating tools in the construction industry were selected: LEED, BREEAM, DGNB, WELL, and Living Building Challenge (LBC).

*BREEAM*: First published in the U.K. in 1990, BREEAM (Building Research Establishment Environmental Assessment Method) was the world's first sustainability rating scheme for the built environment. It has since been applied in more than 70 countries. The BREEAM New Construction 2016 is selected for this study for assessment, which contains requirements for the building scale in the following topics: Management, Health and Well-being, Energy, Transport, Water, Materials, Waste, Land use and ecology, Pollution and Innovation (BRE, 2016).

*LEED*: Developed by the USGBC, LEED (Leadership in Energy and Environmental Design) is a voluntary and market-driven rating tool measuring the sustainability of building construction projects. The first version of LEED was developed in 1998 and, since its launch, it has become one of the most internationally widespread sustainability assessment tools. The current version (v4) has been in use since 2014 and contains mandatory and optional requirements in nine topics: Integrative Design, Sustainable sites, Location and Transportation, Water Efficiency, Energy and Atmosphere, Indoor Environmental Quality, Materials and Resources, Innovations, Regional Priorities (USGBC, 2014).

*DGNB*: The German DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen) system is another variant of the widespread sustainability rating tools, with a life cycle-based approach. The latest international version of the assessment system was published in 2018. This version is applicable to new construction projects with different credit weighting for different functions. In this study, the office function is selected, as it is the most used system version for assessment tools (DGNB, 2018).

*WELL*: The WELL standard (IWBI, 2018) has been published by the International WELL Building Institute since 2014. The current version is the WELL v2, which has been applicable as a pilot system since 2018. The WELL certification defines requirements for more healthy buildings that improve users' well-being and productivity in 11 topics: Air, Water, Nourishment, Light, Movement, Thermal Comfort, Sound, Materials, Mind, Community, and Innovation. The rating tool includes mandatory and optional requirements that are needed to reach the different certification levels.

*LBC*: The Living Building Challenge standard was first released in 2006 by the Living Future Institute. Raising the bar above the widespread sustainability rating tools, the main goal of LBC is to eliminate any negative impact a building might have on global health. The standard defines 20 challenges (each with the same weight) in seven topics. In this study, the version 4.0 of LBC is assessed, which was published in 2019 (ILFI, 2019).

### 7.3 Methodology

Studies show that, when evaluating and comparing sustainability assessment tools, only considering their general characteristics does not provide a comprehensive analysis, it is necessary to include the topic, index, and indicator level of the

different tools (Li, Chen, & Wang, 2017; Reith & Orova, 2015). Following this principle, this study attempts to examine the index level of the selected systems in detail.

The following steps are carried out in this study to provide a clear picture of the extent to which regenerative sustainability criteria are incorporated into the selected tool:

1. Determination of regenerative sustainability goals and their thresholds (their required level of performance) based on a literature review. This would provide the basis for assessing how regenerative goals are covered in the selected rating tools.
2. Assessment of each index in the selected tools by the following aspects:
  - Related regenerative topic – each credit is connected to a re-generative topic determined in step 1.
  - Related aspect of the relevant topic (see Fig. 7.1),
  - Type of connection to the topic – Direct: compliance with the requirement of the indicator directly contributes towards a goal defined in the relevant topic of regenerative architecture. Indirect: compliance with the requirement of the indicator does not directly contribute towards its goal, but the implemented solution indirectly affects the relevant goal.
3. Assessment of the level of coverage of regenerative topics:

<b>Place</b>	<b>Wellbeing</b>	<b>Equity</b>	<b>Energy</b>	
<ul style="list-style-type: none"> <li>• regenerative land use</li> <li>• local community agriculture</li> <li>• biodiversity</li> <li>• community connectivity</li> <li>• bioclimatic design</li> <li>• regenerative heritage</li> <li>• topophilia</li> </ul>	<ul style="list-style-type: none"> <li>• working conditions connected to nature</li> <li>• IAQ</li> <li>• biophilic design</li> <li>• water quality</li> <li>• healthy food</li> <li>• accessibility</li> <li>• design for active lifestyle</li> <li>• visual comfort</li> <li>• thermal comfort</li> <li>• acoustic comfort</li> <li>• mental health</li> <li>• medical support</li> </ul>	<ul style="list-style-type: none"> <li>• diverse, inclusive users</li> <li>• accessibility</li> <li>• investment in local / global community</li> <li>• integration of cultural heritage</li> <li>• transparency of company procedures</li> <li>• regenerative CSR programs</li> </ul>	<ul style="list-style-type: none"> <li>• non-polluting energy sources</li> <li>• onsite renewable supply</li> <li>• net positive energy</li> <li>• onsite storage for resiliency</li> </ul>	
<b>Water</b>	<b>Carbon</b>	<b>Resources</b>	<b>Education</b>	<b>Economics</b>
<ul style="list-style-type: none"> <li>• net zero water use</li> <li>• local stormwater management</li> <li>• wastewater treatment onsite without chemicals</li> </ul>	<ul style="list-style-type: none"> <li>• net zero lifecycle CO2 emissions</li> <li>• carbon negative technologies</li> </ul>	<ul style="list-style-type: none"> <li>• material transparency</li> <li>• elimination of toxic materials</li> <li>• design for disassembly</li> <li>• responsible sourcing</li> </ul>	<ul style="list-style-type: none"> <li>• participatory processes</li> <li>• inspiration / education</li> </ul>	<ul style="list-style-type: none"> <li>• participation in sharing economy</li> <li>• restorative enterprise building</li> <li>• circular economic value chain</li> </ul>

**Fig. 7.1** The regenerative goals defined for the nine topics. (Based on Brown et al., 2018)



- Quantitative assessment: the percentage value of credits covering each regenerative topic is determined, so the relative importance can be determined within each system. This analysis will show which topics are prioritized by the greatest number of rating tools. The results of the quantitative assessment is calculated using the weighted score of the credits in the rating tools. Then the potential scores of credits grouped to each category should be summed. To be able to compare the different assessment tools, the results are shown as ratios of a possible total score.
- Qualitative assessment: the coverage of each regenerative topic is assessed by the following qualities: Topic is not addressed in the rating tool; indirectly addressed; some aspects are addressed; every aspect is addressed, lower benchmarks; every aspect is addressed, same benchmarks.

## 7.4 Results

### 7.4.1 *Determination of Regenerative Goals*

For the purposes of this study, the fundamental document of the EU funded COST-RESTORE project has been selected as a basis to determine the goals of regenerative sustainability. This study is in line with the definition of regenerative sustainability detailed in the introduction section. COST is a European framework supporting transnational cooperation among researchers, engineers, and scholars across Europe, which funded the RESTORE project that aims to affect a paradigm shift towards restorative sustainability for new and existing buildings across Europe and to promote multidisciplinary knowledge. In the report of Brown et al. (2018), a definition of regenerative architecture is presented organized into nine topics: place, energy, water, well-being, carbon, resources, equity, education, and economics. For each topic, a list of aspects was extracted from the report which is used here to see how the selected rating tools can incorporate them. The following paragraphs detail the nine topics and their regenerative goals, as shown in Fig. 7.1.

The regenerative aspects related to the place topic focus on the integration of the site into the local natural and urban community. The specific goals include the incorporation of design principles (bioclimatic design), regenerative land use options, and community connectivity.

Regenerative energy and water use means net positive water and energy use. The definition of these topics directly referenced from Living Building Challenge (ILFI, 2019), as this standard is leading the way to regenerative energy and water use. Closely connected to these goals is the carbon topic that targets zero carbon emissions, but not just in the use phase but during the whole life cycle of a project. The full list of regenerative aspects related to these topics is shown in Fig. 7.1.

The well-being topic of regenerative architecture focuses on the comfort and health of building occupants, just as the WELL certification system (IWBI, 2018), which is directly referenced as the most advanced rating tool regarding this topic.

Resources topic defines regenerative resource management with a life cycle approach, which includes responsible sourcing, transparent reporting of built-in materials, the elimination of toxic materials, and the inclusion of options for disassembly during design.

The equity topic targets building users by design and operation goals for inclusivity, accessibility, transparency, and investment in local/global community as well. The education topic also targets building users and wider community with goals of wide participation and inclusion of education programs.

The economics topic focuses on the integration of a project to the circular economic value chain. The linking of sharing economy to the built environment is also considered.

Regarding the benchmarks for the defined regenerative indicators, the current literature indicates some quantifiable goals for some regenerative aspects. In case of energy, water, and carbon use, net positivity serves as regenerative benchmarks. In other cases, there is no clear limit between sustainability and regenerative goals, like in the case of determining the regenerative comfort parameters. And goals where the level of compliance cannot be quantified (e.g. in case of the goal of biophilic design).

Due to the various types of benchmarks, during the assessment, a simplified method was used to evaluate the relation of the strictness of requirements in the different assessment tools to the regenerative benchmarks: 1 – the contribution of the requirement is unquantifiable (e.g. the LEED Integrative Process credit requires to attempt an energy optimization of the project building, which cannot be translated to a quantifiable value); 2 – the credit has lower benchmarks than the regenerative benchmark (e.g. in the LEED assessment tool, the maximum points can be achieved by 50% improvement in the proposed building performance rating compared with the baseline); 3 – the credit requires the same strictness as regenerative benchmarks (e.g. the LBC assessment requires net positive energy use) or it represents the most stringent values possible (e.g. according to IWBI (2018) WELL requires PM2.5 concentration less than 15 µg/m indoors).

#### ***7.4.2 Results of the Quantitative Assessment***

During the weighting process of each system, different approaches and assumptions were necessary:

- The LEED assessment tool includes mandatory credits that do not receive scoring. Therefore, these were not calculated in comparison, but are mentioned in the assessment separately.
- The BREEAM system also includes prerequisites. For these, the same process was followed. The BREEAM assessment calculates weighting and the inclusion

of different criteria based on the functionality of the building. For the purposes of the study, a fully fitted office function was considered without special functions like cold storage or laboratory.

- For the WELL assessment, the total score was the sum of all credit scores, and the maximum score per credit category was not considered.
- The LBC tool does not assign scores to its credits, so all credits were taken into account with the same weight.
- For the DGNB system, the credit weighting for offices was taken into account.

The results of the qualitative assessment only calculate with the regenerative topics that are directly incorporated in the indicator system.

Figure 7.2 shows the results of the assessment for the five systems included in this study.

For the LEED rating tool, the mandatory requirements cover the energy, water, well-being, and carbon categories. Regarding the optional credits, 24% of them incorporate the energy category and similarly high percentages are associated with the coverage of the place (22%) and the well-being categories (19%). Also, 20% of the credits are not directly associated with regenerative goals.

The BREEAM rating tool provides more even coverage of the nine categories in its optional credits. Like in the LEED system, the place, energy, and well-being categories receive the highest coverage, but, unlike LEED, this system incorporates indexes from all categories.

The category coverage assessment of the DGNB system shows that energy is the most important topic in this system as well (21%), but the resources and economics topics also have high weights in DGNB. Unlike in LEED, here the water topic is the least covered (2%).

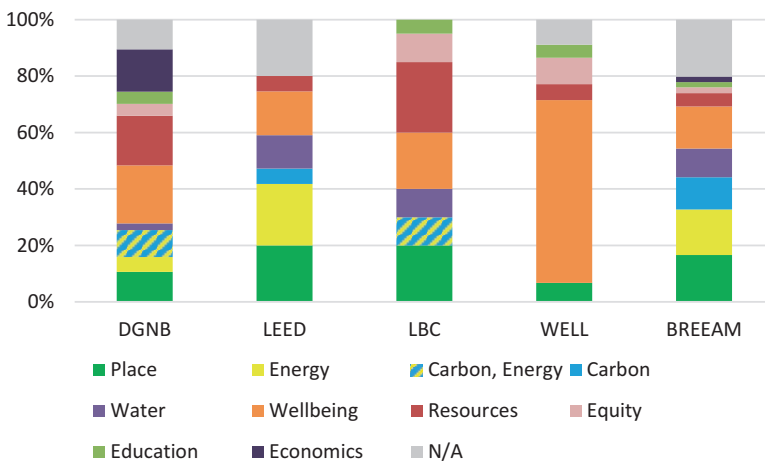


Fig. 7.2 Share of weighted credit values (%) covering each category

**Table 7.1** Results of the qualitative assessment of the coverage of regenerative goals

	Place	Energy	Water	Wellbeing	Carbon	Resources	Equity	Education	Economics
BREEAM	x	x	x	x	xx	x	x	x	x
LEED	x	x	x	x	xx	x	-	-	o
DGNB	x	x	x	x	x	xx	x	xx	xx
WELL	x	-	-	xxx	-	x	x	xx	-
LBC	xxx	xxx	xxx	x	xxx	xx	x	xx	o

Grey: no aspects are covered; yellow: some aspects are covered, indirectly; light green: some aspects are covered, directly; green: all aspects are covered; dark green: all aspects are covered, regenerative goals

The majority of metrics in the WELL system are related to well-being (65%), but the four other included categories (place, resources, equity, and education) are incorporated evenly.

The LBC system covers all categories the most evenly. This system has the highest proportion of credits in the resources, place, and well-being topics.

This assessment shows the extent to which these nine topics are incorporated into the selected tools for evaluating regenerative architecture. Table 7.1 includes the results of the assessment. It shows that three of the nine topics are covered at least partially by all these rating tools. The place category is present even in the WELL system, as the regenerative goal of high community connectivity by access to amenities and public transport and the strengthening of local agriculture are goals that also indirectly affect human well-being and health. The well-being and resources topics are also included in every tool, due to the widespread goals of establishing an interior comfort and Indoor Air Quality (IAQ) by installing healthy materials. However, LBC and WELL target more strict levels of comfort and material sourcing and transparency than the more traditional sustainability rating tools, so that they not only limit the negative effects of an artificial environment but also attempt to implement positive effects, such as improved health and productivity.

The table also shows that regenerative economics goals are the least covered in the different systems. DGNB provides the best results, as the rating tool is aligned with circular economy principles. The other systems mainly reference regenerative economic goals, with including indicators requiring the participation in sharing economy (e.g. sharing community spaces with local community or shared transport facilities).

Regarding the depth of alignment with regenerative goals, LBC targets positive impacts for all regenerative goals in four topics (place, energy, water, and carbon). In two other categories – resources and education – LBC covers all topics, but the requirement could be more ambitious (e.g. the participatory project development is only partially included in the rating tool). Table 7.2 also shows that, in the Well-being and Equity categories, some of the goals are not addressed in the system, and the least covered is the Economics category.

Regarding the other rating tools, WELL incorporates all the regenerative well-being goals and partially covers only four other topics. DGNB and BREEAM incorporate all the categories, but, in most cases, not all aspects and with less ambitious

**Table 7.2** Results of the LBC assessment about covering regenerative goals

<b>Place</b>	regenerative land use	local community agriculture	biodiversity	community connectivity	bioclimatic design	regenerative heritage	topophilia	xxx
<b>Covered</b>	3	3	3	3	3	3	3	
<b>Energy</b>	non polluting energy sources	onsite renewable supply	net positive energy	onsite storage for resiliency				xxx
<b>Covered</b>	3	3	3	3				
<b>Water</b>	net zero water use	local stormwater management	wastewater treatment onsite without chemicals					xxx
<b>Covered</b>	3	3	3					
<b>Wellbeing</b>	working conditions connected to nature	IAQ	biophilic design	water quality	healthy food accessibility	design for active lifestyle	visual comfort	x
<b>Covered</b>	3	3	3	0	0	0	0	
	thermal comfort	acoustic comfort	mental health	medical support				x
	2	0	0	0				
<b>Carbon</b>	net zero lifecycle CO2 emissions	carbon negative technologies						xxx
<b>Covered</b>	3	3						
<b>Resources</b>	material transparency	elimination of toxic materials	design for disassembly	responsible sourcing				xx
<b>Covered</b>	3	3	2	3				
<b>Equity</b>	diverse, inclusive users	accessibility	investment in local / global community (charities)	integration of cultural heritage	transparency of company procedures	regenerative CSR programs		x
<b>Covered</b>	3	3	3	0	3	0		
<b>Education</b>	participatory processes	inspiration / education						xx
<b>Covered</b>	2	3						
<b>Economics</b>	participation in sharing economy	restorative enterprise	building circular economic value chain					o
<b>Covered</b>	1	0	1					

0 – Not covered; 1 – Indirectly covered; 2 – Covered; 3 – Covered, same goals

goals. LEED does not cover the equity and education topics at all, nor does it set ambitious goals in the other categories.

## 7.5 Discussion

The results of the quantitative and qualitative assessments showed that, on average, the well-being-related aspects of regenerative architecture are included with the highest weight in the five assessment tools. It also shows that the education-, economic-, and carbon-related issues are underrepresented. It should be noted that the

carbon category coverage is indirectly improved, as the energy and some of the resources related requirements contribute toward net positive carbon goals.

The analysis of the five selected rating tools suggests that the typology of the tools, based on their purpose (sustainability, wellness, and regenerative systems), is the defining factor about how they incorporate regenerative goals. As expected, since it was developed specifically to address regenerative sustainability, LBC is much more comprehensive in its incorporation of the identified aspects, addressing the majority of issues highlighted in the academic literature. Meanwhile, on the other end of the scale, WELL focuses on the narrowest goal, as in providing healthy buildings for occupants, but by doing it through the incorporation of the widest range of health-related regenerative aspects as possible. In the middle stand the mainly sustainability-oriented rating tools (LEED, BREEAM, DGNB) that provide a good coverage to the regenerative goals that originated from traditional sustainability goals, but with limited thresholds and limited coverage of education and equity topics. From among the three sustainability-focused systems, LEED performs the worst, as it does not cover the equity and education topics at all, nor does it set ambitious goals in the other categories.

## 7.6 Conclusions

To provide a basis for the assessment rating tools, this research conducted a literature review of regenerative architecture. The definition of the topics and goals of regenerative sustainability showed that while the concept is well defined, its application supported by performance metrics needs further refinement. Several of the defined regenerative goals do not have clear performance thresholds that can hinder their inclusion into market-accepted assessment tools.

The previous chapters show evidence that while in most cases the assessed credits of the five rating systems are not primarily developed to promote regenerative architecture, they incorporate a significant portion of regenerative goals, especially goals targeting well-being-related issues and goals about the deeper connection to natural and built environment. The extent to which this is true varies significantly between the rating tools. However, a significant gap exists about the incorporation of 'soft' topics, such as education and equity. This may be because these goals have less direct and quantifiable evidence on improving the environmental dimension of sustainability, therefore these were left out from the sustainability-focused rating tools.

Despite the conclusive evidence in literature that the main factor in the decision-making processes of construction projects is cost- and return of investment-based, the studied rating tools incorporate the least amount of economics-related aspects of regenerative sustainability.

The previous paragraphs summarized the main identified gaps in this study. Based on these, the main areas for improvement are evident: improve the performance threshold of sustainability assessment systems to close the gap towards

regenerative goals; improve the in-depth coverage of economics topics; and include soft regenerative aspects into sustainability assessments. It is recognized that the update of these systems is a complex task and a balance is targeted between leadership in sustainability performance and market readiness, but it is also necessary to constantly challenge these rating tools when new ideas emerge.

Regenerative sustainability principles not only intended to affect the building scale but its goals can be more easily translated when the different scales of the urban fabric are considered together. Therefore, as a next step for this research topic, the existing neighbourhood- and city-scale rating tools should be included in a similar assessment.

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# Part II

## Innovative Approaches in Professional Design Practice

### 1.1 Foreword by Giulia Peretti and Carsten Druhmnn

Giulia Peretti and Carsten Druhmnn

#### *1.1.1 Bridging the Gap Between Design and Construction Following a Life Cycle Approach Consisting of Practical Solutions for Procurement, Construction, Use & Operation and Future Life*

One of the questions faced by RESTORE is how a building can be built, operated and maintained in a regenerative manner. The easiest answer to this question is that this can be achieved through integration of restorative and regenerative principles into the construction and operation process. However, the current state of the art in construction and operation does not include, or only includes partially, sustainable or regenerative values. Therefore, RESTORE aimed at bridging the gap between design and practice, providing guidance for those involved in the process, ensuring that no contradictions arise (e.g., cost and efficiency vs. responsibility and environmental effects). Analyzing the current state of the art in the European construction sector, it was noted that barriers can undercut a paradigm shift from the “business as usual” to a regenerative economy, making the realization of regenerative projects difficult.

Thus, the goal is the development of robust strategies to guide a transition from traditional construction process towards one which incorporates regenerative values including the following main stages of the building process:

- **Procurement** (considering what follows the design stage and proceeds the construction phase, inclusive of bidding, tendering, and procurement).

- **Construction** (from the preparation of the site, up to the management of the construction site, including materials and technologies used during the construction process).
- **Operation** (starting from the commissioning, and going through the operation and maintenance of the building).
- **Future life** (investigating what is happening to the building after its preliminary life, considering refurbishment, retrofitting, reuse, adaptation, and in the worst case, demolition and dismantling).

The mission of improving the building life cycle by integrating regenerative principles is based on six priorities and considerations, which have driven the approach taken by RESTORE:

### **Theory vs. Practice**

This main aspect regards the investigation of the process in order to allow a smooth and effective implementation of theoretical concepts and design into practice. This includes the analysis of the instruments, from tools to regulations, which support the realization of regenerative concepts.

### **Implementation of Regenerative Concepts and Aspects Needed Throughout the Whole Process**

The bases of a successful realization of a regenerative building are set in procurement and tendering of activities related with the building (design, site, maintenance). Furthermore, a regenerative building does not end with commissioning, as its operation, as well as what happens after its primary use, can be even more important.

### **Urban Scale vs. Building Scale**

It is not only buildings that can be regenerative. The regenerative principles must be applied and integrated at the urban scale, from place, landscape and infrastructure, to the city level.

### **Regulation and Standards**

The awareness of policy makers is crucial for the successful and wide implementation of regenerative targets. Therefore, it is instrumental to investigate if in the actual scenarios there are legislative and certification frameworks that yet support the realization of regenerative projects.

### **Existing Buildings or New Construction**

When approaching a traditional End of Life, existing buildings need to be refurbished or retrofitted in order to assure a better second and future life. Moreover, an approach which allows the regeneration of buildings (recycling, reuse, and disassembly) needs to be integrated into the design and construction phases.

### **Regenerative Economy**

Moving towards a regenerative economy is a key factor in the current building sector. One main question is how buildings can lead to a regenerative economy

considering all stakeholders, as well as the users, involved in the construction and operation process.

**Stakeholders**

From the designer to the investor, from the construction company up to the municipality, a shift is urgently needed from a “consumer” approach to a “prosumer” one. Currently, people use buildings as building users (until they are used up) and they do not look after buildings as prosumers or as inhabitants. Considering this assumption all stakeholders need to think more about regeneration of resources and of the environment.

COST RESTORE WG3 “Regenerative Construction and Operation” leaders

# Chapter 8

## Covering the Gap for an Effective Energy and Environmental Design of Green Roofs: Contributions from Experimental and Modelling Researches



Laura Cirrincione and Giorgia Peri

**Abstract** Green roofs are components of the building envelope that have become increasingly popular in urban contexts because other than providing numerous environmental benefits they are also capable of reducing building energy consumption, especially in summer. However, despite all these advantages, green roofs are still affected by some limitations. Specifically, there are some gaps affecting the energy modelling consisting in the absence of a proper database, information (growth stage, leaf area index, and coverage ratio) relative to the different green roof plant species, which technicians could use in case of lack of actual field data to perform energy analysis of buildings equipped with green roofs. These gaps concern also environmental and economic assessments of such technology. In fact, the currently available green roof LCA and LCC studies seem to underestimate the role of the substrate on the overall environmental impact and the role of the disposal phase on the life cycle cost of the green roof. In this chapter, all these aspects are addressed, and contributions to their solution, which arose from both experimental and modelling research, carried out by the authors are presented.

**Keywords** Green roofs · LCA · Radiative heat exchanges · Energy analysis · Environmental analysis

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## 8.1 Introduction

Green roofs represent an increasingly important building-passive component in urban contexts due to the many benefits that can be attributed to them. Green roofs allow indeed to reduce the air pollution (Abhijith et al., 2017; Zhang et al., 2015), mitigate noise (Liu & Hornikx, 2018; Van Renterghem, 2018), improve the management of runoff water (Soulis, Ntoulas, Nektarios, & Kargas, 2017; Vijayaraghavan, Reddy, & Yun, 2019), increase the urban biodiversity (Francis & Jensen, 2017; Köhler & Ksiazek-Mikenas, 2018), and ease the Urban Heat Island (UHI) effects (Bevilacqua, Mazzeo, Bruno, & Arcuri, 2017; Peri, Rizzo, Scaccianoce, & Sorrentino, 2013; Solcerova, van de Ven, Wang, Rijdsdijk, & van de Giesen, 2017; Yang et al., 2018). As regards this latter, a possible reduction of the average ambient temperature ranging between 0.3 and 3 K has been indicated for vegetated roofs, when deployed on a city scale, thanks to the evapotranspiration effect (Santamouris, 2014). A review of all the advantages provided by green roofs is presented in (Shafique, Kim, & Rafiq, 2018).

Apart from the above-cited several environmental benefits, vegetated roofs have also become increasingly appealing as a technological option due to their capacity in decreasing the buildings' climatization energy consumption and, at the same time, improving the indoor thermal comfort levels (Cirrincione et al., 2020). Their suitability in improving the energy performance of buildings equipped with them has largely been addressed in literature over the recent years. Based on a literature review we conducted previously (La Gennusa et al., 2019a, 2019b), it arises that

1. there is a wide agreement among scientists on the fact that, during the summer period, the presence of green roofs provides a thermal protection for the building (Niachou, Papakonstantinou, Santamouris, Tsangrassoulis, & Mihalakakou, 2001);
2. on the contrary, the performance of vegetated roofs in winter is somewhat a controversial issue; in fact, green roofs mostly reduce the total heating load (Silva, Gomes, & Silva, 2016), but, in some cases, they do not produce any advantage or even cause slightly adverse conditions (Jaffal, Ouldboukhitine, & Belarbi, 2012; Santamouris et al., 2007);
3. vegetated roofs have mostly a positive impact on the total energy consumption of buildings (Jaffal et al., 2012; Niachou et al., 2001; Santamouris et al., 2007) implying a net reduction of the total annual energy demand compared to traditional roofs.

The reasons of such behaviour can be traced in some characteristics of this type of roof that have an influence on green roof thermal and energy performance. Specifically, factors that contribute to reduce the energy demand for cooling purposes. Thus, the above-mentioned positive effect can be summarized as follows:

1. Direct shading of the roof by the vegetation
2. Cooling of the air surrounding the roof due to the evapotranspiration process
3. Higher value of the roof albedo (typical values range from 0.7 to 0.85 [Saadatian et al., 2013]).

While items that contribute to reduce the energy demand for heating purposes can be summarized as follows:

1. Additional insulation layer provided by the technological system “green roof” added to the roof
2. Lower thermal convention on the external surface due to the presence of the vegetation.

Nonetheless, some circumstances that may increase the heat losses, rather than decreasing them, may occur. Among these, the climatic conditions and especially the precipitation regime of the site where the green roof is located, which have an influence on the effect provided by green roofs in winter, and particularly their additional insulation level which modifies the soil humidity content and in turn the soil thermal conductivity.

Despite all the so far mentioned numerous important benefits related to the use of green roofs as building envelope component, there are currently some modelling gaps increasing the time required for their design phases, on which improvements can be made; these gaps concern both environmental and economic aspects. Hereafter, we address the points mentioned above and list some contributions to their solution, particularly referred to extensive green roofs, that arose from both our experimental and modelling research.

## 8.2 An Insight into the Energy Modelling of Green Roofs and on some of Its Currents Gaps

As far as the modelling of green roofs is concerned, it should be noted that the high complexity characterizing the heat transfer occurring in a green roof, especially due to the presence of the vegetation and substrate, makes it complicated to implement a detailed model (Del Barrio, 1998). Therefore, it becomes necessary to assume simplifying hypotheses. Among these hypotheses, one is related to the behaviour of the canopy layer and it consists in approaching the vegetation layer through the so-called “big-leaf approach”, which is typically used to assess the solar absorption attributable to the green roof canopies (De Pury & Farquhar, 1997; Monteith, 1965).

In order to properly model the energy performance of buildings provided with green roofs (considered as passive components), some reliable, yet simplified, mathematical procedures have been implemented and are available in literature. An extensive review of them is well presented in (Quezada-García, Espinosa-Paredes, Polo-Labarrios, Espinosa-Martínez, & Escobedo-Izquierdo, 2020). Among these, the one developed by Sailor (Sailor, 2008) has also been implemented in one of the most widely used building energy simulation software, i.e., EnergyPlus (EnergyPlus). Table 8.1 lists the typical input parameters requested by this simulation tool for calculating the different heat transfer components of the energy balance of a green roof and thus its contribution to the energy consumption of building. As it can be observed, green-roof-related input data are essentially related to vegetation and soil layers.

**Table 8.1** Main input parameters required by EnergyPlus to calculate the effect of a green roof on the energy consumption of a building equipped with it (Peri, Rizzo, Scaccianoce, La Gennusa, & Jones, 2016)

Green roof's layer	Parameter	Parameter's unit	Parameter's description
Canopy	Leaf reflectance	(-)	It measures the percentage of incident solar radiation reflected by the leaf.
	Leaf emissivity	(-)	It is the ratio between the thermal radiation emitted by the leaf and that emitted by a black body at the same temperature.
	Leaf area index (LAI)	(-)	It measures the vegetation density.
	Height of the plants	(m)	It represents the average height of vegetable species.
	Minimum stomatal resistance	(s/m)	It measures the resistance offered to vapour diffusion from the pores on the plant leaves.
	Roughness class	Smooth/ medium/ rough	It gives an indication on the surface texture of the leaves.
Substrate	Soil thickness	(m)	It is a geometrical property of the soil.
	Conductivity of dry soil	(W/(mK))	It indicates the substrate's capability to transfer heat by conduction.
	Density of dry soil	(kg/m <sup>3</sup> )	It indicates the mass of dry soil that occupies a unitary volume.
	Specific heat dry soil	(J/(kg K)).	It indicates the amount of heat needed to provide to the unitary mass of dry soil to increase its temperature of 1 degree.
	Thermal absorptance	(-)	It measures the percentage of radiation absorbed by the soil in the infrared, ultraviolet, and visible range of the electromagnetic spectrum.
	Solar absorptance	(-)	
	Visible absorptance	(-)	
	Saturation volumetric moisture content of the soil layer	(-)	It represents the maximum volumetric water content that the substrate can store.
Residual volumetric moisture content of the soil layer	(-)	It indicates the minimum possible volumetric water content that a soil can undertake after a drying process.	

### 8.2.1 Radiative Inter-Canopies Heat Exchanges: The Lack of a Proper Database of Pertinent Physical Parameters

Relatively to the energy issues, one of the biggest limitations is represented by the lack of knowledge of the mechanisms and physical parameters that govern radiative exchanges between the plants and the external environment and between the plant essences themselves (“intercanopies heat exchanges”).

Based on a literature review carried out by the authors, aimed at investigating the availability and typology of some parameters related to vegetation and soil (i.e.,

experimental or analytical data, obtained both from experimental applications and theoretical data on plant canopies, plant species, and growth stage which the available data are referred to) (Peri et al., 2016), it has emerged the absence of a proper database containing information (growth stage, leaf area index, and coverage ratio) for different green roof plant species, which technicians could utilize in the eventuality of a lack of specific field data. This circumstance has been found especially in the case of shortwave radiation exchange inside the green roof canopy layer, which is a component of the green roofs' energy balance that, as demonstrated by Feng et al. in their work (Feng, Meng, & Zhang, 2010), plays an important role in the green roofs' energy balance. More specifically, it has been noticed that the current database containing the required data parameters to model this component of the radiative exchanges occurring within green roofs' canopies has some inherent limitations:

- is so far quite limited because it is referred only to a few plant species;
- almost all investigated parameters range of values are usually rather large (e.g., LAI values found range from 1 to 5), which could make even more challenging the choice of the values most appropriate for each of the models;
- (existing databases) do not fit this kind of roof peculiarities, represented by the fact that such component consists of living elements (i.e., vegetation) that grow and/or decay with time, modifying important parameters involved in the modeling of the green roof, such as the (LAI) and the coverage ratio (La Gennusa, Peri, Scaccianoce, Sorrentino, & Aprile, 2018; Peri et al., 2016; Santamouris et al., 2007). Changes in such variables, which obviously influence the building energy savings related to green roofs (Silva et al., 2016; Zinzi & Agnoli, 2012), have been found to be frequently simplified instead, meaning that the available values in literature concern specific growth levels of specific plant species.

Therefore, in our opinion, the absence of a proper database appears of no negligible importance because a technician, who is tasked to assess the green roof impact on the energy consumption of a building equipped with it, might be forced to refer to common values, which do not represent the specific vegetated implantation; this circumstance may imply a simulation scenario not comparable with the actual one, that might lead to an inaccurate assessment of the buildings' thermal loads (heating and cooling).

In this respect, we have performed an evaluation of the buildings' energy estimation errors that might occur when using generic values for the green roofs' vegetation parameters. The outcomes of such estimation were compared to the results obtained from experimental data, deriving from a monitoring campaign (conducted by the authors) that is described in the following (paragraph 1.2).

In detail, the building yearly energy needs, both as summation of heating and cooling then separately, have been calculated, hypothesizing four different scenarios relative to the vegetation parameters to give as input to the utilized software (DesignBuilder©). In particular, the four considered parameters' set of values were the following:

- Field monitored data
- Fixed minimum values
- Maximum values
- Average values.



**Table 8.2** Potential errors due to the use generic vegetation data (Peri et al., 2016)

Set of data assigned to the vegetation parameters	Ranges of errors potentially occurring		
	<i>Cooling</i>	<i>Heating</i>	<i>Annual (heating + cooling)</i>
Minimum values	10% and 24%,	14% and 33%,	8% and 17%,
Maximum values	4% and 14%,	12% and 45%,	2% and 10%
Average values	1% and 9%.	7% and 19%.	1.5% and 7%

The simulations' outcomes, listed in Table 8.2, put in light the need of improving the database with data specific for the typology of installed green roof, in order to render the building energy performance simulations more reliable. In fact, as it can be observed from the results, significant errors (up to 45% for heating) in the estimation of thermal loads might be related to the use of generic data.

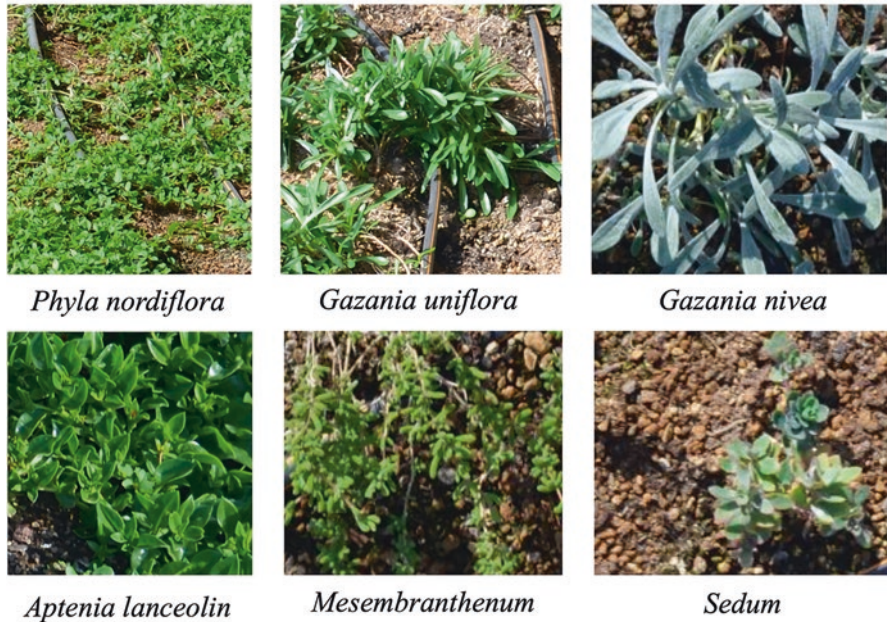
### 8.2.2 *An Experimental-Side Contribution Towards More Reliable Energy Performance Simulations of Buildings with Green Roofs*

In order to contribute to populate the database of parameters related to the vegetation layer of extensive green roofs, required by the current calculation tools to assess the effect of a specific green roof on the energy consumption of a building, we decided to experimentally measure three important physical parameters governing the green roofs energy performance:

- Coverage ratio ( $\sigma_f$ )
- Leaf area index (LAI)
- Foliage temperature ( $T_f$ ).

The choice of these three parameters relies on the fact that the LAI provides information on the depth that the solar radiation has to go through before reaching the roof (indicating the level of its attenuation by the vegetation), while the coverage ratio,  $\sigma_f$ , identifies parts of the roofs directly hit by the solar radiation, which are then characterized by a different energy balance. We measured the growth-related parameters of these two plants according to technical protocols that refer to techniques widely diffused in the agrarian field. On the other hand, the foliage temperature,  $T_f$ , is clearly an important parameter of the vegetation's energy balance and, in turn, of the green roof's energy balance.

Six plant species were experimentally investigated with reference to different growth levels in the same lapse of time: *Phyla nordiflora*, *Aptenia lancifolia*, *Mesembryanthemum barbatus*, *Gazania nivea*, *Gazania uniflora*, and *Sedum* (see



**Fig. 8.1** Plant species investigated in this study

Fig. 8.1). These vegetable species are planted into three plots of extensive green coverings, which are sited in the campus of the University of Palermo.

A simple optical procedure was used to obtain the coverage ratio (Walter, Burnham, Gilliam, & Peterjohn, 2015), based on a pixel-counting procedure applied to some green roof squares digital pictures (to this aim, wooden squares were built ad hoc).

As regards the LAI measurements, a “destructive” procedure was used, consisting in leaf removal from plants with a subsequent leaves measurement by means of a leaf area meter.

Finally, the leaf temperatures, for every species and in both the upper and lower layers of the canopy, were taken using an infrared thermometer, in order to obtain a more representative value.

Proper ranges of the cited parameters have been found for each species. A more detailed description of the measurement campaign is presented in (Ferrante, La Gennusa, Peri, Rizzo, & Scaccianoce, 2016).

As for the leaf temperature, its dependence on climatic parameters has been analysed as well and a correlation with some meteorological variables was estimated. In particular, the obtained distribution of experimental points for both the solar radiation and the air temperatures highlighted a linear equation as the best fitting curve (see Fig. 8.2). Graphs show that the correlation between the foliage temperature and the solar radiation is stronger compared to the one between the foliage temperature and the air temperature, as confirmed by the obtained autocorrelation

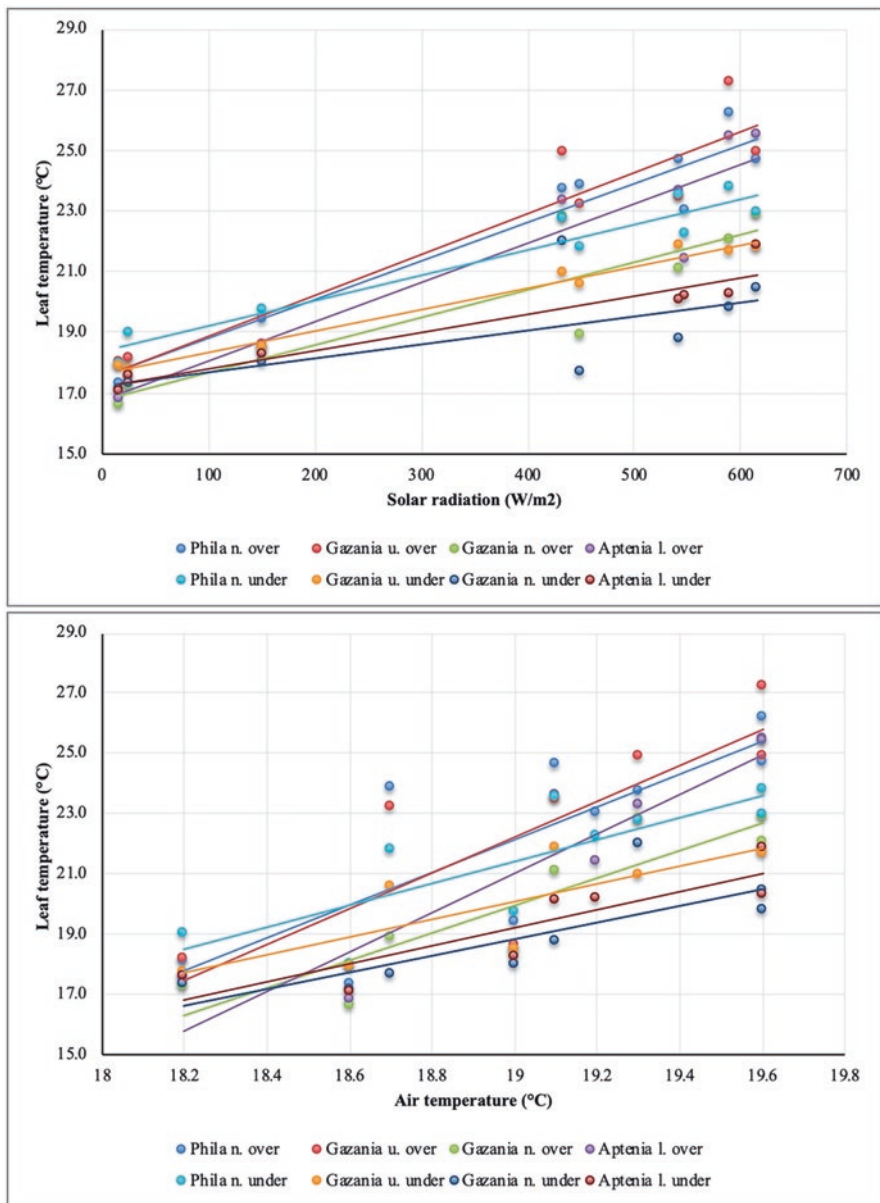


Fig. 8.2 Leaf temperature opposite solar radiation (up) and air temperature (down). (Adapted from Ferrante et al., 2016)

coefficients values. This could have been expected, considering that leaves are more affected by the presence and/or absence of direct solar than by the air temperature, the response to the modifications of such parameter is in fact slower.

Clearly, in the aim of realizing a continuous and homogeneous green coverage to reduce the impact of solar radiation on the building roof, the thickness of the water storage layer also plays a role in the optimization of the components, other than the type of plant species, which is the most important factor. In this respect, we also conducted a monitoring campaign where the ceiling temperatures were measured in some rooms sited below an experimental green roof consisting of different plots, characterized both by distinct water storage thickness and plant species (Cirrincione et al., 2020). As expected, results pointed out a general propensity in achieving lower temperatures when the green coverage is taller and when the water storage layer is thicker; a ceiling temperature difference comprised between 1 and 3 °C was registered with respect to the plots presenting lower green coverages and thinner water storage layers.

### 8.3 The Environmental Impact of a Green Roof

Provided that, as mentioned in the Introduction section, vegetated roofs have become increasingly popular in urban contexts, in our opinion it seems quite relevant in understanding the actual environmental impact of such components, in order to understand whether their large-scale implementation might be a cause for concern.

#### 8.3.1 *The Life Cycle of the Substrate: A Lack of LCA Studies on Green Roofs*

Although, in recent years, the growing interest in green roofs has led to a growth in the number studies regarding their overall performance, especially from a thermal point of view, and their effectiveness in different climatic contexts, (Bevilacqua, Bruno, & Arcuri, 2020; Bevilacqua, Mazzeo, Bruno, & Arcuri, 2016), specific environmental analyses regarding the substrate, currently available in literature, seem to be somehow lacking (Koura, Manneh, Belarbi, El Khoury, & El Bachawati, 2017; Sailor & Hagos, 2011; Zhao, Tabares-Velasco, Srebric, Komarneni, & Berghage, 2014). Indeed, based on a literature review performed by the authors on green roof studies addressing environmental analyses of these components, it has emerged that the role of both the substrate and the disposal phase on the overall environmental impact of the green roof (Peri, Traverso, Finkbeiner, & Rizzo, 2012a, 2012b) is currently underestimated.

Two interesting studies about green roof performances and their comparison with standard roofs (Kosareo & Ries, 2007; Saiz, Kennedy, Bass, & Snail, 2006) analyse such building components by means of the well-known life cycle assessment (LCA) methodology. This is an internationally standardized procedure (ISO 14040 and ISO 14044) and essentially allows estimating the potential environmental impacts of given product/service though its entire life cycle on a given set of impact categories, such as, for instance, global warming, eutrophication, acidification, representing these latter well-known environmental issues. Nevertheless, both the analyses result not being fully exhaustive comprehensive: concerning the one performed in (Saiz et al., 2006), this observation is mostly linked to the disposal phase being completely overlooked, while regarding the study reported in (Kosareo & Ries, 2007), it principally relates to the LCA lacking of a green roof significant element, i.e., the growing medium.

### ***8.3.2 An LCA Contribution Towards More Complete and Proper Analyses of the Whole Environmental Impact Exerted by a Green Roof During Its Whole Life Cycle***

In order to contribute in covering this gap and thus allowing a full and accurate utilization of the LCA methodology to achieve a more comprehensive description of the environmental performances of this building component, without the vegetation layer, a classical LCA methodology has been applied to a specific extensive green roof, built on the top of a Research Institute building sited in a small Sicilian town near Palermo (Italy). The entire life cycle of the substrate has also been included in the analysis, besides taking into account also the end of life of the green roof.

Green roof data related to the vegetation have not been considered in the analysis as it was not possible to obtain primary data (such as water and fertilizers) from the owners and/or handlers. Nevertheless, this is a typical limitation when one tries to carry out the LCA of a green roof (Kosareo & Ries, 2007; Saiz et al., 2006).

A comprehensive description of the inventory phase and impact assessment phase is reported in (Peri et al., 2012a, 2012b).

The outcomes of the study (briefly summarized in Fig. 8.3) have underlined the importance of including the substrate in such kinds of analyses. More specifically, from our analysis it has emerged that the presence of the substrate should not be overlooked because the substrate, compared to the others elements, plays a significant role in the environmental impact of the end-of-life phase of green roofs. In fact, we have discovered that the substrate disposal in landfill (treatment hypothesized in the analysis) causes a dramatic “Aquatic Toxicity” potential.

It is also worth noting that the substrate requires the use of substances, such as fertilizers, that in the common environmental impact of buildings would not be normally considered. In other words, when performing an LCA of a building, whose

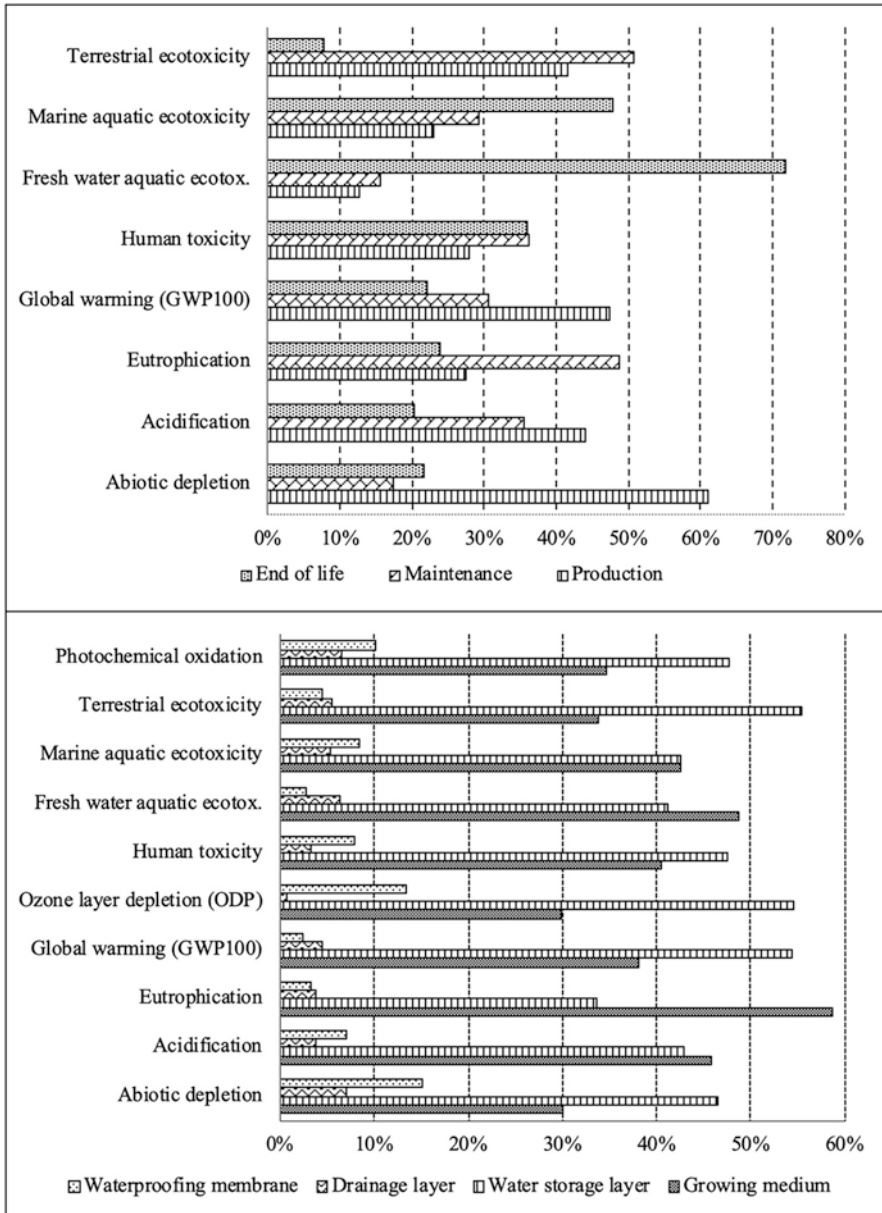


Fig. 8.3 Summarized characterization results of the LCA showing the weight of the substrate on the environmental impact of the green roof. (Adapted from Peri et al., 2012a, 2012b)

roof is different from a green roof, the use of fertilizers is generally not contemplated because no cultivation soil is involved. In fact, the environmental impact of a building without a green roof is not commonly influenced by these substances. Considering the impact of fertilizers is important, because fertilizers cause, on the one hand, NO<sub>x</sub> and N<sub>2</sub>O emissions during the use phase of the green roof and, on the other, their production process causes a high “Eutrophication and Terrestrial Toxicity” potential, as resulted in our study (Peri et al., 2012a, 2012b).

## 8.4 The Economic Impact of a Green Roof

As mentioned in the Introduction section, vegetated roofs have become increasingly common in urban contexts, especially for the many benefits they are capable of providing. In light of that, the knowledge of the actual cost of such technology from a life cycle perspective appears of no negligible importance too. In fact, obviously the feasibility of the adoption of the green roof as a building component depends on its life cycle cost. If this is too high, then this solution will not be economically viable and probably have to be discarded despite all the technical advantages it provides.

On the other hand, from the standpoint of people occupying a given building (tenant and/or owner) and thus paying the current costs of the electric energy, indeed reduced by the presence of the green roof, it might be useful to have at disposal simple but reliable criteria for assessing the economic feasibility of green roofs compared to other roofing options during the duty phase of the building.

### 8.4.1 *The Life Cycle of the Substrate: A Lack of LCA Studies on Green Roofs*

Although, over the last years, the economic evaluation of green roofs has gained more attention (Shafique et al., 2018; Shafique, Azam, Rafiq, Ateeq, & Luo, 2020; Ulubeyli, Arslan, & Kazaz, 2017), along with the environmental one, literature put in evidence how some components of the green roof life cycle cost analysis are often not taken into consideration. Specifically, the role of the disposal phase seems to be underestimated and/or lacking (Peri et al., 2012a, 2012b).

#### 8.4.1.1 **An LCC Contribution Towards More Complete Analyses of All Life Cycle Cost of a Green Roof**

In order to contribute to the overcoming of this gap, we applied the Life Cycle Costing (LCC) methodology suggested by D. G. Woodward (Woodward, 1997) (that seems to be one of the most utilized and generalizable) to a real extensive green roof, by also extending it to the disposal phase, which was missing in previous

**Table 8.3** Cost components of the analysed green roof life cycle

Cost components	Total green roof [€]	Functional unit 1 m <sup>2</sup> [€]	[%] incidence
Initial investment cost	6154	75 (for purchase of materials and installation)	36%
Maintenance cost hypothesizing a life span of 40 years	10,100	123 (for adding substrate and inspection to remove infesting and fertilizing)	60%
End of life cost for the hypothesized scenario	784	9 (landfill and incineration)	4%
The total life cycle cost	17,000	207	100%

LCC and Benefit-Cost Analyses (BCA) studies. This case study (Peri et al., 2012a, 2012b) also allowed to perform a complete and proper application of the LCC methodology to achieve an economic evaluation of this component, at least for the abiotic components (vegetation in not, indeed, included in the present study). Results of the study have been elaborated and the following Table 8.3 has been carried out.

As it can be observed from the analysis, it emerged that the cost for the disposal of an extensive green roof has only a slight incidence on its total life cycle cost. In addition, the analysis showed that the cost of the disposal of the substrate seems to be the main responsible for the disposal cost of the whole roof (85%). The same conclusion can be drawn with respect to the initial capital cost, where the substrate resulted responsible for 44% of the total cost (Peri et al., 2012a, 2012b).

#### 8.4.1.2 A Contribution Towards a Simplified Economic Appraisal of the Feasibility of Green Roofs

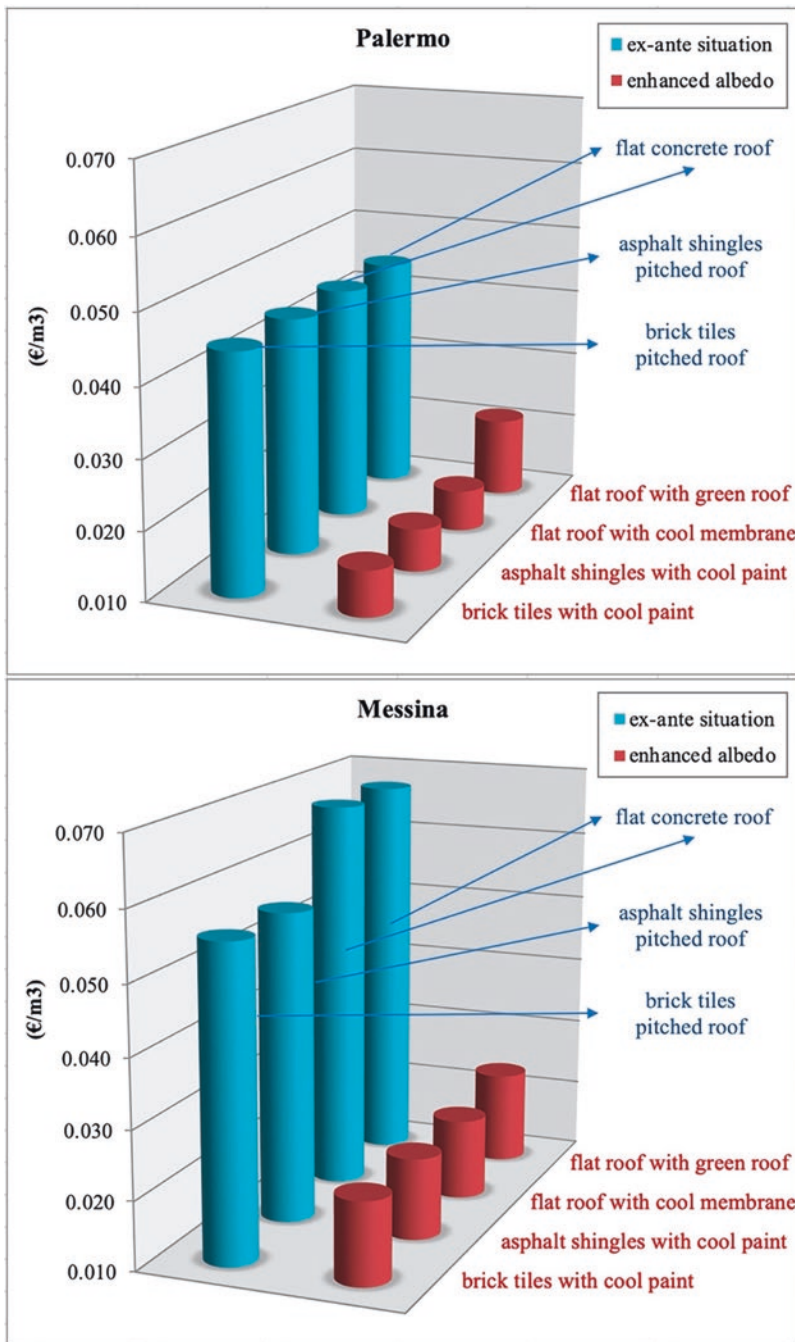
Obviously, when analysing an important building component, such as a green roof, economic aspects also need to be taken into consideration.

Results of a simple procedure to estimate the green roofs' economical effectiveness has also been briefly summarized here (see Fig. 8.4), based on a previous study conducted by the authors (Di Lorenzo et al., 2019), in which the evaluation of the periods of time in which a certain building requires an active cooling support in order to maintain the required indoor comfort conditions (estimated service time) has been transformed into the cost of the corresponding needed electric energy. Specifically, Fig. 8.4 comparatively shows the specific costs (kWh/m<sup>3</sup>) for the ex-ante and the enhanced albedo scenarios of two Sicilian cities, Palermo and Messina.

The choice of an economic criterion concerning the running cost of the air conditioning system relies on the consideration that people usually decide to rent a building where to live based on the running cost of the HVAC systems.

As it can be observed, at least in the performed analysis in both cities, a higher reduction of the climatization costs has resulted when installing cool paints or cool membranes on the existing roofs rather than in case of adoption of green roofs. Despite some simplifying assumptions (some of them typically made in building





**Fig. 8.4** Electric energy costs reduction of buildings with green roofs. (Adapted from Di Lorenzo et al., 2019)

simulation) clearly affecting the results, this method can represent a preliminary and useful tool to support decision-makers when assessing the economic feasibility of these two technological alternatives.

## 8.5 Conclusions

This chapter deals with an increasingly important passive component of the building envelope, which is green roof. Some of the current gaps affecting the energy modelling, as well as the environmental and economic assessment of these building components have been presented. Contributions to their solution, which have arisen from both experimental and modelling research carried out by the authors, have been addressed in this chapter. Specifically, part of it provides a contribution in overcoming the current gaps related to the Life Cycle Costing (LCC) analyses phases, by taking into account the green roof disposal costs. In detail, it has arisen that the cost for the disposal of an extensive green roof has only a slight incidence on its total life cycle cost (4%).

The lack of knowledge regarding the substrate in the application of the classical LCA methodology, as it has been demonstrated, also represents a critical aspect, which negatively affects green roofs' energy performance assessment. This issue has also been dealt with by reporting results of an LCA conducted on a green roof (whose greening type is extensive), where the analysis of a specific substrate was properly included by also considering the role of fertilizers used for the green roof maintenance. Specifically, it has been found that the substrate is the greatest contributor to some impact categories, such as Fresh Water Aquatic ecotoxicity (49%), Eutrophication (59%), and Acidification (46%).

In addition, the absence of a proper database containing information (growth stage, leaf area index, and coverage ratio) relative to the parameters characterizing different green roof plant species, which technicians could use when a lack of field data occurs, has been pointed out. Besides, an estimation of the errors likely occurring when using not specific vegetation data for an energy estimation of a building equipped with a green roof, is presented; it has resulted that significant errors (up to 45% in the case of heating and up to 24% in the case of cooling) in the estimation of thermal loads might occur when using generic data for the vegetation parameters of an extensive green roof.

Finally, in order to provide a building's users (i.e., people occupying a given building, which are thus responsible for the energy bill) with an easy and yet effective tool for assessing the economic viability of green roofs, some observations regarding the economic appraisal of green roofs have been included as well.

In conclusion, based on considerations presented in this chapter, further analyses are highly recommended. In fact, there are still several research areas and technical difficulties that need to be addressed, as for instance the evaluation of the initial high construction and maintenance costs in sight of a proper economical evaluation (Mahdiyar et al., 2016; Tassicker, Rahnamanyiezekavat, & Sutrisna, 2016), or the

consideration of possible leakage occurrences (Baryła, Karczmarczyk, Brandyk, & Bus, 2018).

Furthermore, another aspect that emerged from the research activity on green roofs carried out so far by the authors regards the importance of the availability of adequate simulation tools (La Gennusa et al., 2019a, 2019b; Mazzeo, Bevilacqua, De Simone, & Arcuri, 2015), in order to facilitate both the design and assessment processes. Green roofs represent an increasingly important building passive component in urban contexts due to the many benefits that can be attributed to them. Green roofs allow indeed to reduce the air pollution.

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# Chapter 9

## Gender Matters! Thermal Comfort and Individual Perception of Indoor Environmental Quality: A Literature Review



Edeltraud Haselsteiner

**Abstract** The use of technology in construction has allowed a significant increase in comfort and the construction of energy-efficient buildings. However, for indoor environmental comfort, there is no universal standard that fits all. The indoor climate is perceived individually and the requirements are subjectively shaped. In this paper, a literature review is carried out to describe particular aspects relevant to gender. The aim is to raise awareness of these aspects in order to advance equality orientation as an integral part of planning and energy-efficient building concepts. The findings show that thermal comfort is an essential parameter, and up to 3 °C of differences between women and men were found. This difference is most evident in offices where women show a better cognitive performance in a warmer environment, while men do better in colder temperatures. Gender was also found to be an influencing factor of satisfaction with humidity, acoustic conditions, visual comfort, privacy, air quality, health aspects, light preferences, and brightness perception. Moreover, sick-building syndrome is more common among women. In conclusion, the literature confirms that essential indoor environmental quality (IEQ) parameters vary significantly across men and women and should be taken more into account in the practice of building technology.

**Keyword** User satisfaction · Individual sensitivity · Cognitive performance and productivity · Comfort standards · IEQ assessments · Energy-efficient building technology

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## 9.1 Introduction

### 9.1.1 *Comfort Standards and Gender*

Building technology developments towards low-energy-, passive house-, or positive energy buildings made standards and regulation of the indoor climate a central aspect of energy-efficient construction. In this context, comfort criteria and standards have been established and implemented with a focus primarily on energy efficiency. In attempting to follow energy efficiency standards, a narrow view of comfort is unavoidable (Ortiz, Kurvers, & Bluysen, 2017). Comfort has been studied in terms of values and standards for the thermal environment, air quality, acoustic, and lighting. Accordingly, indoor environmental quality (IEQ) factors are based on single standard values for thermal comfort, the quality of air, light, and acoustics. The approach of measuring these factors separately, according to standardized parameters, neglects possible interactions or differences in the perception of different people (Ortiz et al., 2017).

Although energy monitoring analyses were frequently supplemented by social science surveys, the questions focused on average values, and limited to the overall satisfaction and acceptance by the users (i.e., Ornetzeder, Wicher, & Suschek-Berger, 2016; Pastore & Andersen, 2019). An analysis of existing works on the subject of user behavior in energy-efficient or green buildings shows that, although certain diversity aspects (primarily socio-demographic characteristics, such as education, income, and household size) are included, it is not sufficient to derive solution strategies able to adequately address different target groups (Haselsteiner, Susanne, Klug, Bargehr, & Steinbach, 2014). In particular, the gender aspect is usually only considered as a social demographic factor in the study design, and often neglected in the evaluation (Haselsteiner, 2017).

Whereas categories of sex are defined according to biological differences, gender focuses on roles that are constructed and reproduced by society, and these roles can also change over time. It is, consequently, crucial to reveal unilateral or restrictive gender ascriptions and practices in any field of action. This also applies to IEQ parameters. The objective of this article is to outline the gap in gender aspects when considering IEQ, and to look at them in a more differentiated manner. People cannot be categorized according to homogeneous groups, and are confronted with different role expectations, attributes, and different opportunities and framework conditions (i.e., Hanappi-Egger & Bendl, 2015). Hence, this means that thermal comfort and indoor environmental quality should not only focus on single gender but rather addressing “users”, trying to understand different needs while taking diversity into account. The intersectionality of various diversity dimensions – such as age, origin, disability, economic conditions, etc. – have to be taken into account. Only further differentiations enable a precise analysis of subjective needs and interests. This can only be met if an intersectional approach is also included in the IEQ assessment.



### ***9.1.2 Indoor Environmental Quality and Its Importance for Well-being, Health, and Productivity***

The indoor environment quality (IEQ) is an essential factor for well-being, health, and productivity (Al Horr et al., 2016; Al Horr et al., 2016). Findings in the literature show eight physical factors that affect user satisfaction and productivity in an office environment (Al Horr, Arif, Kaushik, et al., 2016).

1. Indoor Air Quality and Ventilation
2. Thermal Comfort
3. Lighting and Daylighting
4. Noise and Acoustics
5. (Office) Layout
6. Biophilia and Views
7. Look and Feel
8. Location and Amenities

Although thermal comfort is the most important parameter of IEQ, other aspects interact with the ambient temperature in a complex interplay (Frontczak & Wargocki, 2011). In western countries, people spend more than 90% of their time indoors. The indoor environment quality is therefore decisive for physical and mental health. The most important, although not given enough attention yet, is the adaptation of IEQ to individual preferences. How important it is to pay particular attention to gender criteria can be derived from the medical field. In medicine, it has slowly been recognized that medical research and treatment shows a clear gender bias. Drugs are tested on men, guidelines are written by men and symptoms of women, that of a heart attack, for example, are often not recognized because these symptoms have been classified as “atypical” and not “according to the standards”. Women still die more often than men after a heart attack (Mehta et al., 2016). Moreover, a recent study shows that mortality also depends on who treats them. If women are treated by a female doctor, the chance of survival is significantly higher (Greenwood, Carnahan, & Huang, 2018).

In building technology, gender-specific approaches which imply a differentiated body reaction between the sexes, or differences in the perception of indoor climate according to sexes, if not negated, are at least dismissed as very small and negligible. Since research on physiological differences and the medical treatment of women and men has already received widespread recognition, it is surprising. Karjalainen (2012) states in her literature review that study results can be traced back to 1970, in which differences in thermal comfort between men and women were demonstrated (i.e., Fanger, 1970). Even if some of the results of the study found only slight or no differences (Amai, Tanabe, Akimoto, & Genma, 2007; Liu, Lian, Deng, & Liu, 2011, see review from Karjalainen, 2012), it is obvious that, similar to medicine, women also perceive indoor qualities, such as air quality, thermal comfort, or lighting – which are very much connected with physiological properties – differently compared to men.

### 9.1.3 Objectives

The objective of this chapter is to outline individual aspects that address the interplay between gender and the perception of indoor environmental quality. Relevant scientific publications were searched in which gender differences are shown based on their findings. The aim is to raise awareness of these aspects to advance equality orientation as an integral part of planning and energy-efficient building concepts. This study does not pretend to be a complete literature review. Rather, the basis of this article is an exploratory literature study, in which key individual aspects are collected, main gaps are identified, and some questions are formulated, in order to state where the author considers essential to continue researching.

## 9.2 Method

The research is based on an exploratory literature review. To collect relevant research publications, the following keywords were used: “indoor environmental quality + gender” and “thermal comfort + gender”. Google Scholar and ScienceDirect have been the major electronic databases. As a first step, papers were analyzed that had already carried out a comprehensive literature study on the subject of gender, individual differences, and IEQ (i.e., Karjalainen, 2012; Wang et al., 2018). Additionally, the method “reference by reference” was used to find relevant publications. From this, research gaps were identified in connection with the time of the respective publication. The search was then repeated, and only papers published in 2019–2020 were selected and examined in detail. Additional selection criteria that were applied include:

- adult users (>18 years),
- gender-specific evaluation (title, abstract, or author-specified keywords),
- building typology: residential buildings, offices, and educational buildings,
- publication years: 2019, 2020.

The search on the two electronic databases Google Scholar and ScienceDirect showed only slight overlaps. From both databases, the first 50 most relevant papers according to the ranking were examined more in detail as to whether gender aspects were used not only as a socio-economic aspect in the selection of the subjects but as an actual evaluation criterion. To close further gaps in research, 2019 and 2020 publications were also subjected to a “reference by reference” search. Finally, 20 papers explicitly addressing gender aspects in their studies, published in 2019–2020 were identified. In total, 44 papers were analyzed, and the findings included and documented. Table 9.1 provides an overview of the literature review studies which formed the basis for further literature search. More publications are shown in Tables 9.2–9.6, at the beginning of each section as an overview of findings assigned to the respective topics.

**Table 9.1** Summary of literature reviews that investigated IEQ gender differences

Study	Procedure/data	Title
Al Horr, Arif, Katafygiotou, et al. (2016)	Literature review	Impact of indoor environmental quality on occupant well-being and comfort: A review of the literature
Al Horr, Arif, Kaushik, et al. (2016)	Literature review	Occupant productivity and office indoor environment quality: A review of the literature
Frontczak and Wargocki (2011)	Literature review	Literature survey on how different factors influence human comfort in indoor environments
Karjalainen (2012)	Literature review	Thermal comfort and gender: a literature review
Jungsoo Kim, de Dear, Cândido, Zhang, and Arens (2013)	Literature review and data analysis	Gender differences in office occupant perception of indoor environmental quality (IEQ)
Wang et al. (2018)	Literature review	Individual difference in thermal comfort: A literature review

### 9.3 Literature Review: Findings and Discussion

#### 9.3.1 Individual Sensitivity and Comfort Criteria

##### 9.3.1.1 Thermal Comfort

Field studies and studies in controlled environments have been carried out to assess parameters for thermal comfort and determine individual differences (see Table 9.2). A significant number of these studies have analyzed gender issues in more detail. Table 9.2 provides an overview of these studies and shows key results.

It becomes clear that women and men rate the environmental conditions differently (Bae et al., 2020; Choi et al., 2010; Frontczak & Wargocki, 2011; Indraganti, 2020; Karjalainen, 2007; Rupp, Vásquez, & Lamberts, 2015). Under the same thermal conditions, women are 50% more often dissatisfied with the indoor climate than men (Karjalainen, 2012). Women are more likely to perceive the indoor temperature as too cold or, in some cases, too warm (Bajc & Milanović, 2019; Indraganti & Rao, 2010; Jowkar et al., 2020; Karjalainen, 2007; Jimin Kim et al., 2019; Parsons, 2002). Karjalainen (2007) found in a quantitative study in Finland that 18% of women, but only 8% of men, feel uncomfortably cold on a weekly basis, or more often (weekly, daily, or continuously) at home. The percentage is even higher in offices: 40% of women stated that they feel uncomfortably cold weekly or more often, while only 16% of men stated the same. Overall, Karjalainen (2007) concludes that women feel more comfortable at higher temperatures. These results coincide with results from other studies (Bajc & Milanović, 2019; Indraganti & Rao, 2010; Jowkar et al., 2020; Jimin Kim et al., 2019; Jungsoo Kim et al., 2013; Parsons, 2002). Women have a preference for a slightly warmer environment, while

**Table 9.2** Overview of IEQ studies that investigated thermal comfort and gender differences (listed in alphabetical order)

Study	Place	Procedure/data	Building typology	Findings (cited from the respective literature)
Al-Khatri, Alwetaishi, and Gadi (2020)	Muscat, Oman and Jeddah, Saudi Arabia	Environmental measurements and questionnaire survey; students in high school classrooms; $n = 657$ , (female = 269, male = 388) students)	Educational buildings	Despite the heavier insulation level of the female students, around 56% of them were thermally (neutral) compared with almost 20% of the male students
Bae, Asojo, and Martin (2020)	Minnesota, USA	Questionnaire survey; 30 workplace buildings across eight years (2009–2017); $n = 2275$	Office buildings	Male occupants have a greater tendency to be satisfied with thermal conditions, acoustic conditions, electric lighting, and privacy than female occupants; the biggest gaps between male and female participant satisfaction scores were found related to adjustability of the thermal conditions, privacy- overall, temperature, and thermal conditions – Overall
Bajc and Milanović (2019)	Belgrade, Serbia	Environmental measurements and questionnaire survey	Office buildings	Men were more sensitive to the higher temperatures, preferring colder working environment, while women stated to feel more comfortable in slightly warmer environment; men were more tolerant to noise, while women were more sensitive to poor air quality

(continued)

**Table 9.2** (continued)

Study	Place	Procedure/data	Building typology	Findings (cited from the respective literature)
J.-H. Choi and Yeom (2019)	Southern California	Experiment chamber (human subject experiments to examine physiological responses); students; <i>n</i> = 18, (female = 7, male = 11)	Laboratory	The results revealed significant correlations between overall thermal satisfaction levels and local body skin temperatures, as well as heart rates; results of this study also verified that there are significant differences in the thermal satisfaction and physiological responses of males and females in the same thermal environment; the average thermal satisfaction level of females is significantly higher than that of males
J. Choi, Aziz, and Loftness (2010)	Pittsburgh, USA	Environmental measurements and questionnaire survey; POE, users satisfaction survey; 20 office buildings; <i>n</i> = 402 (female = 212, male = 190)	Office buildings	Females are more dissatisfied with their thermal environments than males especially in the summer (cooling) season (mean thermal satisfaction level 2.76 for females and 3.87 for males)
Dosumu and Aigbavboa (2019)	South Africa	Questionnaire survey; Ekurhuleni metropolitan municipality; <i>n</i> = 100, (female = 66, male = 34)	Office buildings	Significant differences in the factors affecting the IEQ of buildings based on the individual characteristics (age, gender, and ethnicity)
Indraganti (2020)	Qatar, Japan and India	Data analysis; sets of data = 12,192, and ASHRAE database I and II containing 10,551 sets of data from seven more countries	Office buildings	Except Japan and South Korea, women are more dissatisfied than men with their thermal environments in all countries investigated; female subjects in Asia are 37.3% ( <i>p</i> < 0.001, <i>N</i> = 22,343) more likely to be dissatisfied with their thermal environments than their male counterparts

(continued)

**Table 9.2** (continued)

Study	Place	Procedure/data	Building typology	Findings (cited from the respective literature)
Indraganti and Rao (2010)	Hyderabad, India	Environmental measurements and questionnaire survey; estimated clothing insulation; transverse questionnaire survey (1 day) and longitudinal survey (4 days per month, 33 days in total); dataset = 3962 in total; five naturally ventilated apartments; occupants of 45 flats; $n = 113$ , (female = about 35, male = about 64)	Residential buildings	Significant gender differences were found among people voting neutral (men 29%; women 38%); more men had 'slightly warm' sensation (38%) than women (31%); women prefer a warmer environment than men; women had a different perception of the thermal environment (higher sense of belonging) and thermal acceptance in women was higher
Jowkar, Rijal, Montazami, Brusey, and Temeljotov-Salaj (2020)	Scotland, UK	Environmental measurements and questionnaire survey; two university campuses; $n = 3465$ (female = 1157, male = 2308)	Educational buildings	Thermal perceptions of females were shown to be colder than males in university classrooms; despite the similar comfort temperature for both genders ( $\approx 23$ °C), heavier clothing insulation optimum acceptable worn by women ( $\approx 0.92$ clo) than men ( $\approx 0.83$ clo) and the higher optimum acceptable temperature of females (23.5 °C) than males (22.0 °C) support the warmer thermal requirements of women compared to men

(continued)

**Table 9.2** (continued)

Study	Place	Procedure/data	Building typology	Findings (cited from the respective literature)
Karjalainen (2007)	Finland	Quantitative interview survey and laboratory experiment; controlled experiment to simulate real use of thermostats; students, $n = 68/152/80/60$ per test case; quantitative interview survey: $n = 3094$ (females = 1556, males = 1538)	Residential buildings, office buildings and educational buildings	Females are less satisfied with room temperatures than males, prefer higher room temperatures and feel both uncomfortably cold as well as hot more often than males
Jimin Kim, Hong, Lee, and Jeong (2019)	Seoul, South Korea	IEQ sensors (real time) and observation of occupants' behaviors	Office buildings	Female occupants felt colder than the male occupants (25 °C instead of 24 °C when all occupants were females)
Liu, Wu, Lei, and Li (2018)		Laboratory experiment; testing 12 different clothing ensembles at four air temperatures: 10, 16, 22, and 28 °C; students; $n = 20$ , (female = 10, male = 10)	Laboratory	Women are more sensitive to a colder thermal environment; females measured overall skin temperatures were lower than those of their male counterparts (particularly hands, feet, and lower body parts)
Lu, Liu, Sun, Yin, and Jiang (2019)	China	Questionnaire survey; two climate zones: Cold climate and hot summer and warm winter region; 12 (LEED) high-star green buildings; $n = 1400$	Office buildings	Relationship among gender, different climate zones, and temperature tolerance: i.e., men in the hot summer and warm winter (HSWW) region are more tolerant of cold and women are more tolerant of heat, women in the cold region have good cold tolerance and a better heat tolerance in HSWW regions

(continued)

**Table 9.2** (continued)

Study	Place	Procedure/data	Building typology	Findings (cited from the respective literature)
Maykot et al. (2018)	Florianópolis, Brazil	Environmental measurements and questionnaire survey; two office buildings; 116 field studies; $n = 584$ (female = 238, male = 346)	Office buildings	Comfort temperature was 24.0 °C for females, and 23.2 °C for males; in fully air-conditioned building, significant differences were found for comfort temperature for females and males (24.2 °C and 23.4 °C, respectively)
Nakano, Tanabe, and Kimura (2002)	Japan	Questionnaire survey; $n = 406$ (female = 184, male = 222)	Office buildings	A significant neutral temperature Difference of 3.1 °C was observed between the Japanese female group and the non-Japanese male group; Japanese females reported a higher frequency of <b>sick building syndrome</b> -related symptoms compared to other groups
Parsons (2002)	UK	Laboratory experiment; $n = 36$ (females = 16, males = 16)	Laboratory	For identical level of clothing and activity minor gender differences in thermal comfort responses for neutral and slightly warm conditions; in cool conditions, females tend to feel cooler than males

(continued)



**Table 9.2** (continued)

Study	Place	Procedure/data	Building typology	Findings (cited from the respective literature)
Rupp, Kim, Ghisi, and de Dear (2019)	Australia	Data analysis; sets of data = 11,500; Australian database of thermal comfort field studies, derived from different building typologies	Office buildings, school buildings and residential buildings	Females were more sensitive to indoor temperature-change than males: In air conditioned buildings women were 19% more sensitive than men, while in natural ventilated buildings women were 46% more sensitive than male counterparts; in office buildings women were significantly more sensitive to indoor temperature-change than men
Schellen, Loomans, de Wit, and van Lichtenbelt (2013)	Netherlands	Laboratory experiment; <i>n</i> = 20 (females = 10, males = 10)	Laboratory	Women have lower skin temperature than men; in women, the overall thermal comfort sensation is significantly affected by the temperature of the skin and the extremities; women are more likely to feel uncomfortable and dissatisfied with thermal comfort than men

(continued)

**Table 9.2** (continued)

Study	Place	Procedure/data	Building typology	Findings (cited from the respective literature)
Thapa (2019)	Darjeeling, India	Environmental measurements and questionnaire survey; ten different naturally ventilated buildings; $n = 2608$ , (female = 1125, male = 1483)	Educational buildings and residential buildings	Female subjects showed a lower clothing insulation (mean 0.83 clo) than the male subjects (mean 0.87 clo) in almost all cases except in office buildings, where it was the opposite; lower thermal sensation vote (indication of feeling of sensation of warmth or coolness) shown by female subjects; female subjects preferred higher indoor operative temperature than males; significant higher mean comfort temperature for female than for males
Yeom, Choi, and Kang (2019)	USA	Laboratory experiment; immersive virtual reality Environment (IVE) and real indoor environment (IE); measurement tests focused on skin temperature, recording of thermal sensation on a check list); students; $n = 16$ , (female = 6, male = 10)	Laboratory	Male had higher skin temperatures in the IE condition than those in the IVE condition, while the reverse was true for women; female had higher skin temperatures in the IVE conditions than those in the IE condition

men prefer slightly cooler conditions. However, only a few differences between men and women were found at neutral temperatures. This means that women are much more sensitive to temperatures that are too warm or too cold, while they hardly feel normal temperatures significantly differently than men (Karjalainen, 2012; Lan, Lian, Liu, & Liu, 2008). Nevertheless, it should be highlighted that women have a more urgent need for individual adjustment to a comfortable temperature level than men (Karjalainen, 2012; Jungsoo Kim et al., 2013; Wang et al., 2018).

In part, these differences can be justified physiologically. On average, women have 20% less body mass, 14% more body fat, and 18% less body surface than men (Burse, 1979). The skin temperature of women is lower than that of men (Lan et al., 2008; H. Liu et al., 2018; Schellen et al., 2013; Yeom et al., 2019), women have lower blood circulation in their hands when it is cold (Karjalainen, 2012), and sweat

less in presence of hot temperatures than men (Mehnert, Bröde, & Griefahn, 2002). Another study (Schellen et al., 2013) showed that among women the overall thermal comfort sensation is significantly affected by the temperature of the skin and extremities. Despite these physiological distinctions, other authors consider differences in thermal comfort to a limited extent to be physiologically justified, but cite cultural and psychological factors as more likely (Karjalainen, 2007; Luo et al., 2016; Nicol & Humphreys, 2002). This is why cultural adaptation and country-specific acceptance and adaptation behavior should be taken into account (Lu et al., 2019; Luo et al., 2016; Thapa, 2019; Zhang, Cao, Wang, Zhu, & Lin, 2017). Behavioral adjustment, such as clothing due to outside temperatures, or individual devices to regulate thermal comfort, for example, the use of fans in warm regions or electric blankets in cool countries, could justify differences based on gender-specific behavior. Nevertheless, both in field studies and especially in laboratory situations, clothing is an influencing factor, and the insulation values of clothing in men and women were explicitly taken into account (Al-Khatiri et al., 2020; Parsons, 2002; Thapa, 2019).

In building design, it is now recommended, even with central control, to always allow an individual adjustment of the room temperatures of  $\pm 2$  °C. As a study from Japan shows, the differences reinforced by cultural variances can also be higher. A field study in an office building in Japan with a very multinational workforce found that Japanese women preferred a 3.1 °C higher neutral temperature level than a male comparison group with non-Japanese (Nakano et al., 2002). This indicates that gender aspects intersect with cultural aspects, which highlights the intersectionality and shows the necessity of understanding (and acting upon) gender in connection with various diversity dimensions, such as age, origin, disability, economic conditions, etc.

Perception of comfort not only differs because of individual preferences, but also because of behavioral aspects, or in combination with other comfort aspects. Rupp et al. (2019) reported that women were significantly more sensitive to indoor temperature-changes than men in naturally ventilated buildings and office buildings. Muzi, Abbritti, Accattoli, and dell’Omo, M. (1998) found gender differences in buildings with air conditioning systems; however, no differences in naturally ventilated buildings. In the field study conducted in Italy in air-conditioned offices, more women than men found the temperatures to be too hot (Muzi et al., 1998). Other study results show that the perception of comfort varies when people are allowed to have control over the air conditioning and ventilation (Schiavon, Yang, Donner, Chang, & Nazaroff, 2017). Negative effects of higher temperatures can be mitigated when personally controlled air movement is used. Thermal comfort, perceived air quality, feelings of sick building syndrome, or cognitive performance are equal or better at 26 °C and 29 °C than at the typical indoor air temperature setpoint of 23 °C, if a personally controlled fan is available for use (Schiavon et al., 2017).

Although studies show that women have different thermal comfort requirements than men and that these are also physiologically justified, the gender aspect is not adequately taken into account in IEQ assessments. The results show a differentiated picture of distinguishing features, which can vary depending on the cultural

conditions of the clothing, building type, or building technology. To meet these different needs, the existing buildings and IEQ standards would have to be subjected to a gender-specific analysis.

### 9.3.1.2 Light Sensitivity

The different sensitivity to artificial light and brightness was examined by several authors (Chellappa et al., 2017; Cirrincione et al., 2018; Knez & Kers, 2000). The results indicate significant gender-specific differences in light sensitivity. Table 9.3 shows an overview of relevant findings.

In contrast to women, men had higher brightness perception and faster reaction times in a sustained attention task during blue-enriched light than non-blue-enriched. After blue-enriched light exposure, men had significantly higher all-night frontal NREM (Author's note: Non-Rem) sleep slow-wave activity (SWA: 2–4 Hz) than women, particularly during the beginning of the sleep episode. Furthermore, brightness perception during blue-enriched light significantly predicted men's improved sustained attention performance and increased frontal NREM SWA (Chellappa et al., 2017: 1).

Men react to blue-enriched light more clearly than women, even in very poor lighting conditions (i.e., 40 lux). Moreover, authors found significant differences in light preferences and subjective perception of brightness between men and women: women preferred light at 2500 K (87.5%) rather than 6500 K (12.5%), while the opposite was observed for men (6500 K: 62.5%, 2500 K, 37.5%) (Chellappa et al., 2017). The subjective perception of brightness of light revealed similar gender-specific differences: men perceived light at 6500 K as significantly brighter than at 2500 K, whereas women perceived no significant differences between light at 6500 K and 2500 K (Chellappa et al., 2017). These results also confirmed evidence produced by other authors (i.e., Knez, 2001; Knez & Kers, 2000).

Artificial lighting in offices and other workplaces plays a central role for many people throughout the day. Knez (2001) examined memory and problem-solving skills with different light intensities and colors. In a multi-criteria analysis, gender-specific differences with different lighting were found to be significant. Men performed better than women with tasks to memory and problem-solving skills in the 'warm' (3000 K) and 'cool' (4000 K) lighting, and poorest in the artificial 'white daylight' (5500 K). Conversely, women performed better in artificial white daylight lighting and perceived the room light, across all light settings, as more expressive than men (Knez, 2001). Studies show that subjective and individual aspects emerge also in the perception of different light colors (Cirrincione et al., 2018; Gennusa et al., 2017).

Moreover, Andersen et al. (2009) found a significant gender difference in window opening behavior influenced by brightness. Females opened the window more often when they perceived the environment as bright, while men were not affected by the illumination. Likewise, women were less likely to have the lights on when they felt warm or cold as compared with neutral, while conversely, men were more

**Table 9.3** Overview of IEQ studies that investigated light sensitivity and gender differences (listed in alphabetical order)

Study	Place	Procedure/data	Building typology	Findings (cited from the respective literature)
Andersen, Toftum, Andersen, and Olesen (2009)	Denmark	Questionnaire survey; $n = 933$ (summer survey) + $n = 636$ (winter survey)	Residential buildings	Females opened the window more often when they perceived the environment as bright, while men were not affected by the illumination; likewise, women tend to have the lighting turned on when they felt cold or warm compared to neutral, while the possibility for men that the light was turned on was higher when they felt cold or warm compared to neutral
Chellappa, Steiner, Oelhafen, and Cajochen (2017)	Boston, USA	Laboratory experiment and data analysis; light exposure of 40 lx at 6500 K (blue-enriched) or At 2500 K (non-blue-enriched); $n = 32$ (female = 16, male = 16)	Laboratory	Sex differences in light sensitivity, brightness perception and light preference: 62.5% of men preferred light at 6500 K (blue-enriched) while for 87.5% women, light at 2500 K (non-blue-enriched) was favored; blue-enriched light significantly improved men's attention performance; men had higher brightness perception and faster reaction times in a blue-enriched light than non-blue-enriched
Cirincione, Macaluso, Mosca, Scaccianoce, and Costanzo (2018) and Gennusa et al. (2017)	Palermo, Italy	Laboratory experiment and questionnaire survey; light exposure of five different types of LED lamps and the humans' non-image-forming reactions; $n = 20$	Laboratory	Subjective/individual aspects of why different light colors are preferred for lighting (i.e., Color rendering of warm white sources are preferred)

(continued)

**Table 9.3** (continued)

Study	Place	Procedure/data	Building typology	Findings (cited from the respective literature)
Knez and Kers (2000)	Sweden	Laboratory experiment; light exposure of three different lamps: 'Warm' white lighting (3000 K), 'cool' white lighting (4000 K), artificial 'daylight' white lighting (5500 K); $n = 108$ (females = 54, males = 54)	Laboratory	Females perceived the room light, across all light settings, as more expressive than did males; males performed best in the 'warm' and 'cool' white lighting, and females performed better than men in the artificial 'daylight' white lighting
Knez (2001)	Sweden	Laboratory experiment; light exposure and tasks to memory and problem solving skills; $n = 108$ (females = 54, males = 54)	Laboratory	Interaction effects between color of light and gender on long-term memory showed that males performed best in the 'warm' and 'cool' white lighting, and that women performed better than men in the artificial 'daylight' white lighting.

likely to turn on the lights when they felt warm or cold, compared to neutral (Andersen et al., 2009).

The effect of artificial light on humans is known in medicine as increased health risk (e.g., permanent exposure to artificial light, night shift work, etc.), but is also used in reverse in some medical treatment methods (i.e., light therapy; blue light therapy in newborns to prevent newborn jaundice, or therapy for skin diseases such as neurodermatitis, psoriasis, or acne). This suggests that there is a close connection between comfort criteria and health and that significant differences between the sexes should not be neglected.

### 9.3.1.3 Other Comfort Criteria, Corresponding Aspects, and Health

In addition to thermal comfort, lighting and daylight, air quality, humidity, and acoustics are essential comfort criteria. However, very little research has been done into the interaction between different comfort criteria, although this is just as important. Table 9.4 shows an overview of relevant studies.

**Table 9.4** Overview of studies that investigated other comfort criteria, corresponding aspects, health and gender differences (listed in alphabetical order)

Study	Place	Procedure/data	Building typology	Findings (cited from the respective literature)
Andargie and Azar (2019)	Abu Dhabi, UAE	Environmental measurements and questionnaire survey; university campus; <i>n</i> = 156, (building A: 76.8% male +23.2% female; building B: 49.5% male, 50.5% female)	Educational buildings	Gender was found to be a significant driver of satisfaction with air quality, reported happiness, reported productivity, as well as measured productivity; gender shows a significant relationship with the reported levels of difficulty concentrating as well as the cognitive metrics of the performance test (e.g., number of questions answered)
Bae et al. (2020)	Minnesota, USA	Questionnaire survey; 30 workplace buildings across eight years (2009–2017); <i>n</i> = 2275	Office buildings	Male occupants have a greater tendency to be satisfied with thermal conditions, acoustic conditions, electric lighting, and privacy than female occupants; the biggest gaps between male and female participant satisfaction scores were found related to adjustability of the thermal conditions, privacy- overall, temperature, and thermal conditions – Overall

(continued)

**Table 9.4** (continued)

Study	Place	Procedure/data	Building typology	Findings (cited from the respective literature)
Bajc and Milanović (2019)	Belgrade, Serbia	Environmental measurements and questionnaire survey	Office buildings	Men were more sensitive to the higher temperatures, preferring colder working environment, while women stated to feel more comfortable in slightly warmer environment; men were more tolerant to noise, while women were more sensitive to poor air quality
Bakke, Moen, Wieslander, and Norbäck (2007)	Bergen, Norway	Environmental measurements and questionnaire survey; blood samples, and objective assessment of indoor environment (temperature, air velocity, relative humidity, CO <sub>2</sub> , and dust); four educational buildings (refurbished university buildings); university staff and students; <i>n</i> = 173 (female = 92, male = 81)	Educational buildings	Gender was relevant to physical health symptoms associated with indoor environment factors; women reported more often symptoms (fatigue; feeling heavy-headed; difficulty concentrating; itching, burning, or irritation of the eyes; dry throat; and cough) and had more frequent complaints about the physical work environment (i.e., temperature too low, “stuffy air”, “dry” air) than did men; men and women perceived physical indoor environment factors differently

(continued)



**Table 9.4** (continued)

Study	Place	Procedure/data	Building typology	Findings (cited from the respective literature)
Brasche, Bullinger, Morfeld, Gebhardt, and Bischof (2001)	Germany	Questionnaire survey and data analysis; ergonomic data from German ProKlimA-project; 14 office buildings; <i>n</i> = 1464 (female = 888, male = 576)	Office buildings	Higher prevalence of sick building syndrome (SBS, symptoms affecting the skin, mucous membranes, and nervous system) in women, women suffer more SBS than men independent of physical environment, personal and most work-related factors (44.3% of women, and 26.2% of men); prevalence rates in women are related to professional education, number of persons per room, and job characteristics; women characterized by low professional education and unfavorable job characteristics report more frequent SBS-complaints
Kraus and Novakova (2019)	České Budějovice, Czechia	Questionnaire survey; institute of technology and business; students; <i>n</i> = 299, (female = 53, male = 246)	Educational buildings	Women express greater dissatisfaction with humidity comfort, visual comfort, color comfort, and total satisfaction

(continued)

**Table 9.4** (continued)

Study	Place	Procedure/data	Building typology	Findings (cited from the respective literature)
Jungsoo Kim et al. (2013)	North America	Literature review and data analysis; post-occupancy evaluation (POE) database from the Center for the Built Environment (CBE); $n = 38,257$ (females = 21,452, male = 16,805)	Office buildings, residential buildings and educational buildings	Females had lower satisfaction ratings than males on all 15 IEQ factors (including thermal comfort, air quality, lighting, acoustics, office layout & furnishings, and cleanliness & maintenance) addressed in POE questionnaire; noticeable gaps between females and males were registered on 'temperature' (9.4%), 'sound privacy' (7.5%) and 'air quality' (6.8%)
Lee, Park, and Jeong (2018)	South Korea	Questionnaire survey; 30 office buildings; $n = 240$ (female = 120, male = 120)	Office buildings	Differences exist between genders in noise and lighting satisfaction levels, sick building syndrome-(SBS) related symptoms (eye, nose, skin) and musculoskeletal disorder (MSD) complaints of hand/wrist/finger
Pellerin and Candas (2003)	France	Laboratory experiment; $n = 108$ (female = 54, male = 54)	Laboratory	Results showed that females accepted noisier environments than males, suggesting that thermal comfort is dominant for women

(continued)

**Table 9.4** (continued)

Study	Place	Procedure/data	Building typology	Findings (cited from the respective literature)
Pigliatile et al. (2020)	Perugia, Italy	Environmental measurements and tests (human response to thermal stimuli and physical environmental parameters, physiological signals, and subjective responses); $n = 62$ (winter sample = 34 + summer sample = 28)	Laboratory	Gender is affecting thermal perception and acoustic comfort
Recek et al. (2019)	Slovenia	Questionnaire survey; $n = 714$ , female = 621, male = 93)	Residential buildings	The self-perceived IEQ, might be influenced by gender, where male respondents might have perceived IEQ factors differently
Reynolds et al. (2001)	U. S. (Midwest)	Environmental measurements and questionnaire survey; six office buildings; $n = 368$ (females = 282, males = 86)	Office buildings	Higher proportion of females reporting work-related SBS symptoms
Yang and Moon (2019)	Seoul, South Korea	Laboratory experiment; students; $n = 60$ , (female = 30, male = 30)	Laboratory	Effects of multisensory interactions on acoustic comfort, thermal comfort, visual comfort, and indoor environmental comfort showed effects of gender and differences in the range of each physical factor

In a study in France, tolerance to noise was examined in parallel with thermal behavior (Pellerin & Candas, 2003). The respondents were able to choose between adopting the temperature or the noise level. The study authors came to interesting results: women are more tolerant of noise than men, but more critical of thermal aspects than men. A study from Belgrade (Bajc & Milanović, 2019) came to different conclusions: men were more tolerant to noise, while women were more sensitive to poor air quality. Nevertheless, that gender is not only affecting thermal perception, but also other comfort criteria like acoustic, humidity comfort, visual comfort, air quality or lighting, as confirmed in other studies (Bae et al., 2020; Jungsoo Kim et al., 2013; Kraus & Novakova, 2019; Pigliautile et al., 2020; Yang & Moon, 2019).

Studies that have not explicitly examined the aspect of gender show that thermal comfort dominates overall satisfaction with the indoor climate and, for example, is rated as more important than visual and acoustic comfort or good air quality (Frontczak & Wargocki, 2011; Rupp et al., 2015). Further, the dissatisfaction with the thermal environment leads to lower comfort expectations regarding other indoor environmental quality factors, and conversely increases expectations if the thermal environment is rated as satisfactory (Geng, Ji, Lin, & Zhu, 2017). Andargie and Azar (2019) found that gender was a significant driver of satisfaction with air quality, reported happiness, as well as measured productivity.

Other important and gender-relevant findings are related to health. Sick-building syndrome is more common among women than among men (Bakke et al., 2007; Brasche et al., 2001; Lee et al., 2018; Reynolds et al., 2001). A study in an office building in Japan also pointed out the connection with dissatisfaction with thermal comfort (Nakano et al., 2002).

In summary, the literature confirms that thermal comfort should be given a special priority over other comfort criteria, and this in turn has a high priority, especially for women, but also other aspects should be taken into account.

### ***9.3.2 Behavioral Aspects, Information, Knowledge, and Participation***

To achieve balanced interior qualities, behavioral aspects, information, knowledge, and participation are further points that should be considered differentiated according to aspects of gender. Table 9.5 provides an overview of relevant studies and results.

The results of an Austrian study on energy-efficient buildings (passive houses) indicate increased interest and greater concern among women about air quality (Haselsteiner et al., 2014). They ventilate more often, and are sensitive to poor air quality. Ventilation, or ensuring good air quality, is more often seen as a task by women. Accordingly, dissatisfaction is higher if it is not possible to produce sufficient air quality. The fact that women are more dissatisfied with the quality of air

**Table 9.5** Overview of IEQ studies that investigated behavioral aspects and gender differences (listed in alphabetical order)

Study	Place	Procedure/data	Building typology	Findings (cited from the respective literature)
Andersen et al. (2009)	Denmark	Questionnaire survey; $n = 933$ (summer survey) + $n = 636$ (winter survey)	Residential buildings	Females opened the window more often when they perceived the environment as bright while men were not affected by the illumination; likewise, the probability of women having the lighting on was higher when they felt warm or cold as compared with neutral, while the possibility for men that the light was turned on was higher when they felt cold or warm compared to neutral
Chen et al. (2020)	Brazil, Italy, Poland, Switzerland, United States (U. S.) and Taiwan	Questionnaire survey (human-building interaction in office spaces; energy use behavior and impacts of environmental control features accessibility); dataset from six countries; university staff and students; $n = 3472$	Office buildings	Women were less likely to choose a technological solution than men when feeling both too hot and cold; gender differences continue to emerge in group environmental control features (ECFs) operations; men might have the desire to act independently from others' opinions; whereas, women have a stronger desire to preserve group harmony, and thus tend to agree with the majority; additionally, some cultures expect women to be more submissive, and this gender stereotype may motivate women's tendencies to conform
Haselsteiner et al. (2014)	Austria	Questionnaire survey; $n = 225$ (female = 132, male = 70)	Office buildings, residential buildings and schools	Women ventilate more often and are sensitive to poor air quality

(continued)

**Table 9.5** (continued)

Study	Place	Procedure/data	Building typology	Findings (cited from the respective literature)
Indraganti, Ooka, and Rijal (2015)	Chennai and Hyderabad, India	Environmental measurements and questionnaire survey; 28 office buildings (13 mixed mode, 14 completely air-conditioned and one naturally ventilated building); datasets in total = 6048 (4 seasons); occupants; $n = 2787$	Office buildings	Women had slightly higher comfort temperature than men; more women exercised frequent control of windows; higher clothing insulation in female (0.63 clo) than male (0.53 clo); women accepted the thermal environments better than men
Karjalainen (2007)	Finland	Quantitative interview survey and laboratory experiment; controlled experiment to simulate real use of thermostats; students, $n = 68/152/80/60$ per test case; quantitative interview survey: $n = 3094$ (females = 1556, males = 1538)	Residential buildings, office buildings and educational buildings	Males use thermostats in households more often than females; difference between males and females is more remarkable in the office environment than the home environment

than men is particularly evident in studies of productivity in offices and schools (Indraganti et al., 2015; see Sect. 9.3.3).

Although women are more dissatisfied with the room temperature than men, they are less likely to use the thermostat to regulate the temperature (Chen et al., 2020). Fifty-one percent of respondents in a study in Finland state that men use the thermostat more frequently to regulate temperature, while only 31% of women do so (Karjalainen, 2007). The additional laboratory experiment showed that women would set higher temperatures than men with the thermostat. To exclude differences in clothing, the study points out that in Finland, clothing for men and women in offices is not a significant distinguishing feature (Karjalainen, 2007). Women have the feeling that they cannot control the room temperature, whereas the majority of men state that they know how the air conditioning and ventilation system works.

Gender-specific criteria for indoor environmental quality also relate to different information behavior, such as the prioritization of costs, or other decision criteria about energy-efficient construction methods, technologies, and their use. Different information behavior and knowledge aspects regarding the use of energy-efficient technology between women and men should be emphasized. Information behavior is largely shaped socially and culturally (Chen et al., 2020). It is much more relevant for women to obtain concrete application-oriented information, and they are less

interested in technical background information, i.e., on the topic of the Passive House (Haselsteiner, 2017).

As a result, participative approaches to achieve planned indoor environmental quality goals that include diversity aspects of user groups should be implemented more frequently. This requires an interdisciplinary approach and an integrated planning process that includes various technical disciplines.

### ***9.3.3 Productivity, Indoor Environmental Quality, and Gender***

Differences between men and women seem more remarkable in the office environment than in the home environment (Karjalainen, 2007; Jungsoo Kim et al., 2013; Rupp et al., 2019). Surprisingly, the relationship between temperature and cognitive performance has hardly been researched according to gender criteria. Table 9.6 summarizes some studies that examined IEQ and gender-specific effects in connection with productivity.

A large laboratory experiment, in which more than 500 individuals were asked to accomplish a set of cognitive tasks (math, verbal, and cognitive reflection), showed that the effects of temperature vary significantly across men and women: “At higher temperatures, women perform better on a math and verbal task while the reverse effect is observed for men. The increase in female performance in response to higher temperatures is significantly larger and more precisely estimated than the corresponding decrease in male performance. In contrast to math and verbal tasks, temperature has no impact on a measure of cognitive reflection for either gender.” (Chang & Kajackaite, 2019: 1). A study by Bajc and Milanović (2019) came to similar results: men in office environments were more sensitive to higher temperatures but more tolerant to noise, while women tolerated higher temperatures but were more sensitive to poor air quality. The higher sensitivity of women compared to men about IEQ, particularly thermal comfort and air quality, is also confirmed in other studies (Simone & Fajilla, 2019). Findings suggest that simple variations in room temperature have a marked impact on cognitive performance and that taking into account gender-specific considerations could increase productivity significantly.

Studies on whether thermal comfort is perceived differently in the workplace than in apartments show both differences due to the location and gender-specific differences. A quantitative survey was carried out among 3094 people (1556 women and 1538 men) in Finland, with questions about satisfaction with their home-related indoor climate, and another 1000 respondents about the indoor climate at work (Karjalainen, 2007). In a controlled experiment, it was also possible to adopt a fictitious room thermostat in a range from  $-2$  ( $-3$ ) to  $+2$  ( $+3$ ) °C. In addition to their preferences, the age and gender of the test subjects were also recorded. Both in the apartment and at the workplace, significant differences by gender were found in the quantitative survey using interviews: men were more satisfied with the room

**Table 9.6** Overview of studies that investigated productivity, indoor environmental quality, and gender (listed in alphabetical order)

Study	Place	Procedure/data	Building typology	Findings (cited from the respective literature)
Andargie and Azar (2019)	Abu Dhabi, UAE	Environmental measurements and questionnaire survey; university campus; $n = 156$ , (building A: 76.8% male +23.2% female; building B: 49.5% male, 50.5% female)	Educational buildings	Gender was found to be a significant driver of satisfaction with air quality, reported happiness, reported productivity, as well as measured productivity; gender shows a significant relationship with the reported levels of difficulty concentrating as well as the cognitive metrics of the performance test (e.g., number of questions answered)
Bajc and Milanović (2019)	Belgrade, Serbia	Environmental measurements and questionnaire survey	Office buildings	Men were more sensitive to the higher temperatures, preferring colder working environment, while women stated to feel more comfortable in slightly warmer environment; men were more tolerant to noise, while women were more sensitive to poor air quality
Chang and Kajackaite (2019)	Berlin, Germany	Laboratory experiment; math, verbal, and cognitive reflection tasks; students; $n = 543$ (female = 223, male = 320)	Laboratory	Effects of temperature vary significantly across men and women; females generally exhibit better cognitive performance at the warmer end of the temperature distribution, while men do better at colder temperatures
Simone and Fajilla (2019)	Calabria, Italy	Questionnaire survey; university; $n = 253$ , (female = 119, male = 134)	Educational buildings	Men showed higher perceived productivity than women do in all indoor conditions; male workers present mostly low values for temperature, air quality, and artificial lighting; female employees were more satisfied with artificial lighting but unsatisfied for acoustics condition

temperature in offices than women in both winter and summer. Yet, women rate summer temperatures at home better than men (Karjalainen, 2007).

This literature review has shown that there are only a few studies that examine the effect of temperature and cognitive performance by gender. Further research that takes overlapping effects into account or investigates the linking of cognitive



performance and potential heterogeneous effects across gender along with other confounding variables (i.e., age, professional position, working hours, design of the workplace, air conditioning, or natural ventilation) would be particularly important.

## 9.4 Conclusion

In this chapter, an explorative literature review was carried out to describe particularly gender-relevant aspects in all indoor environmental qualities. The results showed that: (1) thermal comfort, in particular, is an essential parameter, and differences of up to 3 °C between women and men were measured; (2) Studies that investigated light sensitivity revealed gender differences in brightness perception and light preference; (3) Gender was found to be also an influencing factor of satisfaction with air quality, humidity, acoustic conditions, visual comfort, privacy, and health aspects; (4) Different levels of satisfaction with IEQ are probably decisive for a differentiated ventilation behavior determined by gender and different application of thermal control features; (5) Gender differences in thermal comfort become particularly relevant when it comes to requirements and cognitive performance at the workplace. Women perform better cognitively in a warmer environment, while men do better in colder temperatures, yet women are more affected by poor air quality. Considering that essential IEQ parameters vary significantly across men and women, these aspects should receive more attention.

The results' consistency makes clear that women perceive indoor qualities, such as air quality, thermal comfort or lighting, differently than men. Hence, people should be the focus of attention and their individual needs should be taken seriously. The fact that women suffer more from sick building syndrome than men, is attributed to the fact that they suffer more from what they perceive as poor thermal comfort, which ultimately highlights the urgency for increased research in this field.

So far, a deeper segmentation according to social aspects has not been explored, nor has the explicit focus on gender aspects, gender mainstreaming, and gender equality as an integral part of planning and an energy-efficient building concept. Besides, further differentiations according to various diversity dimensions in connection with gender, such as age, origin, disability, economic conditions, etc., have so far hardly been investigated.

Even if the proportion of women in technical and male-dominated professions is increasing, women can only be found occasionally, for example, in training as a system technician for heating, air conditioning, and ventilation. Likewise, there are very few women in technical planning offices, or in the development of technical products and components for building technology. This results in a very male-dominated understanding of the functionality and application of these technologies. Aspects of gender and diversity-specific considerations should, however, be firmly anchored in different sustainability standards and IEQ assessments. More women employed in building technology and technological development and planning

would ultimately contribute to sensitize practitioners and the construction industry to all the above mentioned comfort, as well as health and well-being issues.

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# Chapter 10

## Climatic, Cultural, Behavioural and Technical Influences on the Indoor Environment Quality and Their Relevance for a Regenerative Future



Edeltraud Haselsteiner, Marielle Ferreira Silva, and Željka Kordej-De Villa

**Abstract** Research about indoor comfort in future years will increasingly be guided by the pressing need for decarbonizing the built environment due to climate change. Health, efficiency, and satisfaction of work and the feeling of comfort are largely determined by the interior criteria. The sustainable indoor environment is a result of complex factors: air conditioning (ventilation), indoor temperature, heating methods, lighting, and acoustic. This chapter explores and analyzes climatic, cultural, and behavioral factors that play an important role and have an influence on technology for an indoor regenerative environment. This chapter is based on an explorative literature review and reflects indoor environmental quality, users' expectations, and users' behavior from the perspective of different scientific disciplines. Current standards are based on a rational approach to thermal comfort, and indicators are determined on the measured subjects' reactions during stabilized conditions in climatic chambers. It is concluded from these results that people in different environmental conditions react similarly to everyday life. Nevertheless, survey results suggest that achieving the optimal level of the indoor environment is possible when climatic, cultural, and social context is taken into account.

**Keywords** Thermal comfort · Individual sensitivity and behavior · Indoor regenerative environment · Regenerative sustainability

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## 10.1 Introduction

The definition of comfort and its importance is complex and will differ when regarded from various fields like social sciences, engineering, architecture, cultural anthropology, physiology, or psychology. The perception of comfort has progressed throughout history and is based on several technological, economic, social, and cultural influences. In the nineteenth century, the term was initially applied to refer to environmental comfort linked to heat, ventilation, and light (Brager & de Dear, 2003; Rybczynski, 1986). This manner overrides the intricacy of comfort and all cultural and background factors. In reaction to conventional notions of comfort, it is proposed that it should be fluid, that is, adaptable to different possibilities, contested, and controversial, containing responses beyond energy and the environment matters (Chappells & Shove, 2005). Nowadays, comfort is related to physical and thermal well-being and satisfaction (Brager & de Dear, 2003; Rybczynski, 1986).

The indoor climate satisfaction and thermal comfort are the results of a balancing process between the physical environment and subjective comfort expectations. Reactions and behavior are based on experience. Thus, individual requirements and occupants' satisfaction are strongly sociocultural consignable constructs (Chappells & Shove, 2005; Luo et al., 2016). The indoor climate is perceived individually, and the requirements are subjectively shaped. Various studies show different preferences for a comfortable indoor climate according to the origin, climate, behavioral and cultural context, and individually subjective criteria. In particular, thermal comfort depends on other parameters than physical ones. The psychological and physiological human body responds to the environment dynamically, integrating many physical phenomena as light, noise, vibration, temperature, humidity, and others (Rupp, Vásquez, & Lamberts, 2015).

Comfort is primarily about determining ranges and their requirements, objectives, and relevances considered appropriate which are expressed in standards for particular types and uses of buildings (Cole et al., 2008). Many organizations, such as the European Committee for Standardization (CEN), the International Organization for Standardization (ISO), the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE), have each published documents setting out these guidelines in detail (Boduch & Fincher, 2009). In addition, comfort standards will be perceived by professionals in the specific project context and the customer requirements that collectively and individually create the environment for building occupants and operators. Research studies show that psychological necessities are addressed in the planning and control strategies (Cole et al., 2008; Metz, Davidson, Bosch, Dave, & Meyer, 2007; Owen, Frankel, & Turner, 2007). Behavioral features of comfort are often overlooked, apart from those that fit into physiological or psychological categories (clothing, personal control, and activity level) (Cole et al., 2008).

The use of technology in construction has allowed a significant increase in comfort and the construction of energy-efficient buildings. Prior to this development of complex indoor air conditioning technologies (heating, cooling, and ventilation), it



was essential to build buildings in close alignment with the location and the regional climate, using building materials and construction techniques available locally, and construct within the individual behavioral context of use. Today, we have increasingly moved away from this awareness, both with our knowledge and with our craft. Buildings can be constructed according to any comfort standards, without regard to external climatic conditions and regional location factors, purely through technological solutions. However, about 70% of the buildings' final energy consumption is due to lighting and air-conditioned systems. The high air conditioning energy consumption is mainly caused by invariable regulation of the inside temperature without taking the building location and outside temperatures into account (Rupp et al., 2015).

Achieving the optimal level of the indoor environment is possible when the climatic, cultural, and individual behavioral context is taken into account. This chapter explores and analyzes climatic, cultural, and behavioral factors that play an essential position and have an influence on technology for an indoor regenerative environment. Climate is a defining variable that influences culture, design of buildings, and people's behavior. These, in turn, are related to adapting or responding to the indoor climate. The chapter is based on an explorative literature review and reflects indoor environmental quality, users' expectations, and users' behavior from the perspective of different scientific disciplines. Electronic databases were used for literature research (Google Scholar and ScienceDirect). Firstly, papers were analyzed that had already carried out a comprehensive literature study on the subject (i.e., Frontczak & Wargocki, 2011; Ortiz, Kurvers, & Bluysen, 2017; Rupp et al., 2015). Additionally, the method "reference by reference" was used to include the findings from further literature. As a consequence, this chapter is organized into three main sections. Section 10.2 gives an explanation and definition of restorative and regenerative sustainability and a compilation of literature that presents information about climate, cultural, and technological aspects related to human comfort. Section 10.3 discusses the documents retained from the literature search and proposes criteria for regenerative indoor environment quality. In this way, this chapter provides a new contextual insight to reconsider and rethink the aspects and criteria that influence human comfort in a wider and comprehensive perspective.

## **10.2 Relationship Between Climate, Technology, and Cultural Aspects and the Comfort Criteria**

The objective of this section is to evaluate and summarize climatic, cultural, and technical factors that may indicate individual differences in the perception and evaluation of indoor environmental quality (IEQ). Based on the results, we discuss possible contributions to development toward regenerative sustainability. The following sections describe results from an exploratory literature review. In the last section, these results are discussed in terms of regenerative sustainability goals.

### 10.2.1 Comfort Criteria in the Light of Sustainability Goals

Comfort research in the coming years will be increasingly pushed by climate change and the growing need for decarbonizing the constructed environment. The search for greater buildings’ energy efficiency is driving technological development (de Dear et al., 2013). Following this trend, questions and innovations in the design of comfortable interiors are becoming progressively prominent. On the other hand, essential components on the way to solving climate change problems are urgently needed. The gap between high demands for comfort and demands for more efficient lifestyles is becoming increasingly evident.

Several definitions of sustainability are being used today, which may transmit the idea of a state in which the human beings live within the Earth’s carrying capacity (Gibberd, 2003). Consequently, any debate on sustainability encompasses the continuous interaction between the human and natural processes. The conceptual base of the Millennium Ecosystem Assessment is, for instance, that humans are an inherent element of ecosystems and that a dynamic interaction between them exists, with the shifting human condition promoting, either indirectly or directly, transformations in ecosystems and thus leading to changes in human well-being (Cole, 2012).

While sustainability is defined as a strategy not to harm future generations, restorative and regenerative sustainability thinks one step more consistently toward restoring a social, ecological, and healthy balance of the environment (Brown et al., 2018). Restorative and regenerative sustainability implies considerations with the location of a building, that is, the climatic, geological, and vegetative environmental factors and also with people, their traditions, and social and cultural habits. Figure 10.1 shows the emergence of essential sustainability concepts in the direction of development toward regenerative sustainability.

Starting with the Brundtland definition of sustainability in 1987, developments followed by numerous sustainability standards (BREEAM, LEED, DGNB, WELL BUILD, RED LIST MATERIALS) and sustainability concepts (e.g., Cradle to

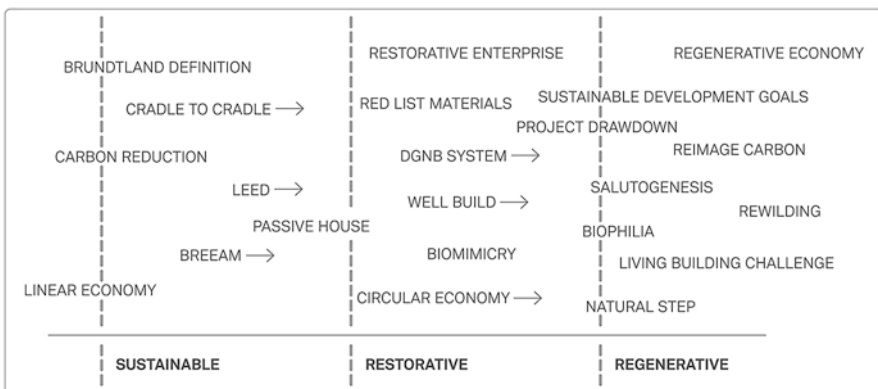


Fig. 10.1 Sustainability, restorative to regenerative (reproduced from Brown et al., 2018)

Cradle, Passive House, Biomimicry). In order to transfer this development to regenerative sustainability in the next step, the change from a linear, growth-oriented economy to a circular economy is essential. In addition, there is a need to shift sustainability concepts from isolated orientated energy efficiency goals toward goals in harmony with nature (e.g., biophilia, salutogenesis, and rewilding). While sustainability standards for IEQ are based on a complex interplay of technical components for energy production, ventilation, heating, and cooling, regenerative sustainability relies substantially on an interplay with natural resources and people.

### ***10.2.2 Indoor Environmental Quality in a Climatic and Cultural Context***

Climate is a defining variable that influences culture, design of buildings, and people's behavior (Luo et al., 2016; Nicol & Humphreys, 2002; Rupp et al., 2015; Zhang, Cao, Wang, Zhu, & Lin, 2017). Although comfort is usually identified with thermal comfort, it also includes air quality, humidity, light, and acoustics. The interaction between thermal comfort and other indoor climate criteria, and how this affects the general satisfaction of residents, was only addressed in a few studies. The research results exhibit that thermal comfort dominates satisfaction with the indoor climate (Frontczak & Wargocki, 2011; Rupp et al., 2015). Thermal comfort is more often rated as critical by residents than acoustic and visual comfort, and high air quality. People who are satisfied with the indoor temperature also rate other indoor qualities, such as air quality and humidity, better (Humphreys, Nicol, & McCartney, 2002). When thermal conditions were inadequate, they diminished the comfort prospect for other indoor environmental quality (IEQ) factors. On contrary, when the thermal conditions were adequate, they raised comfort satisfaction of other IEQ features, which could lower the assessment of the actual compliance of other IEQ features retroactively (Geng, Ji, Lin, & Zhu, 2017). Outcomes from the literature, therefore, suggest that thermal comfort should be given a particular priority over other comfort criteria.

Current standards are based on a rational approach to thermal comfort, and indicators are established regarding the reactions of determined subjects under stable conditions in climate chambers. It is concluded from these results that people in different environmental conditions react similarly to everyday life. Often, however, these values are not confirmed in field studies. Nicol and Humphreys (1973) claim that this might be the consequence of result among the respondents' well-being and their behavior adapting to the atmospheric situation where the field study was performed. Since thermal comfort is first and foremost subjectively rated and perceived, they propose an adaptive approach, largely based on field studies in naturally aerated buildings. The adaptive approach is founded on the behavior of humans to adapt to changing conditions in their environment. Thermal comfort stands in the context of three essential variables: first, the climate; second, the building with its

services; and third, the time in which users respond to changing conditions. Indoor temperatures should be in accordance with the change in outdoor temperature. Thus, local outdoor climate should be respected (Nicol & Humphreys, 2002). Based on Rupp et al. (2015), the adaptive model is supported by three mutually connected elements: psychological (comfort expectation related to external and internal temperature), physiological (acclimatization), and behavioral (opening windows, and the use of blinds, fans, and doors).

Acclimatization can result from personal adjustment (behavior, selection of clothes and activities, reallocation), technological modification (using shades or windows, heating or fans), cultural acclimation (implementation of daily activities, dress codes), and climate conditions (Medved, Arkar, & Domjan, 2019). The reaction to an incentive, as well as the range of possible changes (in clothing, daily activities, etc.), will depend on social factors. Social restrictions effect is to limit number of control options available and therefore restrict the wholeness of the control gained (Nicol & Humphreys, 1973).

Although current country-specific comparisons show that thermal expectations are converging to a winter neutral residential temperature of around 21 °C, there are still significant differences (Luo et al., 2016). Even if these countries are within the same temperature zones, studies have shown that satisfaction with thermal comfort varies significantly from country to country (Zhang et al., 2017). As an explanation for this, the technical equipment is taken into account (e.g., different heating systems), but behavioral and cultural influences are also claimed. While these differences are difficult to pinpoint based on concrete scientific results or have only been investigated in a few studies to date, there are plausible explanations for cultural and climatic adjustments. First, a behavioral adjustment, such as clothing: due to outside temperatures or cultural reasons, clothing that is better insulated against cold or heat is preferred or common. Likewise, the use of individual devices to regulate thermal comfort, for example, the use of fans in warm regions or electric blankets in cool countries. Second, long-term adaptation is inferred. On one hand, physiological differences between ethnic groups are mentioned, but also different psychological ways of thermal adaptation. For example, Zhang et al. (2017) show that the quality of insulation through clothing is considerably higher in Asia (China) compared to North America and Europe. This results in a much higher acceptance of temperatures under common comfort standards. In addition, they also provide a physiological explanation: “On the basis of heat balance, lower indoor temperature leads to more human body heat loss, which makes Chinese to wear more clothes to keep warm” (Zhang et al., 2017: 213). In addition, many research studies show that Chinese/Asians have lower basal metabolic rate than Westerns/whites (Wouters-Adriaens & Westerterp, 2008; Qi et al. 2014).

In general, people try to prevent discomfort, and therefore, they always strive (intentionally or unintentionally) to modify their current condition to more neutral or comfortable state. Consequently, many measures are aimed at health welfare (Ortiz et al., 2017). Accordingly, one should refer to well-being rather than comfort, which also includes health aspects such as stress reduction or health-promoting aspects.

### ***10.2.3 Influence of Technology on Comfort Criteria and Regenerative Sustainability***

Technologies for energy conversion can affect how buildings were built to protect people from harsh environmental constraints. The internal comfort evaluation usually oriented to several physical parameters that impact how people perceive the indoor environment based on their psychological and physiological characteristics. Indoor air quality, lighting, acoustic, and thermal comfort aspects must ensure the indoor environment quality with the minimum possible energy use (Medved et al., 2019). In the context of global warming, an adequate prediction of the built environment provides occupants a comfortable thermal sensation, and further specifies the building's cooling and heating loads (Nguyen, Singh, & Reiter, 2012).

Standards of thermal comfort are necessary to support architects and engineers in defining an internal environment in that significant percentage of the occupants of the building can experience thermal comfort. Occupants in warm climates in buildings with natural ventilation often adapt to weather variations, changing their attitude and regulating their preferences and expectations (Nguyen & Reiter, 2014). Knowing this, the incorporation of the concept of adaptive thermal comfort into the standards makes it possible to adopt different energy efficiency approaches and respond consistently to the demands of sustainable development (Nguyen et al., 2012). In addition, the adaptive comfort approach has emerged to enlighten people's mechanisms to adapt to the immediate environment and to offer an additional methodology for assessing various thermal ambiances and situations (Nguyen & Reiter, 2014).

Therefore, environmental adjustment using technologies is the way occupants interact with buildings, that is, switches, shutters, windows, and other controls. People who operate these mechanisms and experience temperature discomfort may affect the use of energy if systems of the building are not efficiently operated (Azizi, Wilkinson, & Fassman, 2015). The priorities of the project are framed by the predominant model and value system of the cultural and social environment where it emerges. In the same way, the technologies implemented by society express their culture and the way they perceive and involve themselves with natural systems. The degree to which environmental concerns are accentuated in the designing of buildings is also driven by direct social issues following significant events, including uncertainty or economic instability (Cole, 2012). People are affected by climate in many ways, and these are related to adapting or responding to the indoor climate.

The complete building design process demands that the responsible team – architect, engineers (mechanical and electrical), and other developers, and the owners and residents – collaborate to define and implement energy goals (Torcellini & Crawley, 2006). The house design allows users to control comfort in different manners: by using large open-air spaces (taking advantage of or avoid the predominant season winds), considering natural ventilation by capturing and controlling the wind through blinds (direct winds) and directional frames (crosswinds), and by night purges (windows that allow warm air without compromising safety) (Miller &

Buys, 2012). Heating, ventilation, and air conditioning (HVAC) system dimensioning addressing these reduced loads (Torcellini & Crawley, 2006). The lighting is linked to the high demand for electricity, which can be reduced by intelligently adapting the lighting to daylight (Medved et al., 2019), such as daylight implementation with automated controls when available and in dim light, or even better, switching off the lights (Torcellini & Crawley, 2006). The inclusion of a number of possibilities in the design enables higher customization to suit personalized comfort needs. This also points to the fact that “operation manuals” need to be included with homes so that residents can learn how to “run” the house to reach their designed efficiency ratings (Miller & Buys, 2012; Torcellini & Crawley, 2006).

Concerning the implementation of technologies and strategies, barriers for better building performances are identified. Sustainable technologies are desirable from the societal perspective because of their performance in relation to traditional solutions, although they can be unsatisfactory from the viewpoint of an individual company, which may have contradictory goals (Nelms, Alan, & Lence, 2005). The deployment of green features for real estate proposal has to face several obstacles that conventional construction does not face, like higher design costs for green devices and energy-saving material in the design phase, long process of planning and approval of new recycled materials and green technologies, and absence of acquaintance with green technologies causing design and construction delays (Zhang, Platten, & Shen, 2011). Furthermore, the effects of technological developments can be simultaneously challenging and complex to measure (Nelms et al., 2005). In order to comprehend and have a more amplified and real perspective of the situation, it is essential to clarify the connection among the local culture and its technology applied in a specific context to achieve human comfort.

#### ***10.2.4 The Role of Culture and Local Context, in Understanding Technology and Comfort***

Proper technology solutions can promote a shift in building design to “more regenerative.” The choice of adequate technology has to be based on assessment within the whole policy process which is affected by the local situation. The prerequisite for efficient transfer of technologies is a comprehension of a local culture. It must be recognized that the existing built environment represents an important part of local variety, values, and background. A European approach is characterized by robust public policies and state intervention in the areas of cultural heritage, built environment, and “green” topics (Kohler, 2003).

There is a prevailing consensus that the introduction of new solutions into another region with different settings is often compromised (Cole & Lorch, 2003). In addition, solutions that are different from user expectations usually compromise the objective of creating an environmentally advanced construction. Dealing with these concerns is the real challenge for professionals who have to govern behavioral and

cultural change to support adequate levels of comfort which also include environmental issues.

Recent research shows that one of the most important limiting factors is the inability to articulate and understand the backgrounds of local anticipations, social and cultural values, and lifestyle (Cole & Lorch, 2003; Shields, 2003; Wu, Fan, & Chen, 2015). The built environment can be considered as the expression of human preferences and creativity. It mirrors the expertise and priorities of its authors. According to Cole and Lorch (2003), an essential prerequisite for the development of green construction practices is the creation of competences that can modify international information to regional context. That includes cultural needs, habits, standard of living, and lifestyle, along with local weather, technologies, and materials. Therefore, ensuring the success of green buildings may require a transition time in which new training and education, together with reassessment and adaptation to changing settings, will be crucial (Cole & Lorch, 2003: 15).

According to Leaman (2003), behaviors are culturally dependent. They reflect our attitudes to different aspects of life, but at the same time, they are also affected by regulations and different norms. Recently, building-related health standards have been changed drastically, and therefore conditions which were accepted a decade ago are now intolerable.

There are different behaviors of building users in a residential and commercial buildings. Occupants of a residential building have a higher level of influence, and they show their comfort preferences more freely. Occupants of commercial buildings rarely feel such level of control of their working environment. Besides, it is noticed that occupants of commercial buildings who experience more control can also feel a higher level of comfort. Therefore, it is widely accepted that provision and perception of comfort depend on the local context (Ackerman, 2002; Cooper, 1998; Crowley, 2001).

Today, it is essential to recognize additional features in defining the comfort. Climate change is one of them. The construction sector has been detected as a main probable actor to attenuate the climate change (Metz et al., 2007; Ürge-Vorsatz et al. 2007a, b). This will substantially influence the conventional attitudes to comfort. Depending on the approaches implemented, it offers additional incentives to reformulate and widen the range of what occupants experience as adequate indoor environments. To consider the relationships between occupants and between occupants and built environment, the whole process should be integrative, participatory, and interactive in its nature. This is contrary to the conventional approach which is predominantly linear and predictable.

### 10.3 Discussion and Conclusion: Criteria for Regenerative Indoor Environment Quality

This chapter opens a discussion about aspects related to climatic, cultural, technology, and individual behavioral factors that can influence the indoor regenerative environment. Because of this, in order to have a more realistic development and acceptance by the occupants, the culture and local context should be taken into consideration, including social criteria implanted into the operational process.

The behavioral component of comfort considers the interactions between occupants and contains questions of the vicinity of working places and feeling of places, the position related to open and closed offices that reflect potential for isolation or contacts, sense of mutual programs, and so on. Moreover, social comfort relates to the experience of comfort mutual perceptions. This means that the full range of individual factors is taken into account.

A body of research has examined thermal comfort requirements and highlighted interlinkages with cultural and climatic conditions (i.e., Luo et al., 2016; Zhang et al., 2017). Cultural adaptation has to be taken into account, but also individual expectations and country-specific acceptance and adaptation behavior. Comparisons between different climatic zones highlight the connection between external climate and the internal environment as a significant factor (Yan and Hao 2017; Zhang et al., 2017). However, looking at IEQ from the perspective of regenerative sustainability, the required adaptation to climate, culture, and the local context is even more essential (Brown et al., 2018). Energy efficiency is still the dominant element of sustainability standards, that are partial and missing an integral scheme that takes into consideration the behavioral, cultural, and local context.

Ortiz et al. (2017) describe comfort as a response to environmental factors that is affected by cognitive and behavioral notions. We widely agree with this statement and its conclusion, but we would suggest adding the behavioral, cultural, and climatic component of comfort. In order to address the multiple facets of comfort, we must move from the conventional practice to one that aims for interactive adaptability that allows the system to address changing needs over time (Kamholz & Storer, 2009). Furthermore, a regenerative approach asks about the relationship with nature, local resources, and the social context (Brown et al., 2018).

One path in which the construction sector is incentivizing the implementation of sustainable design concepts is the substitution of traditional technologies with those that have a smaller health, ecological, and environmental impact. Technology deployment must be founded on a comprehensive understanding and appropriate assessment of the complete scope of repercussions and project milieu associated to it, from an environmental, social, economic, and technical perspective (e.g., climatic condition, programmatic requirements, and building type). The performance of the technology in one region may differ from accomplishment in other settings (Nelms et al., 2005). In relation to technology, Labuschagne and Brent (2006) concluded that a methodology of quantitative social effect evaluation can still not be implemented for life cycle management and technology reasons. It is suggested that



social sustainability should be embedded in the management of project and technology life cycle through the guidelines and checklists provided in Table 10.1, including also the descriptions of the standards at the respective structure levels (Labuschagne et al., 2005).

**Table 10.1** Definitions of social criteria (adapted from Labuschagne, Brent, & van Erck, 2005; Labuschagne & Brent, 2006)

<b>Internal human resources</b> Social responsibility of the company toward its workforce including employment aspects	Employment stability	A business initiative's impact on work opportunities: the stability as well as evaluating the fairness of compensation
	Employment practices	Evaluation of disciplinary and secrecy practices, employee contracts to comply with the laws of the country, human rights declarations as well as fair employment practice standards
	Health and safety	Evaluates preventive measures as well as the occurrence and handling of health and/or safety incidents
	Capacity development	Career development and higher-education opportunities focus on the training of employees – evaluation of the company's contribution to sustainable product development
<b>External population</b> External impacts of the company on society, for example, availability of services, community cohesion, and economic welfare	Human capital	Individual's ability to generate an income and encompasses aspects such as health, psychological wellbeing, education training, and skills levels
	Productive capital	Measures and entails the resources and infrastructure an individual need in order to maintain a productive life
	Community capital	The effect of an operational initiative on the social and institutional relationships and networks of trust, reciprocity, and support of typical characteristics of the community
<b>Macro social performance</b> Organization contribution to the environmental and financial performance for society	Socio-economic performance	Addresses the external economic impact, for example, economic welfare (contribution to GDP, taxes, etc.) as well as trading opportunities (contribution to foreign currency savings, exports, etc.).
	Socio-environmental performance	Contribution to the improvement of the environment for society on a community, regional, and national level. Environmental monitoring abilities of society, as well as the enhancement of legislation and the enforcement thereof
<b>Stakeholder participation</b> Relationships between the company and stakeholders	Information provisioning	The quantity and quality of information shared with stakeholders are measured
	Stakeholder influence	Evaluation of the degree of stakeholder influence on the decision-making

Regenerative sustainability is based on the regenerative abilities of nature and humans. Bottom-up approaches that empower diverse sectors and societal interests could contribute to a broader understanding of well-being. In order to achieve goals of restorative sustainability, according to the literature reviewed in this chapter, the view of comfort must be expanded in a way to include notions of standards required for energy efficiency as well as to comprise possible interactions and differences among people. As a result, there is a potential to change the way buildings should be designed, exploring the comfort design to be friendly to the occupants, environmentally friendly, aesthetically pleasing, and economically responsible since different climatic, behavioral, and cultural aspects are taken into account beyond the IEQ references.

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# Chapter 11

## Textile as Material in Human Built Environment Interaction



Preben Hansen, Vesna Grujoska, and Milica Jovanoska

**Abstract** As human population grows in number, the amount of (organic and non-organic) waste materials has grown rapidly year by year.

Changes of consumption and lifestyle have generated a higher waste amount. Waste management has become a significant issue in today's society. In 2014, the EU countries registered 2.494 million tons of generated waste, which was an increase in growth of 2.8% compared with data from 2008. Different renewable materials are ending up as waste, such as glass, paper, plastic, textile, which may be used in a recycling process. This chapter will discuss these challenges with the focus on one of these materials, textiles, as building materials.

We also introduce the perspective of Human-Computer Interaction (HCI) aspects, and especially Human-Built Environment Interaction which will give some specific focus on textiles used as recycled materials. The result of the critical literature review in the area of textiles as building material from an HCI point of view suggest a set of interaction design dimensions that can be considered and applied on the usage of textiles for built environments.

**Keywords** Smart textile materials · Insulation · Human-building interaction · Regenerative · Recycled materials

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## 11.1 Introduction

Societal and human concerns about environmental impacts of building practices and materials have been expressed through a growing demand, production, and use of “green” building products (Corcadden, Biggs & Stiles, 2014). At the same time, there is a strong movement in Europe to explore how to integrate natural resources with bioproducts and renewable resources into different industries. For example, bio-design products are one emerging area (Wang, Luo, Liu, Lu, & Hansen, 2017) that may guide humans in changing behaviors for a more engaging lifestyle. Moreover, the building and construction sector is concerned with different materials in order to materialize an engineering idea or model. When it comes to the ecological impact of the production processes of recycled textiles, some countries have a greater demand of different types of textiles compared to others. Part of this demand is based on new implemented top-down regulations, laws, and policies, another part is due to some changes in the business environmental codes (H&M, 2019) and yet another part emerged from bottom-up through people changing their behavior (Parviainen, Lagerström, & Hansen, 2017). Different types of textile materials are, on an everyday basis, discarded and are increasingly considered when it comes to how to recycle, reuse, and use textiles for extensions, additions, and substitutions in different contexts.

The public acceptance and market penetration of the environmentally certified buildings, such as BRE Environmental Assessment Method (BREEAM) and Leadership in Energy and Environmental Design (LEED) is growing, for example, in Stockholm, Sweden. This can be shown through the growth of the environmental awareness of the consumers that are willing to pay more for a green certificate. This process is followed by lots of international, national, regional, and local initiatives and future strategies. Sustainable development is the overall goal of the Organization for Economic Co-operation and Development (OECD) that developed the Green Growth Strategy (OECD Green growth and sustainable development, 2019). The City of Stockholm adopted its first environmental program in 1976 (The Stockholm Environment Program, 2016). Since then, a line of programs has been developed. The environmental program for 2016–2019 is the ninth environmental program and one of the reasons why Stockholm is one of the leading green capitals in Europe regarding sustainability moving in this direction in both governmental, public, and business environments.

For the development of sustainability, Swedish authorities have developed and also adopted the Environmental Code (The Swedish Environmental Code, 2000). This code represents modernized, broadened, and more stringent environmental legislation. The main objectives that this Environmental Code is regulating are: human health; natural and cultural environments; biodiversity; use of land, water, and the physical environment; and the reuse and recycling, as well as other management of materials, raw materials, and energy, of which the last part is of interest to this chapter.

The aim of this chapter is to introduce some fundamentals from the areas of build environments, especially considering textiles as building material, and, on the other hand, general aspects from the Human-Computer Interaction (HCI) discussing the potential of a new emerging research field of Human-Built Environment Interaction, with the focus especially on using textiles as building material.

The chapter first gives a brief overview of production, recycling, and reuse of textiles, followed by a section concentrating on the issues how textiles could be used as building material. Examples of wool and cotton are given. The final section then introduces an emerging research field within HCI, dealing with how people interact with built environments.

## 11.2 Methodology

From a methodological perspective, this chapter is based on a critical literature review. This involves selecting and filtering a set of papers and articles in order to perform a literature in the field(s), but choosing a representative set, and thus, it will not cover entire fields of practices or research. The area scoped out provides first with a literature overview on textiles as material and some of its relevant conditions, especially when considered within the built environment. Finally, the Human Built Environment Interaction is presented. This is followed by introducing its possible application in HCI as an emerging research area, especially focusing on the interaction with built environments. The subarea of human-interaction with textiles and built environments is considered, as an emerging and challenging area.

## 11.3 Textiles: Production, Recycling, and Reuse

In our society, textiles are fundamental, not only providing us with clothing and footwear, but also as components in our homes through carpets, curtains, and furniture. Furthermore, textiles are used in our workplaces, in public transportation, in public urban places, and buildings. The downside is that the textile production, usage, and consumption have a large environmental and climatic impact by using natural resources and chemicals.

According to European Environment Agency (EEA), Europeans are consuming on average 26 kg of textiles per person per year (EEA, 2019). In this report, it is highlighted that EU citizens and consumers discard around 11 kg of textiles per person and per year. The amount of discarded textiles, textile waste, is mostly exported as used clothes, mainly to eastern European countries, Asia, and Africa. This is an increasing activity. Used clothes not exported are mostly incinerated or landfilled. This means that the recycling rate of textiles is low. At least 50% of the material that ends on landfills could be reused (Briga-Sa et al., 2013). Textile recycling may offer the following environmental benefits:

- Decrease landfill space requirements
- Avoid use of virgin fibers
- Reduce consumption of energy and water
- Avoid pollution
- Lesser demand for dyes.

However, despite the benefits mentioned above, the production process of textile is causing a lot of damage and fatigue to the environment as well as to the humans, especially the people working in the production process and, as such, the textile industry is a significant pollution factor for water, soil, and air (Table 11.1).

More specifically, in the production of textiles, synthetic dyes are used for fabrics which have high levels of sulfur, nitrates, acetic acid, soaps, enzymes, chromium compounds, and heavy metals, such as copper, arsenic, lead, cadmium, mercury, nickel, and cobalt. Furthermore, reaction of dyes with chlorine can induce carcinogenic products.

The reuse and recycling of used clothing reduces the environmental burden compared with the purchase of clothing obtained from the original fiber. One way of dealing with this issue is to consider the concept of recycling, reusing, and reducing (RRR). All three levels of recycling, reusing, and reducing can be used as a way of considering the material usage in new ways. We will look closer at cotton and wool as examples, but other natural and organic fabrics are hemp, angora, silk, linen, and bamboo.

Cotton is a natural material that requires big amounts of water for the cultivation process. Even the decomposition process of the cotton fiber is followed up with production of methane. Synthetic fibers biodegrade slower than the natural ones. An important part of cotton produced worldwide is part of the textile fibers used for the production of Denim garments. Types of pollution for cotton is air pollution, water contamination, and solid fabric waste (Zhou, Zheng, Li, & Lu, 2010).

Another natural material that can be used in building is sheep wool. Fibrous agricultural materials, such as straw, flax, cotton, and hemp, have been investigated as potential insulating products, and they are examples of the transition towards more sustainable materials in the construction of homes and other built structures

**Table 11.1** Environmental impacts generated by textiles

Fabric and cloth production		Impact		
Activity	Environmental aspects	Health	Water	Air
Ironing	Consumption of electricity and occupational diseases	x	x	x
Clothing sewing	Consumption of human energy, and textiles and metal waste	x		
Cloth cutting	Noise generation	x		x
Bleaching of tissue	Generation of liquid waste		x	
Cloth dyeing	Generation of liquid waste		x	
Cloth wash (Denim)	Water consumption		x	

From Pichardo et al. (2017)



(Corcadden et al., 2014). Next section presents an emerging research area, in which textiles can be considered as particular interesting elements when moving from focusing on its physical and chemical condition as a material towards a material that humans can interact with in new contexts and as new concepts.

Textiles and its characteristics and conditions that can be exploited and utilized linked to the human not only as clothing and coverings but also as functional, esthetic, emotional, and practical material in different aspects of interior and architectural design, both in urban as well as in rural environments.

## 11.4 Textile as a Building Material

As mentioned in the previous section, textile waste is extensive. The production processes of traditional materials for insulation (acoustic and thermal insulation) cause a negative impact on the environment. As a consequence, a new ‘green’ approach started to emerge. It proposes to introduce new eco-friendly alternatives that include low production costs, and focus on the reuse of waste material in combination with fibrous (porous) structures, which make the recycled textile an interesting solution for building sustainable panels for insulation treatments.

In the previous section, we mentioned fabrics and textiles as possible materials in built environments. According to Pichardo, Martínez-Barrera, Martínez-López, Ureña-Núñez, and Ávila-Córdoba (2017), the use of textile fibers can solve at least two problems, serving a dual function: (a) elimination of an environmental pollutant, and (b) creation of an alternative material for the construction industry. Sheep wool is a bioproduct that has demonstrated some potential and has begun to be marketed and promoted as an alternative insulating material. Wool has several physical attributes that make it attractive as insulation, including strength, hydrophobic and hydrophilic characteristics, thermal performance, and the ability to regulate temperatures and fire resistance (Ye, Wells, Carrington, & Hewitt, 2006). Wool itself is a renewable resource and sheep wool has a low environmental impact, yet the use of alternative materials, particularly sheep’s wool, can still be considered an emerging research topic.

A study by Ballagh (1996) based on the properties of wool concluded that wool isolates vibrations, reducing the sound index by up to six decibels. Desarnaulds et al. (2005) found that sheep’s wool has better sound absorption than mineral wool. Johnson et al. (2003) identified another potential use for sheep wool as a technical fiber, due to wool’s unique physical attributes. Thermal conductivity is typically used to characterize the insulation properties of a material (Corcadden et al., 2014).

The reuse of materials, and especially textiles, is an area of great interest and with potential application due to the high amount of waste it produces around the world. Their integration can be carried out as thermal or acoustic insulation, structural reinforcement, or as coating and finishing material, among others. Different materials and waste with different origins have been studied. Research has been developed to study the potential application of natural material as thermal insulation

(Korjenic, Petranek, Zach, & Jitka, 2011). Textile waste integrates the group of reusable materials that can be included in the building construction and could have different possibilities of application (Briga-Sa et al., 2013). The textile wastes can be from clothes that are no longer used or fabrics as part from other objects, like furniture, etc. Fibers could also be those recovered from various waste streams, which could be suitable for lightweight concrete reinforcement (Zhou et al., 2010). Textile cutting waste has also been mixed with epoxy resin and foundry sand for producing a composite material used for lightweight construction (Pichardo et al., 2017). Regarding thermal insulation, thermal conductivity of the materials ( $\lambda$ ) is the most important characteristic that should be considered since thermal conductivity is a measurement of the ability of a material to transmit heat. Measurements of this parameter have shown that the recycled textile considered have convenient properties as a thermal insulation material. Moreover, fibrous materials have good sound absorbing potential. The acoustic efficiency of the textile was confirmed by analyzing the thermal and acoustic insulation, like cellulose fibers mixed into concrete (Paiva et al., 2011; Briga-Sa et al., 2013; Pichardo et al., 2017).

A variety of techniques for textile recycling exist, but they can mainly be divided into mechanical and chemical techniques (Hawley, 2006). Recycled textile waste can be mechanically re-structured into yarns, woven fabrics, nonwoven fabrics, etc. In order to avoid the use of toxic binders, for producing recycled textiles from natural and synthetic fibers, needle-punching technique can be used. The structure of the textile (mostly polyethylene) is consolidated without any binder, by interlacing the fibers.

The development of smart textiles has grown and is guided by material sciences, especially the new findings at fiber level (e.g., Cherenack & van Pieteron, 2012). However, not everything that is technologically possible is useful; nonetheless, smart textiles bring interactive and dynamic possibilities and introduce the human into the research, production, and use of smart textiles in different situations. Refs needed Smart materials are materials that possess the ability to modify their physical properties in a specific way as a response to a specific external trigger. This means that a smart material may contain sensors, actuators, and controlling mechanisms which make it able to detect the stimulus, respond to it in a specific manner and intensity, in an appropriate time, and return to the original state as soon as the stimulus is removed. Depending on the type of the trigger, smart materials can be:

- Piezoelectric materials (e.g., Chalioris et al., 2016)
- Thermo-responsive materials
- Magneto restrictive materials (e.g., Dapino, 2004)
- PH-sensitive materials
- Chromogenic systems (e.g., Lampert, 2004).

## 11.5 Human-Built Environment Interaction

The process of recycling textiles do not only responds positively to environmental and economic aspects but also gives the opportunity to the user to be part of the procedure by choosing personal belongings for recycling or designs which gives personality to the final product. This is particularly pronounced when using textiles in acoustic treatment. As such, the user interaction with the final product with which he/she has a personal relationship will enhance the experience and understanding of the life cycle of natural materials and their conditions.

Today, the elements of the built environment, such as buildings in urban and rural contexts encompassing both private and public spaces, are quickly changing and are being reconceptualized in different ways, aiming at supporting our lives in the spaces where we live (Parviainen et al., 2017). New demands and awareness are beginning to arise on the fact that we, as humans who live in the built environments, need to be involved in reshaping our needs, behavior, and visions. We want to know not only how our food, air, and soil are being treated but also the built environments that surrounds us. By designing and equipping our built environment with new technologies, such as Internet of Things (IoT) and sensors, we create new ways of *interacting* with our built environment.

This means that we, as humans, are moving between different and more complex spaces, so called ‘blended spaces’ (Benyon, 2012). A blended space involves both our physical world, as well as digital habitat spaces, and we can interact with and between them. In the state of a blended space, we may redefine our habits, needs, demands, and our knowledge and awareness about why and how we want to live our lives. One such redefinition is about the materials that surround us in different forms. Usually, specific materials have their functions, purpose, and task to fulfill, both socially and culturally. However, our conceptualization is that a material has a certain function and we get used to that. It is rarely that we discuss about how a specific material that we use for a specific function/purpose actually can be reshaped or evolve into another purpose and function.

Within the research field of HCI, a specific research area has emerged, called Human-Building Interaction (Alavi et al., 2019a). From within HCI (including Industrial and Interaction Design), the focus is on how humans (or agents) and artefact interact within the spaces they are located in. One of the aspects raised within architectural practices includes ecological and sustainable concerns and the use and utility of materials (such as textiles). According to Alavi et al. (2019b), Human-Building Interaction can be studied encompassing the complexity of people’s experiences in built environment that also integrates computing in different forms. Important interconnected phenomena of the building to study can be: the physical-material, the spatial-configurational, and the social-cultural aspects (Alavi et al., 2019b). In addition, a blended space (Benyon, 2012) aspect can be included, involving people moving between digital and physical spaces. Built environments with different functions (homes, workplaces, hospitals, parks, public transportation,

educational buildings, etc.) bring up a range of contextual requirements that entail the development of focused research.

An interesting approach suggested by Sijakovic and Peric (2018) is discussing the possibility of implementing the biological concept of symbiosis into the field of architecture for redefining the design principles of architectural recycling of resources. The concept of symbiosis serves for the definition of a possible relationship between existing buildings and new intervention in the process of architectural recycling. According to Sijakovic and Peric (2018), the translation and transformation of the biological principles is possible due to a set of criteria for the redefinition of design principles: structure, material, form, and spatial organization. Related to the topic of this chapter is the first of the three redefined design principles: the criteria for building tectonics, which focuses on the interaction between structural elements and material. The tectonic criteria dealing with structure are understood as either that (a) old and new materials are interwoven or (b) a clear division can be seen between the old and new material (Sijakovic & Peric, 2018). One of the purposes of using a symbiotic approach is to allow at least one part of the relationship to benefit either the structure, material, formal, or spatial enhancements.

Textile materials have several properties, such as sensing, flexibility, durability, weight, water absorbance, strength, insulation, etc. Textiles in different forms constitute a medium that bridges the interaction between humans and the humans' world, such as buildings. Even though adding computation like sensors and other technologies to the textile, the interactive textile is enabled with sensing or actuating properties. From an HCI and Interaction Design point of view, there might be several interaction design dimensions (Hallnäs, 2011) involved in the design space for which textiles and textile waste can be framed: Timing, Spacing, Connectivity, and Methodology. Timing refers to how both non-interactive and interactive textile change over time in different ways, such as fading, structure decomposing, and strength. Spacing refers to the fact that all textiles introduce a space. The material itself is a space and as such could embed other properties. Connectivity refers to the interface. The interface could be physical or non-physical. The textile material enables interaction and connectivity. For example, if one would know that the clothes of a certain person or his/her family were used for insulation, he/she would have a very special connection to his/her apartment, house, and even to a particular wall. One's behavior may change due to this knowledge. Methodology refers to the ways in which one uses the material (Persson, 2013, 108–109). This includes the different ways a person may interact with textiles. We all have our relationship, experiences, and memories of a specific material. One of the goals of research within this area is to explore and find new approaches on how we see textiles from a time-perspective, how textiles can enhance, change, populate our spaces and how new types of interaction patterns and behavior could emerge. This will then also lead to the development of new methodologies on how we approach and use textiles in our daily lives, as well as in professional work situations, as part of our built environments. Another interesting example is the breathing wall. It is a system

using textiles that merges normal insulation systems and characteristics of thermal exchange of building walls (Youssef, 2017) and thus interact with humans. Therefore, when the sensor is sensing any changes in the temperature, metal strings bend, decreasing the space between the textile strings, which causes a reshaping of the textile.

By introducing the electronics within smart textiles, the environmental sustainability is decreased because of the difficulties in the recycling process of the electronics, but the concept of the smart materials enhances societal sustainability regarding the personalization and interaction that increase the value of the smart textiles in built environments.

## 11.6 Concluding Remarks

Textile waste is a problem for the environment and may become a worse problem without recycling or other means to lower its environmental impacts. The discussion presented in this chapter on different types of textiles has shown that, after recycling, this type of material has convenient properties to be reused as a building material.

Recycled textile can be used in different forms as structural and non-structural building material. Non-structural use of the recycled textile as a thermal and acoustic insulation was considered in this work. The results have shown that textiles are promising materials and have still open field of work for more advanced development.

The application of a smart concept, through the use of electronics, gives textiles another value. Although the environmental sustainability is lower in that case due to the use of electronics, the interaction possibilities opens up new potential in the societal sustainability. Research in this field is currently intense, the potential and flexibility of these smart materials is perceived and only engineers' and designers' creativity can set or break the limits of their application.

This chapter has provided with a reflective analysis on considering textiles as material in built environments from a regenerative point of view. We hope that research, both from the built environment and HCI communities, can benefit from each other when developing material, material usage, and recycling, as well as involving and embedding human interaction with these materials for the development of more sustainable built environments. We have pointed out several conditions for how to relate HCI with textile as material, especially connected to the built environment as an emerging research field. We show that the importance of exploring textiles as material for interaction design is vital and important from a design and from a circular economy perspective by looking at the spatial and temporal design aspects of textiles, elements that will enable interaction.

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# Chapter 12

## Restorative Design for Heritage Requalification: Selected Roman Works



Luciano Cupelloni

**Abstract** The theme is the urban re-qualification, applied in particular to the architectural heritage and the public space. The goal is the ongoing challenge of outlining a new perspective aimed at “common good” and sustainability. The instrument chosen is the “environmental technological design,” understood as a cultural, scientific, and social position, that is, as a position on the role of architecture. The contribution reiterates the urgency of restoring the transformative power of the design mission to the project, too often reduced to a set of technical compilation procedures. In the best cases, a position that is lost in the complication of procedures, in the extension of time, in the waste of economic and human resources. A crisis of the project as “anticipation” of progressive scenarios, precisely in the most acute, ever more serious phase, of the urgency of the reorganization of urban systems, with a view to environmental, social and economic sustainability. Not a recent urgency, today only brought to light, dramatically, by the reality of the SARS-CoV-2 pandemic. Among the solutions, the design experimental research, well beyond the objective of flexibility, up to the notion of “functional indifference,” understood not as shapeless neutrality, but as the maximum functionality of spatial, architectural and urban quality.

**Keywords** Architectural and Urban Regeneration · Historical Heritage · Public Space · Environmental Technological Design

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## 12.1 Introduction

### 12.1.1 *Project as Layering*

This contribution deals with architectural and urban restoration, applied in particular to heritage buildings and historical public space. The goal is the ongoing challenge of outlining a new perspective aiming at “common good”, as well as sustainability. The instrument chosen is the “Environmental Technological Design”, understood as a cultural position on architecture, as a disciplinary position in the academic sphere, and as an operational everyday life of the architect’s profession.

The urban complexity of the city of Rome is the context in which the experiences described below mature, not only the application and verification of criteria and methods outlined in the research, but also the same definition of original tools and design solutions, largely in a wider context, and precisely from the specificity of the individual cases.

In this perspective, I describe the forms and ways through which – over the years – I have come to draw from studies, experiences, and even from particular emotions, a personal declination of architectural and urban restoration that arises from the profound relationship with the historical reality of architecture, always rooted in its places. When the place is the city of Rome, this relationship becomes a vital relationship, fuelled by a narrative that Rome expresses like no other city in the world (Cupelloni, 2014).

The history of the city is stratification, replacement, reorganization. It is a continuous process, a creative trend, which implies and contains destruction. We would not have extraordinary monuments if other equally important ones had not been torn down or transformed (Cupelloni, 2010).

This is the “tradition” of the city of Rome, the reason not only for the uniqueness and exceptional quality, but also for its modernity.

I still remember, after more than 30 years, the emotion felt in going through the excavation conducted by Christoph Luitpold Frommel and Richard Krautheimer in the courtyard of the Palazzo della Cancelleria. I saw the discovery of the early Christian Basilica of San Damaso below the medieval level, and the fifteenth-century floor of the church, clean-cut by the will of Cardinal Raffaele Sansoni Riario della Rovere at the end of the 1400s, just to build the great palace. The Basilica was an important construction, it was cut horizontally no more than two meters from its footfall. The excavation found it intact, with its frescoed walls, the altar, the floors and the sepulchral stones. And under the Early Christian Basilica, the remains of the great plague epidemics, a tomb from the Republican era and the Euripe riverbed. All immersed in water in an underground and transparent vertigo.

Another case, much more recent, on the occasion of an extraordinary opening of the cistern of the Seven Halls. The cistern is an engineering masterpiece serving the Terme di Traiano. The “Terme”, as well known, were built above the Neronian domus – the Domus Aurea – in turn the result of the great fire of 64 AD. And on the vaults of the cistern, a domus, which reorganizes the previous utilitarian structures

with great breadth. Once again, a wonderful stratification, a vertical section of the Roman culture.

If architecture, as a result of human history, exists only in its place, and if its place is no other than the city, then, there cannot exist an international architecture – which we have long known failed in the version of the International Style but also in today's global unification – but only an architecture capable of grasping the value of memory and at the same time to understand the need for listening. Consequently, the architect must first of all be a "discoverer of stories and places". And not for cultural or narrative reasons, but for a specific goal: to give or return quality to the city as a result of its history, and above all, quality to human life in its city.

In many other cases, on the occasion of projects on monumental complexes of medieval layout progressively transformed, at least until the nineteenth century, from defensive structures into noble residences or on industrial architecture between the late nineteenth and early twentieth centuries, my experience of stratification is daily. In the initial studies and even more in progress, during the realization phase, when the historical knowledge, the archival documents together with the drawings and the thousands of project data overlap, as in filigree, repeatedly, on the matter of the artefacts on which you go to operate. A real cognitive process that does not end in the library or in the archive but which, passing through the surveys, the field analyses, the "section" of the factory, uses observation and the many methods of tests and essays to reach the design solution. From the subtle at times elusive relationship with the artefact, all intellectual although intimate for the inevitable relationship with the architects, we move on to "body to body". From the clean line on paper, from the multi-coloured graphic overlaps, from the dynamic behavioural models, from the representations that approximate reality, we move on to matter, to the subsoil, to the physicality of the space where first dust and then light play a decisive role in that long, dilated, moment of knowledge, of clarification of theories and choices, which is the construction site. The intuition of new spatiality is completed, the set of techniques becomes a system, the geometries and dimensions are compared and all this does not contradict the level of depth and completeness of the project. On the contrary, this is the condition for timely verification, for constant control and development, all the more so if the project has consciously set itself the theme of stratification, of a contemporary doing that preserves and innovates each other, in morphological, technological and environmental terms.

Simplifying, but not entirely, the quality of the historic city has much to do with the terms of sustainability and human well-being. It is enough to reflect on the quality of urban structures, where axes and fires trace the large scale conforming it with fabrics on a human scale, where the great property of kindness translates into parks and public institutions, where architecture configures streets and squares, and these through the arcades and internal courts mediate the relationship between the city and the house.

We can actually say that often "quality is there", before our eyes. In the passive behaviour of masonry or wooden constructions, in the performance of the wall thicknesses, in the conformation and material of the roofs, in the arrangement and

size of the holes, in the intelligence of many minor components such as shutters or shutters, in the regional variants, to protect from heat or cold.

Certainly, these are qualities that are not reproducible as such, but that we must be able to recognize and measure – in the specificity of the cases and conditions of the site and context – setting ourselves the goal of enhancing them, at the urban level, with innovative solutions and at the same time historically consistent.

For the architectural heritage, it is necessary to decline passive technical solutions and active systems eco-efficient, selected or better designed in accordance with the peculiar architectural historical characteristics of the good. The latter aspect is particularly complex. Very often, it has been practiced, reductively, only as energy efficiency. It is an ambiguous, if not incorrect, the approach that applies the logic of retrofit, understood as applying standardized solutions or technological devices, designed for new construction, "overlapping" the existing ones.

On the contrary, the architect is called to be the architect of a process where the project is knowledge and interpretation, a complex outcome of specific conditions and general needs, of never mechanical prefiguration and critical innovation, of constant development, in the design phase and if not in progress, certainly in the life cycle of the work, exactly as history teaches us.

### ***12.1.2 Architectural and Urban Regeneration***

Having ascertained the benefit of saving land, having calculated the multiple economic advantages linked to the presence of already *infrastructured* urban areas, both inherent in the intervention on buildings, there is no doubt that the environmental issue involves a radical paradigm shift. It is quite clear, particularly in the Italian situation, that the theme of intervention on heritage cannot fail to decline according to the broad meaning of "environmental technological requalification", positively interpreting the limitations – albeit sacrosanct – of protection and conservation.

With this in mind, the field, the themes and the chances of intervention on heritage broaden significantly. Certainly, for the often-exceptional quality of our goods, for the profound cultural significance of the protection and conservation of arts and techniques, material testimonies, stories and memories. But above all, for the benefits associated with that mix of conservation, innovation, and functional conversion that characterizes the most advanced interventions, generating positive margins at the architectural level also in terms of eco-efficiency. And for the even more significant opportunities in terms of environmental, social and economic sustainability connected with the intervention on urban fabrics.

Although in very different terms from other regions of the world, today protagonists of the processes of change induced by globalization, in Italy, the theme of the city cannot fail to pose itself in totally opposite ways to those typical of post-war industrialization, the engine of widespread well-being and population growth but also of often uncontrolled expansion, cause of territorial imbalances, of extensive

destruction of the natural heritage, of profound alteration of historical urban structures.

The roles and functions of the big cities have changed, in many European countries, since the nineties of the last century, virtuous processes of urban and territorial reconversion have been experimented. Driven by the response to negative economic trends as far as scientific research and the desire for innovation are concerned, the recent history of European capitals is unmistakable with the stasis of Rome and with the same dynamics of Turin and Milan which, however – unique in Italy – have been able to redefine identity and models. Even more evident – if compared with the chronic crisis of the major Italian production sites – is the ability to renovate “failed” urban centres, such as Marseille or Liverpool, Barcelona, Malmö or Bilbao. And even more complex cases such as the Ruhr industrial region.

In all cases, with the differences in specificity, success coincided with the redevelopment of artefacts and places, with the creative definition of new meanings, roles and functions based on the updated reading of economic processes, with great attention to the quality of the architecture and public space, technological innovation and job creation, social cohesion and citizens’ health.

In Italy, “urban regeneration” is largely just a slogan. The absence of structural policies and the inability of incentive actions to trigger real planning seem to entrust the initiative rather than to the State to the territories, at all scales, regions, cities, municipalities, under penalty of degradation.

Although today 75% of construction production derives from maintenance and renovations, compared to 58% in 2007, Italy is the sixth European country in the ranking of land use, not only in violation of the European target zeroing by 2050 but also with the well-known consequences in terms of erosion of rural landscapes, loss of ecosystem services and vulnerability to climate change.

Rather than urban regeneration, it is the regeneration of an obsolete and inefficient residential heritage in many ways. Operation necessary but insufficient. This is demonstrated by the report “Urban ecosystem 2019” which investigates the urban quality of 104 Italian cities with respect to parameters such as air, water, waste, mobility and the environment. Among the most virtuous cities we find Trento, Mantua and Bolzano, while Milan is in 32nd place, although in first place for public transport and for efficient use of the soil and in sixth for the presence of trees in the city and in seventh for capacity of water purification. If Palermo is in 100th place, Rome does not shine with its 89th.

This highly synthetic picture is completed by the seismic vulnerability and energy inefficiency of a complex heritage that includes countless monuments, infinite architectural assets and an aged and modest if not low build quality construction stock. And when we talk about architectural goods, we mean urban works and systems of various order and degree, ancient and modern and even contemporary.

## 12.2 Case Studies and Design Experimentation

### 12.2.1 *Environmental Technological Requalification*

Very often, in the course of a long personal experience, contact with situations of degradation of artefacts but also of the urban context prevailed. Negative conditions, originating not from lack of quality but from a widespread, serious, loss of quality. Very little care, almost total absence of culture, if not the same notion of maintenance, lack of planning of interventions, widespread impromptu decision-making of government.

All this makes the architect's work complicated, overloaded with expectations, inevitably frustrating even when, in the immediate future, the results are positive. For these reasons, the theme of architectural and urban redevelopment arises as the need to translate increasingly complex objectives into viable but clear solutions, tracing each time the right "measure" of the project. A project that, overcoming the basic category of recovery, is able to give back to the object of intervention – whether it is a building or an urban environment – the lost qualities but also to add new ones in a relationship of mutual and dynamic.

With this in mind, the redevelopment project certainly provides for conservation, does not exclude addition and demolition, obliges structural rehabilitation and seismic improvement, involves functional conversion and regulatory and performance adjustment.

The experiments described below contain this complex cultural and technical condition. In urban, architectural and technological terms, these are projects aimed at finding a coherent balance between conservation and innovation, between restoration and new architecture, between settled identity and contemporary meanings. Projects that aim for environmental sustainability, preserving signs and materials, improving structures and renovating figures, reorganizing spaces and functions to meet new needs, translating the spirit and characters of what remains into an additional architecture, in turn not least the moment of historical stratification.

Experiences such as the "City of the Other Economy" at the Testaccio slaughterhouse, a series of interventions in the Garbatella district and the cultural centre called "Piazza Elsa Morante" outline, each in a different way, original forms and redevelopment solutions, as motivated by cultural, technical and scientific criteria and tools.

### 12.2.2 *The Case of Gioacchino Ersoch's Slaughterhouse*

In the old slaughterhouse in Testaccio, the major work of Gioacchino Ersoch (1815–1902) (see Box 12.1), the project for the "Alternative Economy City" translates an original program into an intervention that tests the **extreme limit of renovation** under strict monumental limitations. Operating on the *Pese del Bestiame*

**Box 12.1**

**The Ersoch Slaughter House complex** is located in Rome into the Testaccio district, closely behind the Aurelian walls between the Cocci's Hill and the Tiber river. Realized in only three years between 1888 and 1891 according to the project of the architect Gioacchino Ersoch (1815–1902), it grows on an area of 10 ha of which 4000 m<sup>2</sup> indoor. The work, that reflects the transition from classicism to modernity, is characterized by large pavilions and light rooftops presenting traditional brick curtains, travertine elements and plasters, as well as innovative iron and cast-iron structures, with a sophisticated balance between monument and industrial rationalism. The complex, dismissed in 1975, became protected only in 1988. For almost two decades, numerous projects have been accompanied by lack of attention, and widespread degradation took over. In 2002, the City of Rome devoted the complex to cultural and educational public services, starting a deep renovation program still hardly in progress (Cupelloni, 2011).

(cattle weights) construction, on the long Ersoch's *portico* from 1888 and the shelters from 1928, rare Roman examples of structures in iron and cast-iron, the architectural project includes restoration and addition, structural rehabilitation and eco-efficiency, conservation of the *facies* and new sign, in the context of a unitary, spatial and material redefinition (Nicolini, 2008). Already a symbol of the original Ersochian relationship between tradition and innovation, the relationship between neoclassical buildings and innovative iron and cast-iron structures is enhanced and interpreted by the contemporary design of the restoration project (Cupelloni, 2011) (see Fig. 12.1).

The central core of the long front extends for more than 200 m; the small square between the modules makes evident the interchange between new volumes and open or only covered spaces, distinguishing the original segments from those that add new signs and elements to the existing structure (Cupelloni, 2011) (see Fig. 12.2).

The response to the functional program – 12 independent cultural and commercial activities on an area of 3500 m<sup>2</sup> – is the covering of the space between the *portico* and the balconies with a new steel structure, that transforms the existing rooftops and the intermediate voids into an additional area. Along the linear development, more than 200 m long, the new skin is divided into different and flexible units that alternate covered or enclosed open spaces – clearly featuring the original parts – as well as the new signs and elements, added to the pre-existing parts (Cupelloni, 2011).

The intervention activates a meticulous conservative restoration of the *Pese del Bestiame* building and the adjacent *portico*, and a complex revamp of the structures in iron and cast-iron (Cupelloni, 2011) (see Box 12.2).



**Fig. 12.1** “Alternative Economy City” at the Slaughterhouse of Testaccio (2007), Rome. Photo by Roberto Bossaglia, Cupelloni’s archive



**Fig. 12.2** “Alternative Economy City” at the Slaughterhouse of Testaccio (2007), Rome. Photo by Roberto Bossaglia, Cupelloni’s archive

**Box 12.2**

**The METALOCK system** (1947, Coventry, UK) is a solution for the cold repair of cracked and broken fusions. It consists of applying shaped bars of steel alloy, with a high nickel content, in small corrugated cavities – carried out with given intervals, perpendicular to the fracture – associated with threaded holes along the fracture line, in which screws of the same alloy are inserted. Used in industrial contexts (machineries, pumps, boilers, etc.) the system was used for the first time in Rome on the cast iron columns on the roof of Campo Boario (Kaltenback, 2009; cited in Cupelloni, 2011)

The new covered spaces, between the old sheds, have been realized with an iron anti-seismic structure completely prefabricated and partially assembled in factory in order to facilitate the final assemblage in relation to the pre-existent structures (Randaccio, 2009; cited in Cupelloni, 2011). The new structures are statically independent from the older ones, and technically reversible.

The unique combination of old roofs and new volumes is enclosed by a glass shell, that – also thanks to the open space organization – ensures the maximal transparency to the originally open structures. Glazed facades and skylights lead to an efficient control of the thermal behaviour, benefitting from orientation and position, which are obviously not modifiable conditions. The control of the impact of sun/air made it possible to maximize the solar heat gains during the winter time, and to minimize the solar radiation during the summer. General and detailed solar diagrams informed the design of the sunscreen system. The glazed south-east façade is protected by a system of horizontal plates, located on the lower part, completing the shading effect of the existing rooftop. The openings system of the new roof is a technological solution that provides natural light without summer overheating, while allowing for the positioning of PV panels (Cupelloni, 2011).

The sheds facing north-west are protected by vertical panels and horizontal projections, limiting the overheat in the summer's afternoon. Located besides the sheds, the flat roof-lights, covered by an inox steel multi-perforated double slab, provide the total protection from solar radiation during the summer and allow for the maximum entrance of direct radiation during the winter, while diffusing luminosity in every season. Studies for the protection of the glazed façade from direct solar radiation, were coupled with aerodynamic flows analysis. The analysis has resulted in a regenerative climate adaptive design where the flows are conveyed, from the frontal openings, and from the north-oriented rooftop openings, in the shaded zone, providing summer refreshment and air exchange (Toffolon, 2008; cited in Cupelloni, 2011).

The optimization of thermal effects and natural lighting leads to the use of stratified insulating glazing systems, low-E with neutral reflection, set on extruded aluminium profiles with thermal cut, with hinged motorized leaves.

Aiming at the reduction of heat losses, hemp panels are used on the roof and on the facades. Low-energy lighting devices are used for artificial lighting, with high



performance and long life: mainly fluorescent lamps controlled by light sensors, and in some spaces, metal halide lamps. The entire system of furniture and equipment, realized most on design, uses environmentally conscious processes and materials. The complex is equipped with 7 thermo-mechanical independent power houses, with high-performance heat pumps air/water and UTA with dynamical recovery >70%. The nocturne natural ventilation contributes in the summer to the heat reduction inside the building. The complex benefits from a photovoltaic system based on 166 silicon panels, plumb free, with an output of 180 Wp peak power, 30 kWp total power and 40,000 kWh annual production; it reduces the CO<sub>2</sub> emissions of about 25,000 Kg/year (Cupelloni, 2011).

### 12.2.3 *The Case of the Street of the Seven Churches*

In the Garbatella district, in the heart of the urban fabric of the first “garden city” (1920–1935), a historic track, a neglected park, streets and squares, upset by too many cars, have returned to quality, thanks to the accurate design, the attention paid to the materials, and the attempt to put a limit on car mobility, returning public space to the people who live there. The historical character of the Street of the Seven Churches (“*Via delle Sette Chiese*”) and the presence of significant archaeological, architectural and environmental emergencies gives rise to a project that orders a new urban scene, which tells its story (see Fig. 12.3).



**Fig. 12.3** Saint Eurosia square, Garbatella (2002), Rome. Photo by Roberto Bossaglia, Cupelloni's archive

A neighbourhood garden, on the extras of the ancient catacombs, among the unique architecture of Garbatella, becomes a place of new social, spatial and perceptual experiences (see Fig. 12.4).

The project is once again based on the conviction that the values of history – the environmental emergencies, some monumental elements and the architectural fabric of the Garbatella which as a whole insist on the Street of the Seven Churches – must be placed in close and coherent relationship with the contemporary culture and citizens' needs (Andreucci, 2015).

The search for a sensitive balance between the desire to preserve a “memory” of the place and the proposition of formal and technological solutions oriented to “innovation” translates on the one hand into the enhancement of urban stratification and its cultural and morphological values, from the more in new responses to urban, social and functional needs.

The “open” road on the San Paolo hill, the road as an itinerary started by Saint Filippo Neri which then became jubilee – first in the countryside, then as a caesura of urban development – together with the first and second Garbatella, became the theme of the project.

The Street of the Seven Churches is characterized by the presence of singular natural elements – a tufa cliff, green spaces, some tall trees – and by a widespread and significant architectural quality originated from the interventions of the Istituto Popolari houses made in the 1920s and 1930s, designed by the architects Gustavo Giovannoni, Innocenzo Sabatini, Plinio Marconi and others.



**Fig. 12.4** Commodilla Catacombs Park (2008), Rome. Photo by Cupelloni's Archive

The project therefore takes the road as a historically changing complex place, as a succession of events and scenarios where the values of the past and present give rise to a varied path, in terms of quality and spatial conditions. A marked or just defined path, unitary or progressively fragmented by the different characteristics of the building. Clear and noble those of the early twentieth century, anonymous those of the post-war period in a sequence of fabrics on a human scale or of open spaces determined by vehicular circulation.

Unity and fragmentation, simple connection traits, significant areas and “objects”: this is the identity of the place. Therefore, the redevelopment is based, in the first instance, on the desire to make the course certainly legible in a physical sense but above all the “condition of the journey” – authentic *genius loci* – differentiated and in several places completely lost.

The goal is that of a “*promenade*”, of a path where it is pleasant to walk, stop, and meet. In parks, in squares, along large sidewalks protected from car traffic and well lit. Morphologically, the new route is an “interrupted line,” a piece of road rediscovered, a metaphor for archaeological excavation. Physically, it is a rectilinear paved path, of variable width, distinguished by the didactic clarity of the sign and the material used.

The pavement is in fact characterized by a central cobblestone strip that identifies the path, flanked by a basalt lane reserved for the disabled or mothers with strollers, shaded – in several places – by trees and long flower beds with shrubs.

With this in mind, the project proposes relationships and establishes new relationships with the architectural emergencies and episodes that characterize the path, with the aim of responding to the needs of spaces intended for meetings, for children, adults and the elderly. And in this sense, the path is flanked, in addition to the parks, with small rest areas for passers-by, panoramic points, visual angles and real pedestrian squares.

Consequently, the road journeys have been reorganized by eliminating the crossing flows of the neighbourhood, calming speeds and redesigning the roadway with particular attention to the organization of parking areas and green spaces.

In addition, the historical character of the street and the presence of significant archaeological emergencies make it interesting to propose, again, a characteristic aspect: the custom of the architects of Garbatella to arrange on the urban scene the marble remnants found during the excavation of the foundations of the buildings.

In the project, artefacts stolen from the depots, carefully located in new urban fires, and floor inscriptions on stone allow the road to tell its story, through a path full of spatial and perceptual experiences.

Consistent with the position of the project, the choice of materials: preservation of memory and modernity translate into a construction that uses traditional materials – Roman cobbles, basalt, granite and travertine for the floors – but also the steel, combined with wood, for the furnishing elements.

These in particular are made up of seats formed by a metal sheet, folded and perforated to avoid water stagnation with overlapping wooden slats, painted in green to recall the traditional Roman bench or to leave natural inside the park of the Catacombs of Commodilla.

In coincidence with the entrance to the park of the Catacombs, a small square was created, enhanced by inscriptions on the ground, benches and lights facing the entrance to the park and the most important buildings.

The park overlooks the ancient settlement of the Catacombs of Commodilla. Another historical stratification which will be followed by the discovery of important archaeological remains which have undergone restoration. The result is an archaeological and sacred space to which large green spaces and areas equipped for socializing and playing are associated.

### *12.2.4 The Case of the Laurentino 38 Neighbourhood*

The intervention called “Piazza Elsa Morante” is part of an extensive redevelopment programme of the “Laurentino 38” (1971–1984), neighbourhood, the result of a plan of economic and popular housing, public and private, for about 32,000 inhabitants, obviously marked by the problems typical of the metropolitan suburbs. In this case, the intervention works on the contemporary urban fabric (see Box 12.3).

The project’s programme consists in the realization of an Arts Centre interpreted as a new social infrastructure, that is, a “piazza.” The intervention site is a parking lot, covering more than two hectares: twice the size of Piazza Navona, four times the size of the Termini train station’s gallery, in Rome. Crosswise, it is a marginal section at the base of a built-up hill; longitudinally, it is a low plane marked by a row of stone pines (Cupelloni, 2011).

These characters and various other activities dictate the structural rules, limiting the potential building area to a long and narrow strip, and this low position – lower of the surrounding streets – closes off views which just a few meters higher are extensive and evocative (Cupelloni, 2011).

The size of the area is a resource, and at the same time a problem to be resolved, to avoid that “out-of-scale” between man and the urban structure which is one of the major problems of the neighbourhood (Cupelloni, 2011).

In this scenario, the project operates through horizontal planes: the zero quota, pedestrian and featuring greenery, and a second quota on slender steel columns,

#### **Box 12.3**

**The “Laurentino 38” neighbourhood** was designed by a team led by the architect Pietro Barucci, in 1971–1974. The construction began in 1976 and ended in 1984. The general layout is characterized by the repetition of a basic module, consisting of various, almost identical, buildings, connected by bridges, arranged transversely to a large ring road. In 2006, the Municipal Administration demolished three of the eleven bridge buildings, which had become symbols of social and environmental degradation, and started the cultural centre project (Cupelloni, 2011)

made up of precise planes, just below the foliage of the pine trees, lapped by green edges. Between these two floors, the new spaces unwind: the newspaper library, the *médiathèque*, a 200-seat theatre and, on the opposite side, a 350-seater arena. Three buildings designed as open spaces, arranged behind a long metal wing which, crossing them, separates the park from the adjacent street. The linear arrangement produces three spatial environments, connected by the transparency of the buildings, into which the activities of the Cultural Centre articulate: the “water *piazza*,” the main access to the Laurentino 38 neighbourhood, the “little wood” between the library and the *médiathèque*, and the “multimedia *piazza*” between the *médiathèque* and the theatre (Cupelloni, 2011) (see Fig. 12.5).

For a neighbourhood which programmatically has no focal point, the project does not propose an unrealistic, traditional *piazza*, but a series of contemporary “*piazzas*,” Each marked by large steel pylons carrying the photovoltaic panels: “cubes of light” as urban signals (Costa, 2011; cited in Cupelloni, 2011).

The route which connects the “*piazzas*” extends towards the natural reserve, reminding of the typical Roman relationship between city and countryside: simple green mounds – located on the south side with shading and wind protecting functions – bring variety to the views, organizing a sequence of meeting spaces, with wooden letters that write “P E M O R A N T E”. The intervention makes use of ecological and photo-catalytic materials, produces electricity through photovoltaic systems and accumulates rainwater to irrigate the park. The attention to sustainability is expressed particularly in terms of eco-efficiency: orientation and solar radiation studies; technical solutions for the insulation of the concrete skin; transmittance



Fig. 12.5 Elsa Morante Cultural Center, Laurentino 38, Rome Capital. Photo by facetoface



**Fig. 12.6** Elsa Morante Cultural Center, Laurentino 38, Rome Capital. Photo by facetoface, Cupelloni's archive

control through advanced façade elements and simple earthworks. The analysis of solar radiation leads to the design of the horizontal, fixed *brise-soleils* (Cupelloni, 2011) (Fig. 12.6).

The sunscreens, thanks to the various angles, protect the glazed facades exposed to east/south/west from summer insolation, while allowing that daylight comes in during winter. The top skylights perform the same function. In addition, mobile vertical sun shades shield the glazed facades exposed to south/west, protecting the indoor spaces also against introspection from the outdoor (Panzini, 2009; cited in Cupelloni, 2011).

The limitation of heat lost is carried out by mounds on the north side and by walls realized with brick blocks made of mixtures of natural clay and wood flour, free from chemical additives. Panels with mineralized fir wood fibre, bounded with Portland concrete, have been used for the thermal and acoustic insulation of all concrete structures. The solution solves the thermal bridge between wall and ceiling, thanks to the double cast of concrete walls.

Interior and exterior concrete walls are painted with photocatalytic paint, based on TX Active with titanium dioxide, antismog, antibacterial and self-cleaning. Primary aluminium alloy profiles with thermal cut, with politermide and low-E insulating glasses, are used for the glazed facades. Active systems encompass advanced conditioning mechanical plants, made of machinery that uses HFC gas; low-energy and long-life lighting, exceeding the regulations for RAEE collection, recycling and disposal. Mechanical plants include a conditioning plant with recycling for the theatre; radiant panels associated with cooling plants with fan coils for the open space. Four PV plants are realized: three on huge “technological trees” for 10.26 kWp and an energetic production of 13,500 kWh/yr., in addition to the PV on the top of the theatre for 7.84 kWp, and a production of 11,500 kWh/yr. The total

production of the complex is 25,000 kWh/yr., satisfying 20% of the needs, with a reduction of CO<sub>2</sub> emissions equal to about 16,000 kg/yr. Finally, aiming at maximum draining surface and low maintenance costs, outdoor pavements and plant species have been selected with particular attention. Trees and grass lawns are watered through the rainwater collection system, harvesting a total of 250,000 litres (Cupelloni, 2011).

## 12.3 Discussion

### 12.3.1 *Similarities and Specificities*

In short, as proof of the consistency of the criteria and of environmental technological design tools, the cases described, despite the total diversity of place and programme, present strong similarities.

In addition to the evidence of linear development, fragmentation of elements, the seriality of parts, the alternation between full and empty, the continuity between external and internal, it is the methodological process and the innovative value that assimilate the three interventions.

The first case pursues the objective of preserving an asset of so-called “industrial archaeology”, subject to monumental constraint, and at the same time applies technological innovation in terms of environmental sustainability, “by brilliantly solving the question of the client and above all by indicating, with tangible evidence of the realization, possible paths from the methodological and operational point of view for similar operations in which the contemporary, through technologies and compliant figures, can dialogue with history without inhibitions” (Associazione Nazionale Centri Storico-Artistici ANCSA, 2009).

The second tends to rediscover the memory of the place by proposing advanced formal and technological solutions, to respond functionally to new urban and social needs.

The third translates an unnecessary if not harmful expanse of asphalt, motivated only by the abstraction of urban standards, into an integrated system of valuable services, public greenery and relationship spaces, proposing a mode of redevelopment – for “densification” of services – certainly generalizable as an urban strategy based on the quality of an architecture that wants to affirm the strategic value of sustainable construction.

## 12.4 Conclusions

The description of the design experiments, lived through the always complex story of construction, highlights the plurality, the differences of a case study not at all homogeneous that does not allow generalizations and much less coded behaviours.

The recovery of an industrial artefact, the reorganization of a historic road infrastructure, the regeneration of a peripheral area, in all cases, the intervention on the existing urban and architectural heritage is not a noble cause but an obligatory choice, subject to social degradation and urban inefficiency.

In the face of this problematic area, the issue of retraining goes far beyond its theoretical or technical definition, if we refer to the complex, difficult reality of our heritage in an active and not only defensive way. Beyond the schools of thought and the methods experienced in the cases carried out, the question can be defined – in a nutshell – as a "project measure", understood as a possible transformation.

The theme of "measure" therefore involves the question of the "relationship" with the good and its context, with the program and resources, with the chances and constraints. Mostly it is a relationship that does not follow a general rule and sometimes not even a canonical methodology. Too many variables within an infinite case study, complicated by specific intrinsic and boundary conditions, to establish a mode of relationship and therefore of intervention in advance. On the contrary, the only valid theory still seems to be that of the "case by case", understood as a subjective interpretation based on solid historical and analytical foundations.

"Case by case", of course, does not mean the agency or validity of any solution. Although both the prohibition – stated, originally, from Gustavo Giovannoni – to intervene in historical cities with contemporary architecture, and the radical doctrines of the so-called clean slate aimed at material and technological contrast and in any case detachment from historical matter, we must consider that the very notion of architectural or cultural good is not entirely shared. Some see it as a finished result, others as a work of pride, as a dynamic process.

In general – precisely from the experiences described – we can certainly decline at the theoretical level a conception of the project as today's stratification on the historical substrate, based on the reading and therefore on the readability of the history of the human presence and its signs on the territory, the city and its various components (Cupelloni, 2017).

The project can – and must – induce a real transformation action – understood systematically as "*transformatio*" – until the profound change of architectural and spatial characteristics, including the new terms – sometimes also the result of ancient lessons – of environmental, social and therefore economic sustainability, thought as a "temporary" moment of a historical cycle, flexible and open to constant modification.

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# Chapter 13

## 3D Printing Technology Within a Regenerative Construction Framework



**Odysseas Kontovourkis**

**Abstract** 3D printing (3DP) is considered as a promising technology in construction industry due to a number of advantages that among others include fast and accurate construction, as well as elimination of formworks and material waste. Although 3DP technology is at an early stage of adoption in construction industry, its positive contribution towards a more sustainable construction approach is well acknowledged. Nevertheless, various constraints prevent its further establishment that include among others lack of knowledge among construction actors, premature investigation regarding techniques and material properties, as well as limited work on design optimization, cost, and environmental impact performance analysis. This chapter aims to contribute towards this direction by analysing the 3DP cost and environmental impact of a number of brick units, forming walls with different geometrical complexity. Results show that while walls' complexity is increased, there are no significant changes in cost, global warming and primary energy consumption. In contrast, through the application of traditional construction processes, the result values would have been increased proportionally to the degree of complexity. This proves the potential of applying the 3DP technique to the construction of any structure at no extra cost and without increasing the environmental impact. Also, it provides an indication of its potential to be included within a regenerative construction framework.

**Keywords** Sustainable 3DP · Design optimization · Cost · Environmental impact · Material minimization · Design complexity

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## 13.1 Introduction

Nowadays, 3D printing (3DP) in large scale is recognized as an emerging technology that could potentially be applied in the construction industry, bringing about improvements, as well as offering opportunities, towards a more sustainable future. In particular, it can be implemented towards material waste minimization and reduction of time and effort during construction. More specifically, 3DP can positively contribute towards effective material waste management due to its ability to use only the required quantity of materials by avoiding the application of moulds or formwork (Buswell et al., 2007; Camacho et al., 2017; De Schutter et al., 2018). Also, it can contribute towards construction time reduction (Kontovourkis & Tryfonos, 2020), especially in cases of non-conventional and complex designs, where the use of standard construction techniques would be less economically advantageous (Buswell et al., 2005; De Schutter et al., 2018).

The inevitable need for automation in the construction industry through the application of 3DP technology brings a number of additional advantages such as its integration into a seamless workflow, incorporating design optimization techniques, for instance topology optimization. This can be applied during the design stage in order to achieve material and cost reduction, ensuring at the same time the structural efficiency of the systems. Geometrical correlations can be found in the anatomy of natural organisms such as bones, where material is distributed only in areas that is needed, similar to the principles discussed in biomimetics (Vincent, 2014). Recently, direct links with 3DP can be found that offer comprehensive design to fabrication solutions. Apart from environmental impact reduction benefits, these can achieve improvements in regard to architectural design and construction approaches (Camacho et al., 2018).

This chapter discusses the capability of 3DP technology to contribute towards a comprehensive regenerative construction framework, in which design optimization and sustainable 3DP are integrated and have a key role. In particular, this study emphasizes the need of using the specific technology in cases of increased geometrical complexity, where cost and environmental impact reduction is important to be considered. This might provide more affordable solutions in comparison to traditional construction approaches. A number of brick units are used as examples, which are derived from selected masonry walls with gradually increasing complexity. These are examined in terms of 3DP cost, carbon dioxide emissions and primary energy consumption. The purpose is to compare the results based on an incremental degree of complexity and discuss the possibility of using this technology in irregular shapes construction. At the same time, advantages that can bring to construction industry are discussed.

Following part of the chapter provides a literature review in this area of research. Then, the research method is presented, which outlines the regenerative construction framework in general and the sustainable 3DP procedure in particular. This is followed by experimental results and discussion. In the last part of the chapter conclusions are drawn.

## 13.2 Literature Review

In the last few decades, the potential application of 3DP technology in construction industry (Wu et al., 2016) has been interrelated with other investigations like environmental impact, productivity and cost analysis, as well as topology optimization. Also, the technology has been discussed and explored, emphasizing in parallel its application importance. Several research works related to technology readiness and material properties used for 3DP were conducted, focusing either on the application of 3DP techniques (Ngo et al., 2018) or on the material properties related to their workability and buildability (Long et al., 2019). Moreover, other examples were focused on the application of environmentally friendly and recyclable materials like clay and earth-based in comparison with cement-based ones, emphasizing investigation into their mechanical properties (Perrot et al., 2018). In addition, 3DP works were discussed in terms of their environmental impact and cost analysis, particularly related to the application of scale, process cost, construction time and material type (Wu et al., 2016). Also, works were conducted by following economic analysis, in conjunction with environmental analysis of composite-type 3DP materials (De Schutter et al., 2018).

In the category of structural optimization associated with 3DP techniques, main emphasis was given to small- to medium-scale examples. In this case, topology optimization was used as form-finding technique, and then 3DP technique was implemented for the physical production of shapes. Among others, examples include the work on the production of steel nodes used in the construction of tensegrity structures (Ren & Galjaard, 2015) and the work on the design and fabrication of topologically optimized pedestrian bridges using large-scale 3DP (Yuan et al., 2018); also, the 3DP example of a spatial structure that was examined in terms of its structural performance using topology optimization principles (Chen et al., 2019); finally, the work on the optimization and 3DP building elements based on infill patterns using clay and earth-based materials (Kontovourkis et al., 2019a).

Despite the already existing work, the adoption of 3DP in the wider construction industry is still at an early stage due to a number of reasons. These include, apart from the necessity for improving technology and materials, the lack of knowledge regarding its potential benefits that it can bring to the construction industry towards a more sustainable future (Villoria Sáez et al., 2019).

In order to provide an overview on this direction, this chapter attempts to analyse the 3DP cost and environmental impact of selected masonry walls with different level of geometrical complexity. The aim is to examine the sustainable potential of 3DP used in complex shape production through the comparison of results. Also, to identify future benefits in contrast to traditional construction techniques. Finally, to discuss possible contribution towards the development of a regenerative construction framework, where design optimization and sustainable 3DP will mutually interact with each other, providing more sustainable construction solutions. This approach is based on design optimization, aiming at reducing material, and on sustainable 3D printing of solutions, aiming at reducing cost, global warming potential

and primary energy consumption. At the same time, 3DP and accompanied results aspire to positively affect the environment and to contribute and maintain a healthier state and evolvement of social and ecological systems (Brown & Haselsteiner, 2018).

### 13.3 Research Method

The suggested regenerative construction framework consists of two equally significant parts, the design optimization and the sustainable 3DP of an initial geometry. The design optimization incorporates topology optimization and structural analysis, aiming at redesigning a solid geometry in order to achieve material reduction through an infill pattern for 3DP execution. The sustainable 3DP involves 3DP pre-processing, where the cost, the global warming and the primary energy are calculated. Then, 3DP execution, where the infill geometry is physically produced (see Fig. 13.1).

Analytically, in design optimization part, the topology optimization of an initial solid geometry is applied, aiming at material reduction but also at maximization of its stiffness. Towards this direction, an in-house approach based on infill design and optimization is proposed in order to achieve the 3DP of irregular and complex shapes with surface overhang limitations, controlling at the same time the 3DP tool-path. In particular, two main steps are incorporated in this approach. First, material minimization based on topology optimization (TO) principles using bio-directional evolutionary structural optimization (BESO) (Li et al., 2018) in the parametric design environment of Grasshopper (2020) (Kontovourkis et al., 2019a, b). This is done in order to gradually reduce material from a solid to perforated geometry with variety of infill patterns thickness according to structural efficiency constraints. Second, further structural analysis of results using the Finite Elements Analysis (FEA) software ABAQUS CAE (2020) in order to evaluate compressive strength with the aim of being within the allowable limits.

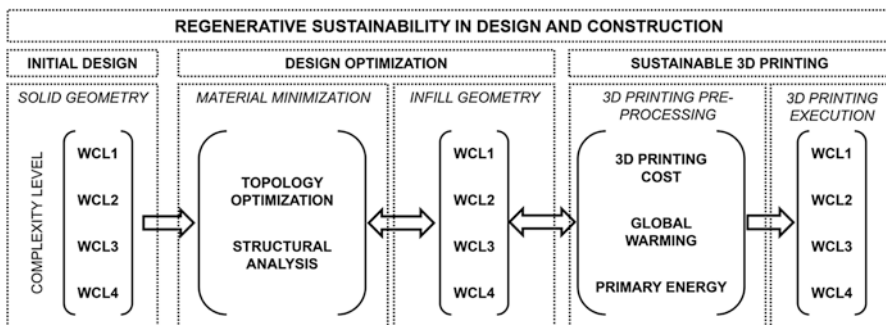


Fig. 13.1 Diagrammatic representation of the suggested regenerative construction framework that involves design optimization and sustainable 3DP

In sustainable 3DP part, the performance analysis of a derived infill geometry is suggested, aiming at identifying indicators that contribute towards a comprehensive sustainable 3DP approach. Among others, these include 3DP cost and environmental impact analysis. The cost analysis incorporates the cost values for the 3DP extruder tool manufacturing and for the overall 3DP construction procedure. The latter is the sum of the cost of the energy consumed during 3DP construction, the labour cost and the cost of material applied. The environmental impact analysis examines the carbon dioxide emissions and the primary energy consumption performance of selected designs. In this part, life cycle analysis (LCA) is conducted, which considers construction materials (A1-A3), transportation to site (A4), construction/installation process (A5) and deconstruction (C1-C4). The global warming (kg CO<sub>2</sub>e) and primary energy consumption (MJ) values are obtained through the use of OneClick LCA software (2020).

In this chapter, the suggested regenerative construction framework is tested through an experiment that deals with the sustainable 3DP performance analysis of selected prefabricated brick units derived from walls with different complexity level (WCL). Specifically, four (4) walls are selected for experimentation, starting with a regular one and moving on to irregular ones with different degrees of complexity. The aim is to compare the results and draw conclusions regarding the effects that the variability in design can bring to the 3DP performance of brick units.

Although the design optimization stage has not been conducted in this chapter, the potential of material reduction is discussed. The aim is to enhance the importance of the regenerative construction diagram as a whole, not only in terms of sustainable 3DP but also in relation to design optimization. Finally, a theoretical discussion on the possible correlation between similar results derived through the traditional construction approach is drawn, in order to stress the importance of using emerging technologies versus traditional ones.

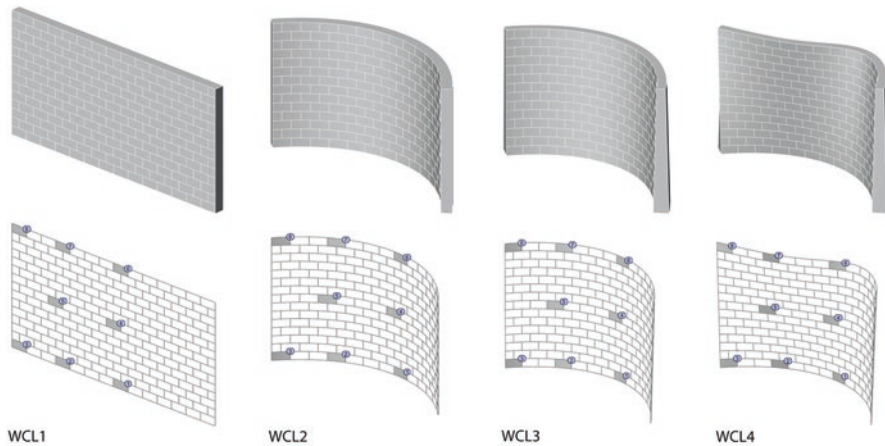
## 13.4 Experimental Results

The geometrical parameters of the selected walls are described in Table 13.1. These examples shall be identified as WCL that is the acronym of wall complexity level. Their measurable information includes walls' base and top lines that control their shape, base and top width, height, overall volume and number of bricks. The selection of specific parameters achieves their gradual shape transformation from a regular wall to a complex one, increasing in this way their degree of complexity. Keeping the same overall volume, the WCL1 refers to a regular wall with linear base and top. The WCL2 is formulated on the basis of two identical and symmetrical curves, maintaining the same thickness throughout its height. The WCL 3 differs in terms of its base and top thickness, while the WCL4 is an asymmetric wall with thickness fluctuating from the base to the top (see Table 13.1).

In all selected walls, the same number of prefabricated brick units are identified, which are located on the same wall's position. Eight (8) brick units for each wall are

**Table 13.1** Overall geometrical parameters of the selected walls in relation to their degree of complexity (WCL1–WCL4)

Wall complexity level (WCL)	Base – top line	Overall dimensions (m)			Volume (m <sup>3</sup> )	Bricks (Num.)
		Length	Base – top width	Height		
WCL1	Linear – linear	6.00	0.25–0.25	3.0	4.5	210
WCL2	Curvilinear – curvilinear	5.15	0.25–0.25	3.0	4.5	210
WCL3	Curvilinear – Curvilinear	4.60	0.35–0.20	3.0	4.5	210
WCL4	Curvilinear – Curvilinear	4.72	0.35–0.20	3.0	4.5	210



**Fig. 13.2** Top: The selected four (4) walls with different degrees of complexity, identifying walls from regular (WCL1) to irregular (WCL4). Bottom: The selected eight (8) brick units on each wall (WCL1–WCL4)

selected for further sustainable 3DP performance analysis, which have specific 3DP characteristics (see Fig. 13.2).

These include the overhang angle in front and in back surface of the brick units (degrees), the brick volume (cm<sup>3</sup>) and the robotic 3D printing time (min). The latter is influenced by a series of input parameters that control 3D printing performance. This experiment considers an infill thickness of 24 mm for all brick units, using an extruder with 24 mm nozzle diameter, 1x3 hex grid infill density and 8 mm layer height. Also, 11 m/sec extrusion velocity and 7 m/sec base layer velocity are selected (explanation on 3DP input parameters can be found in Kontovourkis and Tryfonos (2020)).

In the case of WCL1, the 3DP characteristics are the same for all brick units. More specifically, the overhang angle in front and in back surface is measured at 0°, the brick volume at 12,413.25 cm<sup>3</sup> and the robotic 3D printing time at 97.95 min. In the case of WCL2, the same overhang angle in front and in back surface is measured

at 0°; however, five (5) different brick volumes and five (5) different 3D printing times are observed. Their brick volume ranges between 12,686.99 cm<sup>3</sup> and 12,700.32 cm<sup>3</sup> for brick unit no. 5 to brick units no.1 and 6. The 3D printing time for the same brick units ranges between 100.11 min and 100.22 min. In the case of WCL3, although the overhang angle in front and in back surface for all brick units remains the same, this is measured at 1.43°. Also, eight (8) different brick volumes that range between 11,000.20 cm<sup>3</sup> for brick unit no. 7 and 13,816.73 cm<sup>3</sup> for brick unit no. 1 are observed. In addition, the 3D printing time measurements are different, ranging between 86.80 min for brick unit no. 7 and 109.03 min for brick unit no. 1. Finally, in the case of WCL4, completely different overhang angles in front and in back surface for each brick unit, as well as differences in their volumes and 3D printing times are observed. The characteristics of WCL4 are demonstrated in Table 13.2.

Figure 13.3 demonstrates the bricks variety in relation to the complexity level for each wall. As it can be observed, while in the example of WCL1, all brick units are identical in relation to their overhang angle in front and back surfaces, their brick volume and their 3D printing time, in the example of WCL4 each brick contains different values. This comparison between the walls identifies the different level of complexity and provides a measurable benchmark for discussing their 3DP performance in each case.

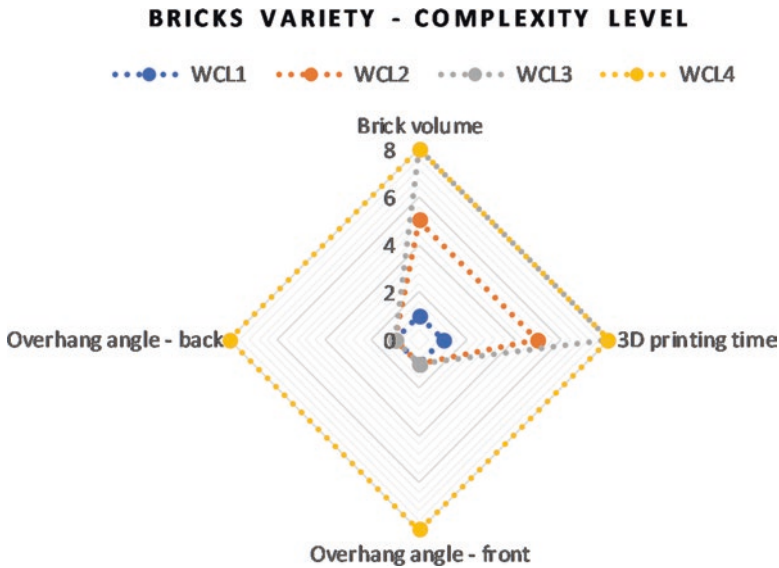
### 13.4.1 Design Optimization

As it has been stated in the section ‘Research method’ of this chapter, in this experiment, the design optimization that deals with topology optimization and structural analysis has not been conducted, due to the concentration of the present research in the sustainable 3DP aspect of the method. However, some important initial information related to this part of the regenerative construction framework are presented herein. The aim is to emphasize the significance of the geometrical results obtained

**Table 13.2** Measurable geometrical and 3DP characteristics for each brick unit in the case of WCL4

Brick unit no.	Overhang angle front – back (degrees)	Brick volume (cm <sup>3</sup> )	Robotic 3D printing time (min)
1	3.02° – (–4.8°)	13,974.24	110.27
2	10.32° – (–13.38°)	13,945.62	110.05
3	0.47° – (–4.11°)	13,899.51	109.68
4	5.04° – (–7.27°)	12,700.27	100.22
5	9.59° – (–12.55°)	12,296.79	97.03
6	3.65° – (–5.67°)	11,818.64	93.26
7	10.45° – (–13.20°)	11,135.85	87.87
8	1.49° – (–3.18°)	10,878.73	85.84



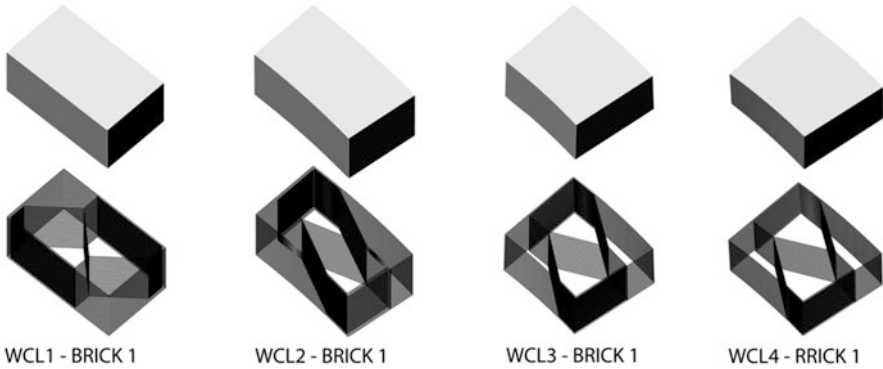


**Fig. 13.3** Graph that demonstrates the variety of bricks in relation to complexity level for each selected wall

through design optimization in relation to the sustainable 3DP performance of brick units.

Specifically, it is observed that the selected brick units in their initial design as solid geometry are at their maximum volumes, which implies the greatest compressive strength. In this case and under certain conditions, the results of sustainable 3DP analysis, which are related to 3DP cost and environmental impact are expected to be maximum. In addition, constraints might occur regarding the 3DP capability of brick units as solid geometries. On the other hand, brick units with infills allow effective 3DP execution, while at the same time their overall volume and weight are reduced. Despite the parallel decrease in compressive strength, this may be within the permissible limits above an infill pattern thickness according to the applied material. Thus, brick units with large infill thickness and material volume are more statically adequate due to their larger compressive strength compared to results where the thickness of their infill pattern is smaller.

Figure 13.4 and Table 13.3 display information related to the solid and infill volume in the case of brick unit no. 1 for all walls (WCL1-WCL4). In the case of 1x3 hex grid infill density and 24 mm infill thickness, as it has been indicated in previous paragraphs, the volume reduction ranges between 42% for WCL1 to 51% for WCL4. The results of infill geometry for all brick units and for each wall are taken into consideration and used in the next steps, which deals with the 3DP cost and environmental impact analysis.



**Fig. 13.4** Solid geometry (Top) and Infill geometry (Bottom) of brick unit no. 1 for all selected walls

**Table 13.3** Information related to the solid and infill volume, as well as volume reduction of brick unit no.1 (WCL1–WCL4)

Wall complexity level (WCL)	WCL1	WCL2	WCL3	WCL4
Brick unit 1 – Solid volume (cm <sup>3</sup> )	21,428.57	21,432.74	26,869.25	27,475.69
Brick unit 1 – Infill volume (cm <sup>3</sup> )	12,413.25	12,700.32	13,816.73	13,974.24
Volume reduction (%)	42	41	49	51

### 13.4.2 3DP Cost Analysis

The 3DP cost analysis of the selected prefabricated brick units for all walls (WCL1–WCL4) is based on the 3DP time and infill volume. It is estimated as the sum of the cost for the 3DP extruder tool manufacturing and the overall 3DP procedure and is calculated as follows:

$$C_{\text{total}(3DP)} = C_{\text{total}(3DP-t)} + C_{\text{total}(3DP-p)}$$

Where  $C_{\text{total}(3DP)}$  is the total cost for 3DP and includes the  $C_{\text{total}(3DP-t)}$ , the total cost of 3DP extruder tool manufacturing, and  $C_{\text{total}(3DP-p)}$ , the total cost for 3DP procedure.

The total cost of the 3DP extruder tool manufacturing is calculated as follows:

$$C_{\text{total}(3DP-t)} = E_{\text{cost}(3DP-t)} + L_{\text{cost}(3DP-t)} + M_{\text{cost}(3DP-t)}$$

Where  $E_{\text{cost}(3DP-t)}$  is the cost for energy consumed during manufacturing of the 3DP extruder tool,  $L_{\text{cost}(3DP-t)}$  is the labour cost and  $M_{\text{cost}(3DP-t)}$ , the cost of materials and mechanical parts consisting the 3DP tool.

The total cost of the 3DP procedure is calculated as follows:

$$C_{\text{total}(3DP-p)} = E_{\text{cost}(3DP-p)} + L_{\text{cost}(3DP-p)} + M_{\text{cost}(3DP-p)}$$

Where,  $E_{\text{cost}(3\text{DP-p})}$  is the energy consumed during 3DP,  $L_{\text{cost}(3\text{DP-p})}$  is the labour cost and  $M_{\text{cost}(3\text{DP-p})}$  is the cost of material applied in each case.

The energy consumed during 3DP procedure is calculated based on the electricity cost according to the time required for 3DP execution. This is the sum of energy required by the industrial robot, the 3DP extruder and the notebook and is calculated at the amount of 6kWh at maximum machine use. The cost of a kilowatt hour (kWh) is estimated at 0.25€. The total cost of 3DP extruder tool is estimated in the amount of 1197 € and is calculated only once in the total production cost of the eight (8) brick units in each wall (WCL1-WCL4). This is due to the ability of 3DP extruder mechanism to be applied repeatedly for the production of one or more prefabricated bricks without any extra cost.

The 3DP cost analysis shows obvious differences between the selected walls based on their complexity level. In the case of WCL1, the same 3DP cost is derived for each brick unit and is calculated in the amount of 18.68€. In the case of WCL2, the 3DP cost ranges between 19.104€ for brick units no. 2 and 7 and 19.118 € for brick unit no. 4. Greater differences are observed in the case of WCL3, where results show a cost range between 16.56 € for brick unit no. 7 and 20.812 € for brick unit no. 1. The greatest differentiation occurs in the case of WCL4, where 3DP cost values range between 16.382 € for brick unit no. 8 and 21.039 € for brick unit no. 1. Table 13.4 shows the cost inputs and Table 13.5 the total cost results of 3DP cost analysis for WCL4.

Figure 13.5 summarizes the 3DP cost per brick unit for all walls (WCL1–WCL4). The results show the same cost for every brick unit in WCL1, while cost gradations appear in the other three walls depending on the differences in 3DP time and infill volume. The differences become more pronounced in the case of WCL4 due to the increasing degree of complexity.

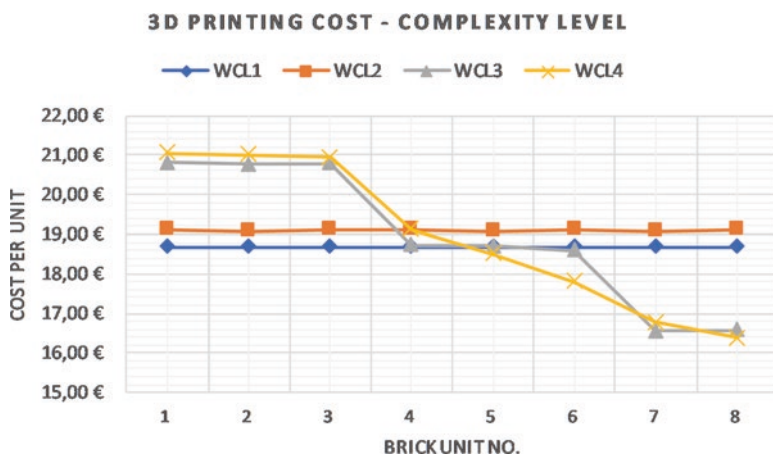
Also, it is observed that the average cost per unit for WCL1 is 18.68 €, for WCL2 is 19.11 €, for WCL3 is 18.93 € and for WCL4 is 18.94 €. In addition, the average 3D printing time for WCL1 is 97.95 min, for WCL2 is 100.16 min, for WCL3 is 97.93 min and for WCL4 is 99.27 min.

**Table 13.4** Cost inputs of 3DP extruder tool manufacturing and 3DP procedure for the selected brick units in the case of WCL4

Brick unit no.	$E_{\text{cost}(3\text{DP-t})}$ (€)	$L_{\text{cost}(3\text{DP-t})}$ (€)	$M_{\text{cost}(3\text{DP-t})}$ (€)	$E_{\text{cost}(3\text{DP-p})}$ (€)	$L_{\text{cost}(3\text{DP-p})}$ (€) per unit	$M_{\text{cost}(3\text{DP-p})}$ (€) per unit
1	1197			2.75	16.193	2.096
2	N/A			2.75	16.161	2.091
3	N/A			2.74	16.106	2.084
4	N/A			2.505	14.717	1.905
5	N/A			2.42	14.249	1.844
6	N/A			2.33	13.695	1.772
7	N/A			2.19	12.904	1.67
8	N/A			2.146	12.605	1.631

**Table 13.5** Total 3DP cost results for the selected brick units in the case of WCL4

Brick unit no.	C <sub>total(3DP-t)</sub> (€)	C <sub>total(3DP-p)</sub> (€)	Average cost per unit (€)
1	1197	21.039	18.94
2	0	21.002	
3	0	20.93	
4	0	19.127	
5	0	18.513	
6	0	17.797	
7	0	16.764	
8	0	16.382	



**Fig. 13.5** Graph that shows the 3DP cost per brick unit for all walls (WCL1–WCL4)

### 13.4.3 Environmental Impact Analysis

The LCA analysis considers adobe as the material of implementation. Also, the results are affected by the energy consumed during 3DP process that is incorporated in the construction/installation process (A5) of the LCA analysis. This is calculated as the sum of the energy required for the 3DP extruder mechanism and the overall 3DP procedure. Also, the results are affected by the material volume of each brick unit, which is associated with the energy consumed during construction material (A1–A3), transportation to site (A4) and deconstruction (C1–C4) of LCA analysis.

The global warming results (kg CO<sub>2</sub>e) show almost similar values in each case (WCL1–WCL4). In the case of WCL1, the global warming is calculated in the amount of 1.11E1 kg CO<sub>2</sub>e. In the case of WCL2, the global warming results range between 1.12E1 kg CO<sub>2</sub>e to 1.13E1 kg CO<sub>2</sub>e. In the case of WCL3, the results range between 1.01E1 kg CO<sub>2</sub>e and 1.21E1 kg CO<sub>2</sub>e. Table 13.6 shows the results of global warming (kg CO<sub>2</sub>e) for each brick unit in the selected wall WCL4.

**Table 13.6** Inputs and results of global warming (kg CO<sub>2</sub>e) for the 3DP of brick units of WCL4 using adobe as the material of implementation

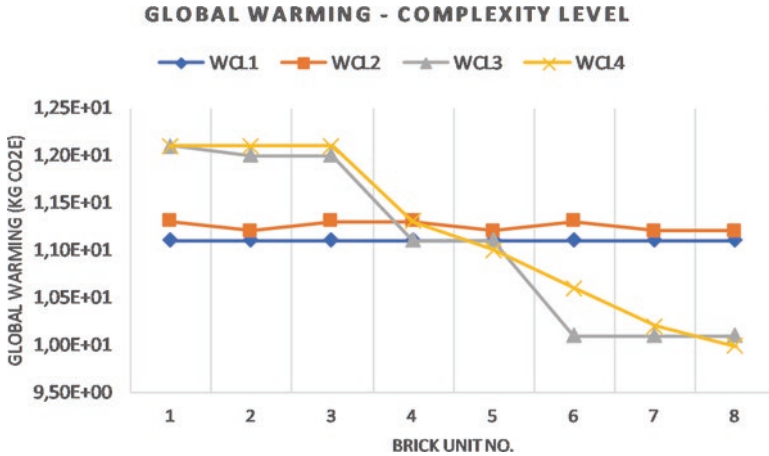
Brick unit no.	A1–A3 Cons. materials	A4 Tran. to site	A5 Const./ Inst. process	C1–C4 De-cons.	Total per unit	Average per unit
1	5.1E–2	5.1E–2	1.19E1	1.4E–1	1.21E1	1.11E1
2	5.1E–2	5.1E–2	1.19E1	1.4E–1	1.21E1	
3	5.12E–2	5.1E–2	1.18E1	1.37E–1	1.21E1	
4	4.68E–2	4.8E–2	1.1E1	1.26E–1	1.13E1	
5	4.54E–2	4.7E–2	1.08E1	1.21E–1	1.1E1	
6	4.35E–2	4.58E–2	1.04E1	1.16E–1	1.06E1	
7	4.09E–2	4.4E–2	9.97E0	1.09E–1	1.02E1	
8	3.98E–2	4.33E–2	9.8E0	1.07E–1	9.99E0	

**Table 13.7** Inputs and results of primary energy (MJ) for the 3DP of brick units of WCL4 using adobe as the material of implementation

Brick unit no.	A1–A3 Cons. materials	A4 Tran. to site	A5 Const./ Inst. process	C1–C4 De-cons.	Total per unit	Average per unit
1	1.19E0	7.39E–1	1.93E2	4.16E0	1.99E2	1.83E2
2	1.19E0	7.39E–1	1.93E2	4.16E0	1.99E2	
3	1.19E0	7.39E–1	1.92E2	4.09E0	1.98E2	
4	1.09E0	6.96E–1	1.79E2	3.74E0	1.85E2	
5	1.05E0	6.82E–1	1.75E2	3.6E0	1.81E2	
6	1.01E0	6.64E–1	1.7E2	3.46E0	1.75E2	
7	9.51E–1	6.39E–1	1.63E2	3.26E0	1.68E2	
8	9.26E–1	6.28E–1	1.6E2	3.19E0	1.65E2	

Similarly, the value of primary energy (MJ) is almost identical in each case (WCL1–WCL4). In the case of WCL1, the primary energy is calculated in the amount of 1.82E2 MJ for every brick unit. In the case of WCL2, the result of primary energy is 1.85E2 MJ for every brick unit. In the case of WCL3, the results range between 1.66E2 MJ to 1.98E2 MJ. Table 13.7 shows the results of primary energy (MJ) for each brick unit in the case of WCL4.

The results of 3DP environmental impact analysis show that the total global warming for the 3DP of a brick unit is calculated in the average amount of 1.11E1 kg CO<sub>2</sub>e for WCL1, 1.12E1 kg CO<sub>2</sub>e for WCL2, 1.1E1 kg CO<sub>2</sub>e for WCL3 and 1.11E1 kg CO<sub>2</sub>e for WCL4. Also, the total primary energy of a brick unit is calculated in the average amount of 1.82E2 MJ for WCL1, 1.85E2 MJ for WCL2, 1.81E2 MJ for WCL3 and 1.83E2 MJ for WCL4. Similar to the results obtained in 3DP cost analysis, the global warming and primary energy results show slight changes in values for each selected wall due to the differences in material volume and 3DP time of each brick units. This is more obvious while the complexity is increased from WCL1 to WCL4 (see Fig. 13.6).



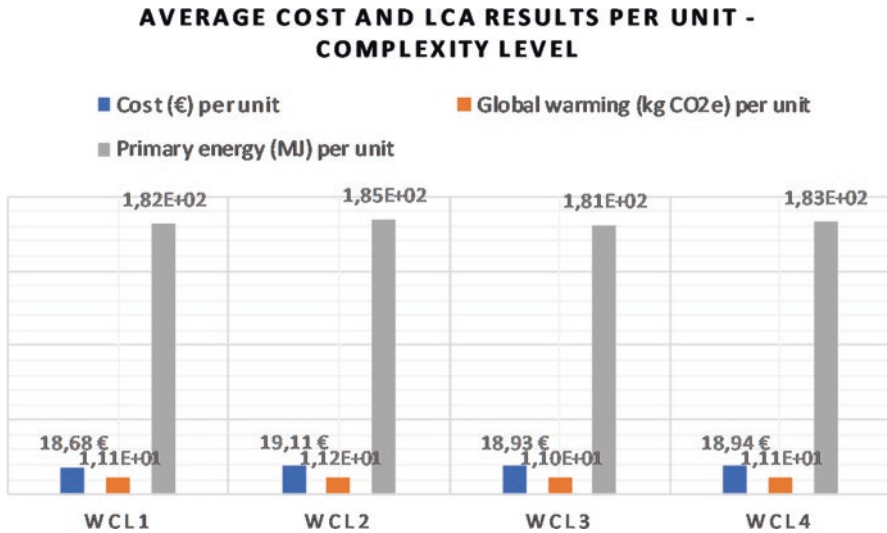
**Fig. 13.6** Graph that shows the global warming per brick unit for the selected walls (WCL1-WCL4)

### 13.5 Discussion

The results derived from this experiment show that the selection of adobe material has advantages in terms of environmental impact analysis due to its superior ecological and recyclable properties compared with other cement-based materials. This achieves to improve the environmental performance of results in terms of global warming and primary energy. Also, the process of material minimization through design optimization allows decreasing of material volume, preserving at the same time structural stability of the brick components. In turn, this influences positively the 3DP cost and environmental impact results due to their dependence with the material volume and 3DP time.

Based on the above outputs, a comparative graph is shown in Fig. 13.7, which demonstrates the average results derived from 3DP cost and environmental impact analysis in relation to the degree of complexity of the selected walls. It is observed that the resulting values do not show any significant changes, while the degree of complexity is rapidly increased from a regular (WCL1) to a fully irregular wall (WCL4). The latter demonstrates large variety of bricks with different geometrical characteristics.

The almost identical results obtained in relation to the increasing complexity of the walls indicate the importance of implementing 3DP in case of irregular designs. In parallel, the results stress the benefits that this technique could bring to the construction industry. This is due to the ability of the 3DP technology to be applied in any design without extra cost or increase in environmental impact. In contrast, the application of traditional techniques for the construction of the same walls with different complexity would provide results with large differences. This is based on the view that in the case of traditional techniques, a significant increment in the cost and environmental impact of results during gradual increasing of wall's complexity



**Fig. 13.7** Graph that compares average cost and environmental impact results of the selected walls with different degree of complexity (WCL1–WCL4)

from WCL1 to the WCL4 could be observed. In this case, the construction technique might be one-off solution and the use of formworks might result in material waste, extra cost and time. The comparison between 3DP and traditional techniques has not been demonstrated herein because it is out of the scope of this experiment; however, further work will focus on this direction.

## 13.6 Conclusions

This chapter aims to review existing 3DP examples with emphasis on their sustainable performance, indicating in parallel their potential for a wider use in the construction industry. It was found that not much research work has been done towards the integration of construction time, cost and environmental impact performance that is driven by structural optimization principles. On the contrary, works in these directions are found to be fragmented and not thoroughly investigated, preventing the establishment of indicators and parameters that can positively influence their performance (Pan et al., 2018).

Towards this direction, the chapter presents a generative construction framework where 3DP technology can be applied in order to positively affect this industrial field. Within this framework, the design optimization and the sustainable 3DP of selected designs with different degrees of complexity play significant role towards the effective implementation of 3DP technology. This is exemplified through the demonstration of an experiment, where four (4) walls with different degrees of

complexity and in particular eight (8) brick units with specific geometrical characteristics are analysed in terms of their 3DP cost, global warming and primary energy performance.

The preliminary results indicate great potential for applying the 3DP technology to the construction industry, especially to automating customized production of geometries with increasing complexity level. This can be done at no extra 3DP cost, global warming and primary energy consumption. In addition, the selection of appropriate materials with superior performances in terms of ecological and recyclable properties and the opportunity for volume reduction through design optimization are important aspects towards environmental impact improvement. Nevertheless, research limits are also acknowledged, such as the initial high cost of purchasing the 3DP mechanisms that include the industrial robot and the 3DP extruders. Their cost depreciation can be achieved in case of increasing production of complex structures.

The results derived from this experiment, might provide an insight on the potential application of 3DP technique to the construction industry towards a more sustainable future. Also, might allow a first understanding on its role within a future regenerative construction framework. Factors that might prevent its widespread use such as lack of knowledge among the construction actors in regard to its sustainable benefits need to be addressed. This can be done through quantitative studies regarding cost and environmental impact performance.

Although, a comparison between 3DP and traditional construction technique has not been undertaken in this paper, future studies will focus on this aspect of investigation. This will allow a rounded and comprehensive examination of the possibilities the 3DP technology can offer to the construction industry.

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# Chapter 14

## From Resilient and Regenerative Materials to a Resilient and Regenerative Built Environment



Ferhat Bejtullahu and Naomi Morishita-Steffen

**Abstract** Urban environmental degradation and disasters are leading to a paradigm shift towards implementing regenerative and resilient concepts on all scales. The interrelationship between microscopic and macroscopic elements of the built environment must be considered from pre-design through to building handover to avoid future disasters and environmental degradation in urban areas. This paper aims to identify synergies between the resilient and regenerative design activities needed on all scales and dimensions. The developed conceptual framework represents the context in which the study is conducted. Cooperation strategies on different scales are required to mitigate the climate crisis by reflecting the dimension of increasing energy consumption requirements from materials to the urban built environment in cities. The methods used to answer the research questions are data analysis from literature and trend comparisons at local, regional and global levels. New approaches and interrelationships were found by testing hypotheses in different design traditions and socio-economic situations. Research findings clearly showed that a new concept has to be created as a cooperative system of discrete disconnected parts in scale-jumping design based on the synergies from regenerative and resilience design and practice. This paper concludes with new concept design principles that need to be implemented in daily life to support the creation of resilient and regenerative solutions for the built environment.

**Keywords** Disaster · Resilience · Regenerative · Design and scale jumping

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## 14.1 Introduction

Many manmade products together with natural materials are used to create resilient and regenerative architecture. Some products are better suited than others as resilient and regenerative building solutions. New strategies in the construction sector are calling for a paradigm shift, a new approach, innovative ideas and continual evolution of culture in relationship with resilient and regenerative materials in architecture.

In this chapter, ‘materials’ are analysed in the context of use for creating micro and macroscopic architectural elements. Many natural materials have been used to create buildings. Some authors call for new uses of green materials as innovative and creative solutions. Green materials such as hemp can be a good alternative to more toxic petrochemical-based materials (Attia, 2016).

However, as pointed out by Ness and Xing (2017: 575), ‘for the construction sector to transition to a circular economy, systemic innovation throughout the value chain is necessary’. Design plays the main role in this transition towards resilient and regenerative products with economic and environmental benefits that consist in cost control and reduced negative environmental impact. Good building design is critical to closing resource loops (Thormark, 2001). The construction sector has been identified as one of the three high-potential sectors for seizing the economic and environmental benefits (SystemIQ et al., 2017).

Changes in microscopic and macroscopic scale transformations are needed to shift the paradigm towards resilient and regenerative architecture. Creating and using adequate construction materials that adapt to the environment is the best way to build resiliently and regeneratively. The paradigm shift is possible by building a microscopic-scale environment, by taking an innovative biomimetic approach for increasing immunity, identifying and avoiding deterioration and recovering damaged materials. This innovative approach towards smart materials will produce a synergy of values placed on the built environment by construction materials and will provide a much higher level of confidence and reliability in the performance of our architecture and built environments.

Buildings, together with the construction industry, account for more global final energy use and energy-related carbon dioxide (CO<sub>2</sub>) emissions than all other industries when material manufacturing and building construction products are included. The built environment consists of manmade building (residential commercial, industrial etc.) and infrastructures such as transportation, communications, streets, energy, water systems, parks and landscaping.

Building end-of-life management is critical to enable material recovery and to prepare for reintegration into the value chain (Nordby, 2009).

Recovering cracks at multiple scales, determined by time, cyclic loading damage and identifying and immunizing against physical damage, will be followed by automated diagnosis and automated healing from chemical damages. Building modelling, tailoring and up-scaling address a diverse range of applications.

The main beneficiaries of resilient materials will be industry, the construction supply chain and those responsible for the provision, management and maintenance of the world's built environment. Working with resilient materials across the supply chain and engaging with complementary initiatives will develop a suite of real-life regenerative architecture. Creating a network in this field will further enhance the diversity and reach of intelligent, self-healing construction materials that will allow for further exploitation of established relationships with the international community to maximize the impact and thereby generate new initiatives in a wide range of related bacteria, chemistry, agents, prophylactics, tailoring and modelling. Nano-structures, polymer composites, sensors, instrumentation and advanced manufacturing will combine to create new biogenic building materials.

New technologies make it possible to revise traditional construction materials and techniques to give new life to renewable and regenerative building materials such as straw, clay and wood-based solutions. EcoCocon is a regenerative example of a prefabricated wall panel composed of locally sourced straw insulation, Forest Stewardship Council (FSC)-certified wood-stud structure and wood fibreboard exterior cladding (see Fig. 14.1). The interior panel surface is ready for interior clay plaster. The Passive House Institute in Germany and the Cradle-to-Cradle Product Innovation Institute have both certified the product meaning that it is suitable for highly energy-efficient construction and is certified to be recyclable. What cannot be recycled can be composted at the end of the building life because it is composed of 98% renewable materials (Kierulf, 2020).

This paper focuses on proactive and reactive dimensions of resilience and regeneration at all scales and the relationships between them. The concepts of resilience and regenerative design use social, spatial and environmental strategies to increase

**Fig. 14.1** EcoCocon wall panel, an example of a regenerative building product (Kierulf, 2020)



a community’s abilities to avoid and reflect on disasters, as well as mitigating climate crisis and decreasing energy consumption. In Fig. 14.2 below, a framework is presented that explains the context in which research is conducted (systems, approaches, construction value chain for building life cycle, causes-effects of disasters and environmental degradation, interdependence of concepts from actions in all scales) together with development criteria at all scales, systems and interrelations between individual actions.

The following questions were raised when identifying the context and global trends on mitigating climate crisis and deflecting increasing energy consumption:

- Do interrelations between resilient and regenerative designs at different scales (from materials to the built environment in the city) and dimensions improve living in harmony with nature?
- How changed approach of design and construction can produce resilient and regenerative elements for a built environment that are socially, spatially and environmentally healthy and safe to human and natural systems at both the microscopic and macroscopic scales?

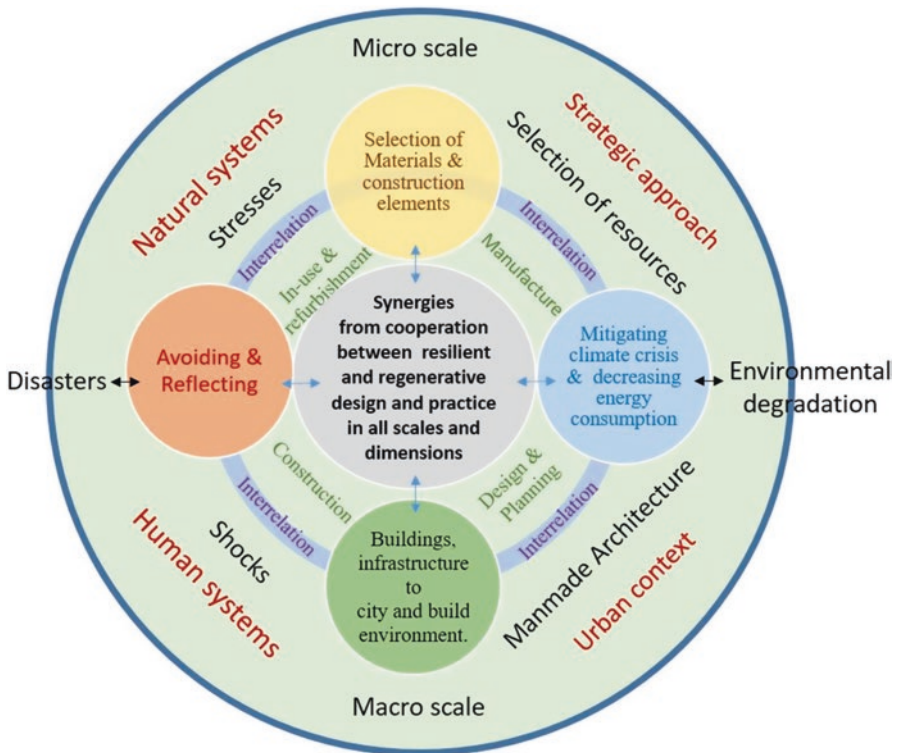


Fig. 14.2 The conceptual framework represents the scope of the conducted study

## 14.2 Methods

The research is empirical and employs a confirmatory approach that builds on the relational view as a primary theoretical foundation. Analytical and comparative methodologies are used to identify trends and linkages between concepts.

Synergies from resilient and regenerative design and practice are identified and presented in the conceptual framework as seen in Fig. 14.2. The conceptual framework represents the content in which the study is conducted. It is based on the accepted theories and experiences. The conceptual framework is designed as an analytical tool for providing solutions for environmental degradation and disasters.

This tool is used to identify conceptual distinctions, organize actions and accepted ideas to serve as the guiding research principles in a way that is easy to remember and apply.

The background of the study is conducted and presented within the context of the points outlined in Fig. 14.2. The illustration uses a systems-thinking approach showing the relationships between human and natural systems to approaches for regenerative design and practice within its overall context. The construction value chain for the whole building lifecycle is prevalent from the microscopic scale at the top to the macroscopic scale at the bottom. The causes and effects of disasters and environmental degradation are visible at the left and right periphery of the circular model. All actions within the built environment interact at all scales with each other and are interdependent.

Analysing the conceptual framework in the figure above, it is easy to identify synergies. A system thinking approach during the decision-making process avoids shocks and stresses, and maximizing interactions from design interrelationships on different scales. Building projects are assessed based on the lifecycle benefits that resilient time scales and regenerative design phases bring to the built environment. All elements of the built environment from the microscopic to macroscopic scales, and other systems, integrate and adopt new flexible concepts to unforeseen challenges in the future.

This conceptual framework is designed based on literature analyses keeping in mind that both concepts (regenerative and resilient design and practice) are reflections on disasters and environmental degradation at all scales, from microscopic through to macroscopic scales.

Disasters are affected by stresses in natural systems and shocks from human systems. Environmental degradation is affected by the selection of resources as a strategic approach and manmade architecture in the urban context. Energy consumption must be decreased as an answer to environmental degradation together with other measures on both the microscopic and macroscopic scales to avoid and reflect on disasters and to mitigate the effects of the climate crisis.

The interrelations between different actions are represented as coloured circles in Fig. 14.2. All scales of resilient and regenerative design and practice produce synergies that come from cooperation on social, spatial and temporal dimensions.

Community participation during the design process is vital at all scales from resilient and regenerative materials to a resilient and regenerative built environment during the entire life cycle planning process, from the implementation to the post-occupancy stage.

Conceptual interdependence from the cooperation between actions at all scales increases its added value to the construction chain for the building lifecycle.

As presented in Fig. 14.2, avoiding and reflecting disasters with resilient design depends on the selection of materials and construction elements during the design process, while the building is in use, and during the refurbishment phase at a microscopic scale. Buildings, urban infrastructure and the built environment during the construction phase are dependent upon macroscopic scale considerations.

It is necessary to take actions that are dependent on a selection of materials and construction elements during manufacturing on a microscopic scale, while on a macroscopic scale, it is dependent on design and planning scales. Mitigating the climate crisis and decreasing energy consumption as reflected by environmental degradation with regenerative design must also be considered.

Cooperation between resilient and regenerative design and practice at all scales and dimensions have shown that synergies can be produced, which will result in a resilient and regenerative environment. The identified interdependence and interrelationships of all actions are essential for the success of the projects for the entire building life cycle from the initial concept to the eventual reuse, disassembly or renewal of the building in another form.

### ***14.2.1 Comparative Case Studies***

The Iranian-born architect and founder of the CalEarth Institute, Nadir Kahlili, developed his concept of SuperAdobe in the 1980s initially as a system to empower the poor and refugees to be able to build their own homes using an abundant natural material: earth (Cal-Earth Inc. 2016a). The system is based upon filling long, tubular-shaped plastic or fabric bags with a mixture comprised of 10% cement and 90% locally available materials: earth (e.g. sand and/or clay), natural fibrous materials (e.g. sticks, straw and/or manure) and water (Morishita, Haj Ismail, & Cetin, 2017).

The importance of involving traditionally excluded stakeholders in an integrated design process can be seen when comparing the application of the ‘SuperAdobe Bags’ from CalEarth (Cal-Earth Inc. 2016d) in the Konbit Shelter project that rebuilt the village of Cormiers in Haiti after the 2010 earthquake, and the application of the same technology for the UNHCR Baniniajar Refugee Camp in Khuzestan, Iran (Morishita et al., 2017).

The Konbit Shelter Project built a community centre and two single-family homes over four years from 2010 to 2014 (Konbit Shelter, 2013a, 2013b, 2013c). In addition, Konbit Shelter also built one family home in 2017 built from bamboo. Konbit Shelter continues active in the maintenance of the buildings in collaboration



with the local community. The team was comprised of a team from American creative communities, a farming organization and the village of Cormiers, Haiti. The team also built up the community because the buildings reflected the local vernacular, incorporated local art and community values and taught the community to work together by building the structures together. Even though the community centre and the SuperAdobe houses incorporated local art and community values, they do not reflect the local vernacular architecture. It thus trained the local population not only about how to build using the SuperAdobe technique, but they earned a good wage while building, and the structures are a source of pride for the community (Curry, 2013). Caledonia Curry, the project initiator, not only ensured that the milestones were celebrated but also brought the team together daily for a shared meal after each day's hard work cementing the bond between the members from both the United States and Haiti (Curry 2017).

CalEarth built the Baninajar Refugee Camp for UNHCR as a shelter project for Marshland Arabs in 1995 (Cal-Earth Inc. , 2016b). Fifteen SuperAdobe houses were built together with the inhabitants of the refugee camp. Because a detailed needs analysis was not conducted before and during housing construction, no accommodation of gender separation in the homes, nor outdoor spaces for each home were considered. The housing did not meet the needs of the inhabitants (Stasi, 2012).

### ***14.2.2 Living Systems in Resilient and Regenerative Architecture and Design at All Scales***

A resilient and regenerative built environment at all scales needs to become a source for producing means and energy, regenerating degradation from the past, and transforming waste into health-giving resources. This requires a whole-systems approach lifestyle and development approach that takes into account both the human and non-human ecology of the built environment.

In the urban context, it is necessary to take a strategic approach and identify synergies in relationships between natural and human systems. Materials, designed elements, buildings, neighbourhoods and cities should not be considered as separated components in different scales but rather designed to become parts of larger systems that function by creating a resilient and regenerative built environment in every scale and dimension.

There are several reasons to move towards co-operations between regenerative and resilient developments.

Resilient and regenerative developments are focused on humans, as well as other systems and dimensions as a natural and united part of ecosystems. Both developments investigate how humans as a part of ecosystems are engaged to create synergies between built environment and natural systems.

Identifying the causes and effects of disasters and environmental degradation on both micro and macroscopic levels help to create new concepts to avoid and recover from disasters, mitigate climate crisis and decrease energy consumption.

A vital part of resilient and regenerative developments considers the context of each place as unique and diverse natural and architectural elements of environmental challenges and opportunities. Understanding social, spatial and environmental contexts help to identify localized responses that allow avoidance and rebounding after a disaster. Localized responses also help to mitigate climate crises and to decrease energy consumption. Every element of built environment in any scale of design has to be built to regenerate natural resources of environment. This approach aims to restore or create the capacity of avoid and reflect upon disasters, mitigate climate crisis and decrease energy consumption with system thinking to reduce human intervention.

Resilient and regenerative design is also about the relationships between architecture elements at all scales within the natural environment. Regenerative design shifts the emphasis towards systems thinking – the practice of understanding how parts influence one another within a whole (Meadows, 2002).

A systems-thinking approach is crucial to resilience and regenerative design and development. This approach supports a constantly dynamic and evolving built environment. Resilient and regenerative design and development is a positive contributor to indoor and outdoor quality of life.

Local reality (i.e. social, spatial and environmental) of a place beyond site boundaries and the human aspirations of design and development are aligned by understanding the systems-thinking approach and master pattern.

The men in the refugee camp were able to earn money for their families by selling cement blocks. They could also use the blocks they manufactured for building new homes. Because the SuperAdobe housing did not meet their needs and because the value of cement-block housing was greater, the SuperAdobe homes were eventually abandoned or destroyed by 2013 (Stasi, 2012).

This shows not only that the selected sustainable building technology is important but also the consideration of local factors such as social context for regenerative solutions. Both projects used the same SuperAdobe technique. Yet, the building team of Konbit Shelter took a very different approach to their project emphasizing joy, art and consideration of the end-users from project initiation to hand over of the successful project to the community. The Baniniajar Refugee Camp illustrates how lack of acceptance by the end-users can lead to project failure in the long term, even with the best intentions.

### 14.3 Results

Systems thinking and institutional promotion are necessary key strategies to maximize synergies between regenerative and resilient designs at different scales while avoiding and recovering from shocks and stresses. The importance of establishing

global networks to promote collaborations between concepts is gaining increasing attention. Networks can bolster urban resilience by providing mutual support and by creating a platform for sharing knowledge, experience and to facilitate peer-to-peer learning, even in the absence of action at higher levels of government (Lu & Stead, 2013).

New concepts and approaches beginning with regenerative and resilient design at all scales and phases are needed for developing processes to creating regenerative and resilient environments. Table 14.1, illustrates jumping scales, levels and system thinking phases in regenerative and resilient design.

The same principles are followed in the resilience and regenerative design scale-jumping processes as spatial and social aspects, including all aspects of systems thinking: from materials, components, structures, buildings, cities, the built environment to human social systems and culture.

Resilient and regenerative key performance indicators at different scales and their meaning during design and construction phases are explained in the above table.

Resilient and regenerative design of materials during the executive phase is presented at a microscopic scale from 1:1 to 1:5. At this scale, building components, fixings and accessories, constructive aspects, the working of the components and how they should be constructed are also presented.

Resilient and regenerative design during the detailing phase is presented showing detailed building drawings, furniture and components at scales from 1:10 to 1:20. The need for a greater scale is obvious for smaller objects, constructions and components.

During the construction phase, resilient and regenerative design buildings are presented at scales from 1:25 to 1:75. The typical scale of 1:50 is used for building de-signs, the relationship between buildings, floor plans and other detail-specific components of architectural, MEP and structural plans.

Resilient and regenerative building design concepts are presented at scales of 1:100–1:150. The first approaches of smaller works and typologies are presented at these scales during the pre-design stage. For larger buildings, drawings and models with greater detail are considered.

Conceptual designs of resilient and regenerative neighbourhoods are presented at scales of 1:200–1:250. Building shape, volume, access, roof characteristics and the relationship amongst built and empty spaces are considered at this scale. These scales are also suitable for plans, sections and elevations of larger buildings for a comprehensive understanding of the proposal. At this scale, neighbourhood planning of resilient and regenerative neighbourhoods can even contemplate some spatial compositions and layouts.

Planning regenerative and resilient cities at scales from 1:500 to 1:1000 allows for contextual understanding without the requirement to show large regional extensions or analyses such as building heights, land use etc.

Surveys of regenerative and resilient built-environment plans are presented at scales from 1:20,000 to 1:50,000. A scale of 1:20,000 is used for urban planning and zoning maps, master plans and aerial photography surveys.

**Table 14.1** Regenerative and resilient design processes and what they represent at different scales and during different phases

Regenerative and resilient	Typical scale	Scale range	Application	Phase
Materials	1:2	1:1–1:5	Items are more common in advanced project phases such as in an executive project. Building components, materials, fixings and fittings, constructive aspects, components function and how they should be built	Executive
Components	1:15	1:10–1:20	Items include detail drawings of structures, components and furniture. It is evident that a larger scale is needed in smaller objects, constructions and components	Detailing
Structures	1:50	1:25–1:75	Items include the building construction, relationships between structures, floors, flooring, specified wall coatings, interior design and detail-specific components such as plumbing, electrical or structural plans	Construction
Buildings	1:125	1:100–1:150	Included items are first designs of smaller projects and typologies. For larger buildings, drawings at greater detail and models with greater detail including structural details and interior layouts are included at this scale.	Idea
Neighbourhoods	1:225	1:200–1:250	Considerations include the building shape and volume, access, roof characteristics and the relationship between built areas and voids. This scale can be used for a broader proposal understanding for plans, sections and elevations for larger buildings. This scale can also be used for planning some neighbourhood spatial compositions and layouts	Concept
Cities	1:750	1:500–1:1000	This scale can be used for a contextual understanding of the project without the requirement to show large territorial extensions, or surveys of building heights, land use or other details	Planning
Built environment	1:20,000	1:2000–1:50,000	This scale can be used for urban planning and zoning considerations such as master plans or aerial photogrammetric surveys	Surveys

Many research surveys have compared the two concepts to clarify the relationship between regenerative and resilient solutions. Regeneration and resilience strategies reduce possibilities for conceptual misunderstandings. Furthermore, additional clarification is needed to establish how urban resilience relates to other key concepts such as adaptation, recovery and sustainability to maximize synergies and minimize trade-offs among them (Chelleri, Waters, Olazabal, & Minucci, 2015).

Regenerative design and development are based on systems thinking for creating resilient communities that harmonize between the built environment and nature. The ultimate goal of the built environment and the developmental processes related to the built environment is to support and enable 'the continual evolution of culture in relationship to the evolution of life' (Mang & Reed, 2012).

Technical strategies such as buffering, redundancy, rapid feedback, decentralization and ecosystem service integration take into consideration a site's path of least resistance. These technical strategies are effective design tools to increase resilience (Watson & Adams, 2010). The built environment is strongly affected by socioeconomic conditions and by human behaviour even though many aspects of regenerative design and resilience developments focus primarily upon the technical side. A community's long-term survival is essentially dependent upon community participation, policy and integrated design processes when considering social aspects (Mertenat & Thomas-Maret, 2012).

Implementing regenerative and resilience concepts will reduce carbon dioxide emissions more quickly than projected. Even with the growth in the green building industry, aggregate carbon dioxide emissions from buildings are projected to grow faster than any other sector through to 2030 (UNEP Buildings, 2007).

To live in harmony with nature, the regenerative conceptual design must identify the needs within the resilience design framework and synergies coming from cooperation at all scales and dimensions.

## 14.4 Discussion

Regenerative concepts implemented by resilient communities will create conditions for a synergy of values focusing on the built environment at all scales operating simultaneously within a project. Many authors discuss the building's role and the building's impact on the resilience and regenerative concept. However, it is not enough. Findings illustrate the need to engage all scales of design and development. Social aspects also need greater consideration for engagement in both the much smaller and larger contexts of community. Synergies must be created within each context. Using the co-operative approach includes environmental issues such as the climate crisis, energy consumption and links issues related to disasters such as the need to avoid and reflect upon disasters. The cooperative approach makes it possible to share values on all scales placed of the built environment, thus enhancing a community's resilience.

It is important to note the need to jump from one scale to another. For example, jumping from the micro-scale of material and elements to the macroscopic-scale of the neighbourhood during different phases while applying systems thinking towards resilient and regenerative design processes (see Fig. 14.3). Scale jumping and comparing relationships between elements (e.g. materials, components, structures, buildings, neighbourhood, cities and the built environment) at different scales will create possibilities to identify synergies within the design process.

The co-operative approach combining resilience, regenerative design and planning is focused on different social, spatial and environmental scales. The performance of the built environment at each scale is analysed in both the pre- and post-disaster phases, and also during the quickly developing consequences of the climate crisis.

The reviewed literature has illustrated vulnerable points: factors influencing the ability of an element in the built environment at every scale to avoid, react, recover, reflect and renew after a disastrous event. The vulnerabilities also exist for individuals or larger communities to respond to disastrous events. (Fig. 14.4).

Figure 14.3 is an illustration of the relationships of the scaled items in Table 14.1. Here the items from the microscopic to the macroscopic scales are presented with one another. Restorative and regenerative designs remain at the centre with all other aspects radiating out in a clockwise direction. The different layers from the central restorative and regenerative designs illustrate the project in all its design phases concerning the surrounding environment. The design phases begin from a small scale of 1:2 with material selection radiating out to the largest scale of the built environment at 1:20,000. The scales follow the design phases in a clockwise direction from the earliest and smallest scale to the latest and largest project scale.

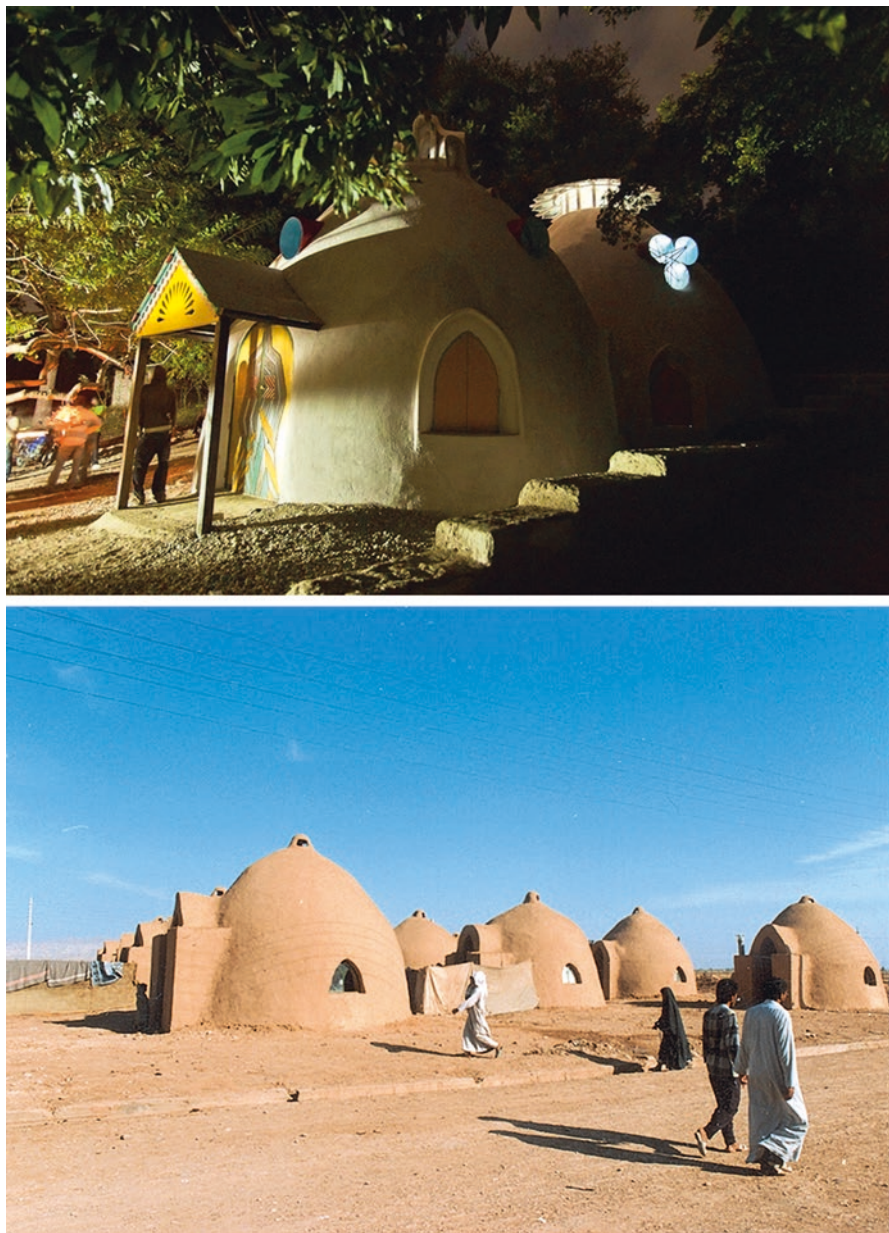
The practically identified synergies and findings are different from the theoretical expectations about the resilient and regenerative built environment. Increased values result by collaborating using the resilient and regenerative approach. Integration is promoted by many theories; however, it has a less positive impact on enhancing the construction of resilient and regenerative buildings.

## 14.5 Conclusions

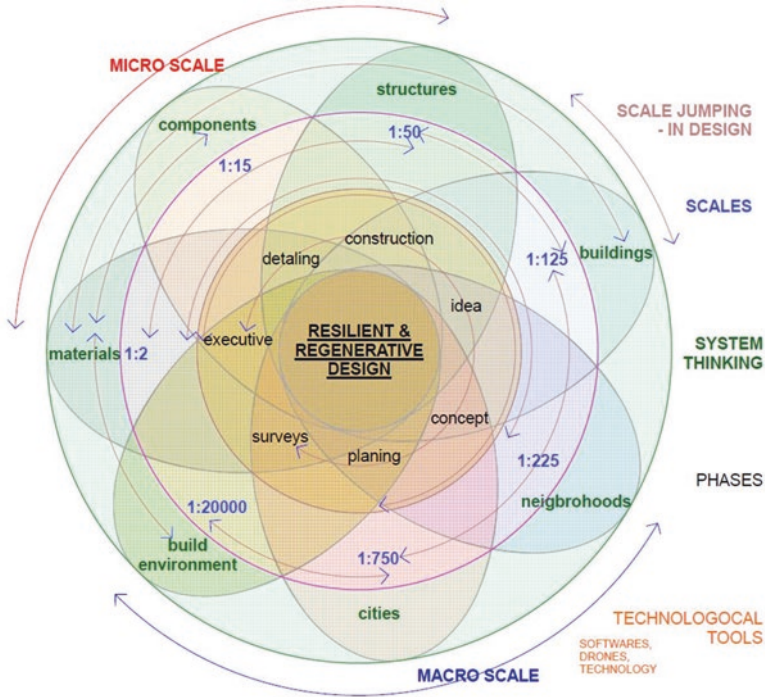
The limitations surrounding the current sustainability approach without considering regeneration and resilience are evident at all scales of the built environment.

Designing and building regenerative architecture is not enough, incorporating resilient and regenerative approaches can produce the synergies. Cooperation between both concepts is needed for applying successful design process on all scales and dimensions.

The interrelationships between measures taken on all scales and compared concepts require a cooperative approach that contributes in collaboration of concepts that will have positive impact to human and natural systems. Simultaneously, implementing stronger policies and partnerships can reduce vulnerability.



**Fig. 14.3** SuperAdobe housing projects in Cormiers, Haiti (top image) (Konbit Shelter [2013c](#)), and in Khuzestan, Iran (bottom image) (Cal-Earth Inc., [2016c](#)). Photo credits Tod Seelie



**Fig. 14.4** Diagram of scale jumping during different phases applying systems thinking of the resilient and regenerative design process

Resilient and regenerative architecture offers a completely different approach to construction: the approach aims to allow anyone who is looking beyond the established trends of the building industry to create their vision for living in harmony with nature.

Synergies are available by making connections with the locally available materials, people and resources. Clay, silt, sand and gravel are commonly found at shallow depths between the bedrock and the organic topsoil. The different soil combinations in the right proportions create one of the greenest and most durable building materials known to man. Such organic building methods create a connection with the place by utilizing parts of the local geological history. The principles of resilient and regenerative design not only make use of what is locally available but also create new resources that can be adapted into new building solutions at both the scale of single buildings and large cities.

Implementing concepts at both the microscopic and macroscopic scales will improve the social, spatial and environmental dimensions of living as a part of nature. Resilient and regenerative design cooperation, collaboration and coordination will address the need for actions to mitigate interrelated vulnerabilities and can build resilience against the climate crisis and regenerative environment against environmental degradation.



Understanding and implementing the concepts of regenerative and resilient design in theory and practice are necessary not only for new architecture but also to consider the opportunities of retrofit architecture that will improve building performance by designing innovative, architecturally significant buildings from existing structures.

We can conclude that there is a need to assess building projects based on the lifecycle benefits that resilient and regenerative design brings at all scales from materials to the built environment. All elements of the built environment from the microscopic to the macroscopic scales and adjoining systems must integrate to adopt new flexible concepts to respond to unforeseeable future challenges. New possibilities need to be considered to improve regenerative and resilient architectural design strategies for intelligent building retrofits. New building life-cycle analysis rating tools need to be developed and effectively used. Multi-disciplinary teamwork using an integrated design approach is necessary to promote, cooperate and work towards creating regenerative and resilient architecture and cities using an iterative process keeping resilience and regeneration of buildings in cities and buildings as a core value. An in-depth needs analysis is essential for the continued success of projects after completion.

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# Part III

## Rethinking Technology Towards a Regenerative Economy

### 1.1 Foreword by Wilmer Pasut and Roberto Lollini

Wilmer Pasut and Roberto Lollini

#### *1.1.1 Rethinking Technology: Low Impact Technology for Regenerative Indoor Environment*

When it comes to conceive indoor spaces, regenerative design entails placing the wellbeing of occupants and their expectations at the center. The accent weight here is on the making of such wellbeing as per the regenerative paradigm, versus the reductionist approach of sustainable design that targets the absence of illness health.

*RESTORE* aimed at defining an overall approach to characterize a regenerative indoor environment and related enabling technologies.

The work on technologies for a restorative environment was inspired by five driving questions:

- What is a restorative indoor environment, and which are its most representative parameters?
- How to measure and assess regenerative indoor environments?
- What is the impact of climatic and cultural differences on users' perception and expectation?
- What is the technology to achieve and maintain a restorative indoor environment?
- How can environmental and social impact analyses be used to evaluate the technology for a restorative environment?

Regarding indoor environmental quality (IEQ) conditions, four main conventional areas were considered and assessed in the literature over the last decades: air quality, hygro-thermal environment, visual environment, acoustic environment. These aspects are strictly connected with occupants' wellbeing, potential

‘sick-building’ syndrome and, on the other side, energy and sustainability issues. Moreover, temperature, lighting, sound and vibration, indoor air quality and personal control are the factors known to highly affect working productivity in offices and commercial buildings. The centrality of the occupants is highlighted by the parameters to define it and by the tools used to evaluate it. The post-occupancy evaluation surveys and indoor measurements proposed by RESTORE emphasize the need of an environment that is tailored on its users.

In addition to the classical IEQ parameters, the perspective of a regenerative indoor environment which boosts occupant’s satisfaction, health and wellbeing, has been emphasized by adding some human related values in the analysis. These are mainly related to the view of the outdoors and to the concept of biophilia, opening new possibilities not only to explore integrated regenerative performance but also to create inspiring environments.

Indoor climate is perceived individually, and the requirements are subjectively shaped. Various studies have shown different preferences in terms of IEQ parameters according to the origin, climate, socio-cultural context and individually subjective criteria. Human body’s physiological and psychological responses to the environment and the comfort perception are subjective, and integrate various physical phenomena that interact in the indoor environment. Any discussion on sustainability embraces the ongoing relationship between human and natural systems. People are integral parts of ecosystems and dynamic interactions among parts drive changes within ecosystems themselves, both directly and indirectly, and thereby cause changes in human wellbeing.

Technologies will be the key to promote a paradigm shift in building design from “less bad” to “regenerative”. However, optimal technology choices need a proper knowledge evaluation framework as it was developed in RESTORE for the collection of solution-sets to achieve the regenerative environment goals. The framework is a means for establishing the links between the environmental aspects, their sub-aspects and the functions required by the building systems and components, in order to clearly define the technology enabling the achievement of the regenerative parameters.

Finally, the regenerative nature of an indoor environment goes beyond the physical walls of a building. Proper technology solution-sets can enable a regenerative indoor environment for building users and for the planet ensuring wellbeing and health. Indoor environmental quality also means minimizing impact and use of resources in the building life cycles, e.g. raw materials, energy, water and emissions. The regenerative solutions must be evaluated in the whole life cycle. Environmental Life Cycle Assessment (LCA) is a methodology that can be used to assess these solutions from a whole lifecycle perspective, including the pre-production stage, production, and implementation, in which environmental characteristics are mainly considered. Economic and social characteristics are measured by applying Life Cycle Costing (LCC) and Social Life Cycle Assessment (S-LCA) frameworks, as additional methods used to measure economic and social implications of the assessed solutions.

COST RESTORE WG 4 “Rethinking Technology” leaders

# Chapter 15

## The Blue Growth Smart Specialization Challenges Towards the Restorative Economy



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**Abstract** The ‘blue economy’ embraces more than five million jobs and the gross added value in the second decade of this century is surpassing EUR half a trillion a year. Now when this growth even accelerates in many more sub-sectors the process goes driven in two ways. On one side, a wave of smart specialization strategies at regional and urban level is under way, in many cases incorporating the restorative economy elements. On the other side, changes just happened even without the respective strategies in the blue economy structure and challenge the established sectors. The purpose of this chapter of the book is to identify the main challenges of the smart specialization strategies at urban and regional level incorporating the blue growth elements that are met towards the restorative economy frames. The methods used are a literature and key policy documents review and some secondary data analysis over performed by the European Commission contractor investigation with reference to a project performed in the sector. As a conclusion the recommendation for sectoral specialization of the coastal areas and its cities’ economy in accordance with the innovative potential for blue growth was outlined, with the understanding it might be fragile due to the unsustainable economic activities in the seas.

**Keywords** Blue economy sectors · Restorative economy · Blue growth · Smart specialization · Innovation

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## 15.1 Introduction

Traditionally, the businesses associated with sea are important for the European economies and what matters more in the last decade proved to be a potential for growth and innovation. The achievement of the last Europe 2020 strategy for growth goals was substantially due to the maritime sector's improvements and innovations. Blue growth is the long-term strategy to support sustainable growth in the marine and maritime sectors as a whole. The 'blue economy' embraces more than five million jobs and the gross added value in the second decade of this century is surpassing EUR half a trillion a year. Now this growth even accelerates in many more sub-sectors (European Commission, 2017). At the same time, even higher growth is possible in a few more sectors and subsectors which were in the focus of the strategy.

The process is driven in two ways. On one side, a wave of smart specialization strategies at regional and urban level is under way, in many cases incorporating the restorative economy elements. On the other side, changes just happened even without the respective strategies in the blue economy structure and challenge the established sectors.

Those sectors include the coastal tourism, marine living resources, marine non-living resources, port activities, shipbuilding and repair and maritime transport. The field research partly is accumulated on the results of the IRISI ('Indexing the Regional Innovative Levels in the Sectors of the Economy – scenario for the identified in the ISSS four priority thematic areas for smart specialization and their positioning towards the circular economy') project financed under the Bulgarian National Scientific Fund. Each of them concerns the issues of the restorative economy either in urban development and changes in the special planning of the industrial sites related to the blue economy, and in regional aspects with the interactions of the other sectors and elements of the infrastructure serving the sustainable urban development.

The aim of this chapter of the book is to identify the main challenges of the smart specialization strategies at the urban and regional level incorporating the blue growth elements that are met towards the restorative economy frames.

## 15.2 The Blue Economy Problems Outline

Unlike the introduction of most terminologies in the business practice today the blue economy terminology was initially tracked in the mid-90s, when the Belgian businessman and futurist [Gunter Pauli](#) (Pauli, 2010) was asked by the United Nations to think about innovative business models of the future. For the last decade most efforts and achievements are related with the documents introduced by the European Union institutions (European Commission, 2009) before it became a focus of researchers. According to the Commission (2009), the blue economy includes economic activities that are marine based and marine related. The

marine-based activities include those undertaken in the ocean, sea and coastal areas, such as capture fisheries and aquaculture, offshore oil and gas, offshore wind energy, ocean energy, desalination, shipping and marine transport, and marine and coastal tourism. The marine-related activities use products and/or produce products and services from the ocean and marine-based activities; for example, seafood processing, marine biotechnology, shipbuilding and repair, port activities, equipment.

The blue economy-established sectors include the marine living resources, marine extraction of non-living resources, maritime transport, port activities, shipbuilding and repair and coastal tourism. While those activities are mostly traditional and profitable, a real challenge is to match them with the logic of the restorative economy and the sustainability achievements. Besides the established sectors in the blue economy, some emerging (a focus in the next section under the blue growth) and innovative sectors bring new opportunities for investment and hold huge potential for the future development of coastal communities (JRC, 2016; Roberts & Ali, 2016). While there are still many challenges to be faced, this chapter makes a step in assessing the potential of the seas and coasts in leading to sustainable economic growth and seeks to support the development of management policies that will ensure it goes in the regenerative economy direction. Hence, the importance of discussing the need to maintain healthy oceans that help preserve and increase the natural capital from which ecosystem services are produced.

Promoting the blue economy is related with substantial funding resources, but governments and coastal local authorities often do not achieve a lot to accelerate investments from public funds and the business in the blue economy, and not with the volumes that would allow the mature sectors to change or that would promote new sectors in the economy (OECD, 2016). In many cases the conditions needed for the blue growth are in relation with the circular economy (Baltov, 2016) and the sources of financing can include changes in governance and greener management of coastal areas and resources. In parallel, correcting market and policy failures through the application of scientific results integrated maritime planning (Avelina & Karim, 2015), and barriers have to be removed to restore coasts, and push entrepreneurship and new jobs (European Commission, 2009). There are funding references for restoring marine environment and infrastructure for interested in protected areas, etc. (JRC, 2016).

The idea of the blue growth is related to the promotion of economic growth, social inclusion and living standards in line with ensuring environmental sustainability of the coastal areas at the seas, oceans and rivers. It refers to the decoupling of socioeconomic development through sea-related sectors and activities from environmental degradation (European Commission, 2009). The blue economy has diverse components, including established traditional maritime industries such as fisheries, tourism and maritime transport, but also new and emerging activities, such as offshore renewable energy, aquaculture, seabed extractive activities, and marine biotechnology and bioprospecting. A number of services provided by ocean ecosystems, and for which markets do not exist, also contribute significantly to economic and other human activity such as carbon sequestration, coastal protection, waste disposal and the existence of biodiversity.

### 15.3 Characteristics of the Blue Growth and the Areas to be Promoted

In 2016, the Marine Investment for the Blue Economy (MARIBE) project, funded by HORIZON 2020, carried out a contextual study of blue growth sectors (details in text Box 15.1). Each sector was reviewed in terms of business life cycles as well as from a socioeconomic perspective. Taking into account a broad range of existing studies and research, nine sectors have been shown to be the most influential in the blue economy.

These sectors are mineral resources, marine food, marine biotechnology; energy; transport and trade; circular economy; marine services; tourism and recreational coastal protection. Many of the activities related to the blue economy take place upstream and downstream of one another, creating a value chain. It is important to consider these value chains in the context of the small and medium-sized enterprises' (SMEs) involvement. Many SME-related activities take place not in the core of the sector, but upstream or downstream (Baltov, 2018). In the maritime transport sector, shipping is the core activity. However, a great deal of value is added in seaports and associated services, as well as in shipyards and other supply activities that support shipping.

Another example is with the fisheries, where opportunities exist to extend the value chain both upstream (e.g. vessel support services) and downstream (e.g. processing whole fish into higher value products). The extent of the value chain will determine the total value that can be realized from a single maritime sector. Emerging technologies show that these value chains act as multipliers, triggering the introduction of new forms of production, technologies, logistics, labour processes, organizational relations and networks (Roberts & Ali, 2016).

The direct relation of the nine sectors to the following social goals focuses strongly on climate change and food security (see Fig. 15.1):

- (a) health, demographic change and well-being
- (b) food security, sustainable agriculture and forestry, marine, maritime and inland water research and the bioeconomy

#### **Box 15.1: The MARIBE project**

The project aimed to unlock the potential of multi-use of space in the offshore economy. This forms part of the long-term **blue growth** strategy to support sustainable growth in the marine and maritime sectors as a whole; something which is at the heart of the **Integrated Maritime Policy**, the EU Innovation Union and the **Europe 2020** strategy for smart, sustainable growth. The project was performed in 18 months. The project was funded by the **European Commission** and led by a consortium of 11 partners from Ireland, United Kingdom, Belgium, Spain, Italy, Malta and the Netherlands.



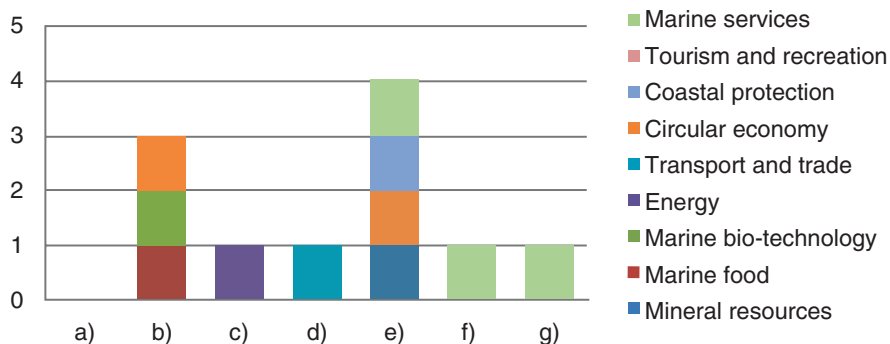


Fig. 15.1 Direct relation to social goals. (Hamza et al. 2018)

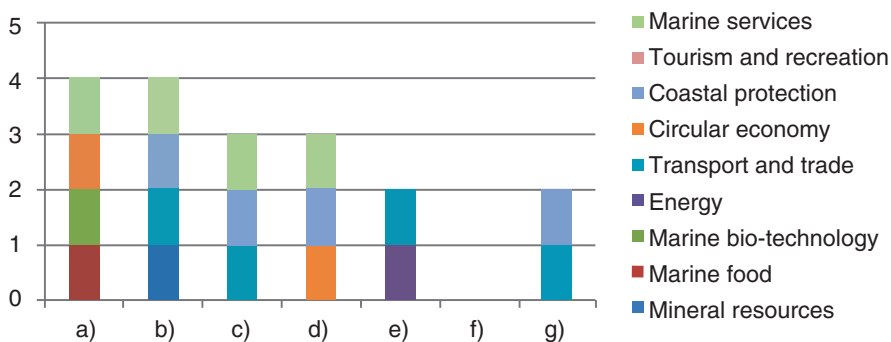


Fig. 15.2 Indirect relation to social goals. (Hamza et al. 2018)

- (c) secure, clean and efficient energy
- (d) smart, green and integrated transport
- (e) climate action, environment, resource efficiency and raw materials
- (f) Europe in a changing world – inclusive, innovative and reflective societies
- (g) secure societies – protecting freedom and security for Europe and its citizens

Indirect relations address health and food security first, followed by clean energy and smart transport (see Fig. 15.2). The tourism sector does not really address any of the social goals, though this does depend on the type of tourism. Exceptions are small-scale, sustainable and local tourism activities that address food security, resource efficiency and smart transport.

Considering one certain sea basin in Europe, towards which still less research over the blue economy issues is conducted and less investments are allocated to the blue growths elements of its economy is the area of the Black Sea. At the meeting of the experts from the Black Sea coastal countries in cooperation with marine experts from leading European marine institutes and organizations, and the European Commission in May 2018, a decision on Burgas Vision Paper was taken (Directorate-General for Research and Innovation DG RTD and Directorate-General DG Mare at

the European Commission expert group, 2018). This vision paper is considering a blue growth initiative for research and innovation in the Black Sea and according to it (Baltov, 2019), incentives for marine and maritime innovation in traditional and emerging blue economy sectors have to be created in four main categories. One is the energy with establishing renewable energy sectors such as offshore wind and waves energy converters.

Then come the aquatic living resources and food including the development of sustainable fisheries, high-tech and eco-friendly aquaculture and the biotechnology including the deriving of high-value novel products from organisms of the unique habitats of the Black Sea. The transport is including the development of sustainable safe shipping for a cleaner marine environment, and certainly the blue tourism.

The considerations and research conducted both by the DG RTD and DG Mare expert group for the Black sea (2018) and by the team of the MARIBE study were mostly following the already established in Commission documents understanding for the sectoral concentration in the blue economy (European Commission, 2013) in established and emerging industries. In a published study of The Economist (2017) over the development of the blue economy, a further description on the innovative trends in its industries were outlined (see Table 15.1). The outline is towards five sectors. Table 15.1 above gives an overview of the five sectors and their development status, as well as drivers for growth to trigger development.

**Table 15.1** Overview of the five sectors of the blue economy

Sectors	Established industries	Emerging industries	Innovative trends	Drivers for future growth
<b>Marine food</b>	Fisheries	Sustainable fisheries	Food processing industry	Food security
	Traditional aquaculture	Freshwater aquaculture and mariculture	Coastal and shore farming of fish, crustaceans, aquatic plants, etc.	Demand for protein and fish consumption
<b>Marine biotechnology</b>		Biotechnology for healthcare products	Functional food	R&D in healthcare and industry
<b>Energy</b>	Offshore wind energy	Tidal and wave energy	Ocean thermal energy conversion	Demand for alternative energy
<b>Transport and trade</b>	Shipping, port infrastructure and services	E-logistics and sustainable shipbuilding	Digitization, automation and environmental technologies	Changes in logistics requirements and regulations
<b>Tourism and recreation</b>	Tourism and coastal development	Ecotourism and authentic experiences		Growth of tourism and coastal urbanization

The Economist (2017)

## 15.4 The Challenges in the Sector of the Blue Energy

By 2020, if the technological and financial challenges are met the pipeline of European projects for which information is available could reach 600 MW of tidal stream and 65 MW of wave energy capacity (JRC, 2016). Taking into account only projects that have been awarded public funds, 71 MW of tidal stream and 37 MW of wave energy capacity could be operational within the European Union (EU) in 2020.

The marine energy projects performed in European countries that have obtained support through the different funding streams (e.g. Horizon 2020, NER 300 and Innovfin) and that are expected to be operational by 2020 account for a substantial amount of wave energy production and even twice for a tidal one. Societal goals met directly are secure, clean and efficient energy (JRC, 2016). The societal goals met indirectly are the climate action, environment, resource efficiency and raw materials.

Speaking of the private investments there are generally three types of investments in offshore wind energy: project acquisition and capital ventures, company mergers and acquisitions, technology funding and advisory for financing in the three types of performance (European Commission, 2018). Merger and acquisition consulting is related to models of projects and their value, some feasibility studies and services for the implementation phase (European Commission, 2009). The investments for the last decade were EUR 1 billion.

The capital expenditure might be different starting for wave energy conversion from 10 to 50 million EUR/MW and for the tidal one at 5–20 million EUR/MW (European Commission, 2017). Now it is expected to lower to 3–6 million EUR/MW in both wave and tidal energy. Only the investors' choice will depend a lot on the governmental policies and the business orientation to the risk (Baltov, 2018). It is assumed both by the Strategic Initiative for Ocean Energy (SI Ocean, 2014) and the European Ocean Energy Association that this year already 850 MW will be installed (OEE, 2016).

## 15.5 Additional Challenges of Smart Specialization Concerning the Urban Development

The importance of the urban areas and cities is clear enough these days when more than 80% of gross domestic product (GDP) in Europe is associated with them, and the substantial part population and consumption of energy is spent with them (European Commission, 2018). At the same time, the blue economy sectors are in many cases situated close or right into these urban areas and they are extremely important for the business dynamics in Europe and generation innovation across the boundaries and changing the other sectors too.

The urban life with its dimensions – economic, social, environmental and cultural – are supposed to be a success and intertwined in urban development just

through an integrated approach (Beel, Jones, & Jones, 2016). Concerning the physical renewal of cities certain actions must be combined in order to promote economic development, education, social inclusion and environmental protection. Strong partnerships between industry, civil society and different levels of government are needed further. Five definite policy objectives are to be set and they are smarter, greener, connected and social Europe, further with a new common goal Europe to cross closer to citizens and to support investment strategies that are locally developed.

But there are also places where persistent problems, such as unemployment, segregation and poverty, are at their most severe. Urban policies therefore have wider cross-border significance, which is why urban development is central to the EU's regional policy. Integrating urban planning and marine spatial planning must be a priority for blue economy. Bringing together spatial planning and integrated coastal zone management through the development of integrated coastal and marine spatial plans might be the steps to guide national government policy-makers, local government officials, marine protection experts and other civic stakeholders.

The key for the cohesion policy of EU in the last period of 2014–2020 is the urban dimension. More than half of the resources of the European Regional Development Fund (ERDF) in the last period are to be spent in urban areas. And in the year of the pandemic even higher amounts might be supposed with the next couple of years with implementation of the projects planned in 2019 and 2020. Not less than EUR 10 billion will be directly spent to integrated sustainable urban development strategies (European Commission, 2018), and those are ERDF funds. More than 700 cities and agglomerations are to be supported for the implementation of integrated strategies for sustainable urban development that were designed in the period.

A decade ago, some 12 priority themes of European and urban importance have been set (European Commission, 2009). They were the epicentre for partnerships identifying problems and recommending solutions through action plans. The action plans are focused to the EU as a whole, the Member States and the cities. On this basis the Urban Agenda is regarded as a coordinated approach to deal with the urban dimension of European, governmental and regional policies and legislation. As some are specific priority topics under special partnerships, the Urban Programme is supposed to improve the quality of life in urban areas (Baltov, 2016). Under it new working methods are regarded to maximize the growth potential of cities and successfully to address social challenges and promote cooperation between the Member States and their cities. The European Commission and other stakeholders are set through it further to stimulate growth, vitality and innovation in Europe's cities (Jones & Jones, 2016). As a referral to the Urban Act the BlueAct (the information on is in the text Box 15.2) is financed exactly under its mechanisms from the EU ERDF funding, and a clear promotion of the cities and regions with active blue economy sectors.

The action plans normally will be proposals under the European Strategic Investment Funds (ESIF), for promoting investments in innovation (Jones & Jones, 2016). The Urban Agenda for the EU at the same time is to put the frames and thus to expect the number and size of cities are increasing by the relative share of urban population, as well as to a change in the functions of cities towards spreading of

**Box 15.2: The BluAct Network**

BluAct was started as a project of the city of Piraeus' Blue Growth Initiative, an entrepreneurship competition promoting incubation to regional businesses aimed at innovation and job creation. Then it was transferred in a network of several European port cities with Piraeus, Ostend, Galati, Mataro, Burgas, Matosinhos and Salerno. The good practices in entrepreneurship were promoted to blue economy and a track for the success stories of the business start-ups was created. The approach was to set up local support groups for Urbact and engage local and other stakeholders by launching the blue economy. This BluAct initiative aims to achieve far-reaching results in the cities involved and other potential cities in the regions.

urban lifestyle (Beel et al., 2016; Brown, Baltov, et al., 2018), In regard to this, the 'smart city' model that arises meets the challenges facing the developing technological and environmental changes. The formulation of contemporary policies to solve social, technological and environmental issues is the main challenge to the development and management of smart cities. They must simultaneously deal with economic development, urbanization and the creation of public services, poverty reduction, environmental protection and socialization of cultural heritage (Kipfer & Wirsig, 2004). To set this 'mechanism' in motion, it is necessary to unite societies (the citizens), institutions, academia, non-governmental organizations (NGOs) and businesses around the great possibilities of new technologies in building a long-term vision for sustainable development of modern cities.

Contemporary digital technologies lead to globalization, help solve environmental problems, necessitate the emergence of new business models and create conditions for significant regional differences in the living standards of the population. A need arises to devise strategies for achieving a balanced and sustainable economic and social development of regions and for overcoming the existing intra-regional and inter-regional disparities (Jones & Jones, 2016; Kipfer & Wirsig, 2004).

The design, building and functioning of smart cities provides the opportunity to come up with effective solutions for optimal utilization and saving of energy, reduction of the consumption of non-renewable resources, control of environmental waste, ensuring sustainable development and optimization of the efficiency of urban systems, that leads to increasing the quality of life of the populations.

## 15.6 Financing and Business Models on the Blue Energy

The Strategic Energy Technology Plan (SET-Plan) of the EU (European Commission, 2009) is supposed to put impetus among the EU-funded programmes for ocean conversion of energy that is in the frames of the European Economic Research Area

(EERA) – namely the New Entrants’ Reserve (NER 300). Three ocean energy projects were awarded around 60 million EUR in total under the first round of the NER 300 programme, which will enable the demonstration of arrays after the year 2016 (European Commission, 2017; Johnson, Dalton, & Masters, 2018). The Action Plan for the Atlantic Ocean area had a definite impact up to now (European Commission, 2013; Johnson et al., 2018).

The Ocean Energy Europe reports 124 million EUR to ocean energy projects between 2005 and 2014, almost 14 million EUR per year (OEE 2016). Now the Horizon 2020 (H2020), the EU’s research and innovation programme, aims to address important societal challenges including clean energy and marine research. As such, it is a powerful tool that can drive the ocean energy sector towards industrialization, creating new jobs and economic growth. In the period 2014–2015, the H2020 programme has funded over 60 million EUR (Johnson et al., 2018; Magagna, Monfardini et al., 2016) of R&D projects in wave and tidal energy. Thirty million EUR of which in demonstration funding for achieving low carbon emissions (LCE 3 and 12). For 2016–2017, a total of 22.6 million EUR was awarded for ocean energy-specific calls, 9.8% of LCE budget. A further 35 million EUR was allocated to blue growth and co-funded calls, which include ocean energy (Johnson et al., 2018).

The main support is structured in two basic approaches. One is the push approach when the grants and certain equity instruments are provided. The second is the pull approach when tariff and mechanisms for revenue stimulus are designed. The pull approach for wave and tidal energy attracts financial support schemes similar to feed-in tariff and renewable obligations (JRC, 2016). Feed-in tariffs are the most common support mechanisms, and are also currently the most popular and sought-after mechanism by investors (European Commission, 2009). At an EU level other available instruments are the Innofin portfolio of blended capital and advisory – provided by the European Investment Bank and the ERDF. Through both of the funding mechanisms the idea is to channel the funding in demonstration type projects. The initiatives for collaboration in regions then will upgrade the creation of marine energy clusters that are to be bones to the supply chains in Europe.

Partly due to the access to the EU funds that were still available in 2020 to the UK proved to have the most advanced support schemes for the “blue” energy sector. For the projects in the last few years its beneficiaries relied mostly on contract for different types of market support (Department of Energy and Climate Change, 2014). The wave and tidal energy conversion for the United Kingdom is assumed to provide higher certainty and positive effects. Those contracts for difference offer a fixed price above the market price for electricity, guaranteed for a period of time. On the other side, the contracts are supposed to perform with less spending and to reduce the project investments.

The technology push approach for wave and tidal energy conversion relates to grants and equity from private investors. The potential in front of them is enormous, the exploitable energy resources are not only in the seas in European equatorial but also in the oceans. This means the possible markets for the conversion energy from the seas are to be opportunities for sectors in the blue economy and also the

manufacturing, construction, etc. Only the uncertainty in future costs is tough to estimate and the market opportunities remain risky.

The design of wave energy conversion projects is problematic if considering some technologies (Baltov, 2018), and certain new infrastructures are needed. They must be focused on reinforcing networks for installation and redesigning the harbours required for some major marine renewable projects. Wind energy is at a mature investment with the achievements in the Baltic Sea for example. But the majority of investors still are not confident enough when approaching the commercial options of wave or tidal devices in the water (Johnson et al., 2018; Meygen, 2014). Then they may consider a commercial array depending on demonstrating that similar technology have the technical capacity to generate reliably. From the rest of the world the Caribbean had proved some potential though it comes with complication due to hurricanes. Another potential synergy is with oil and gas and their supply in the marine areas. But many basins inside EU still do not prove a market development for the “blue” energy sectors.

The sustainable blue economy is expected to grow at pace over the next decade and offers significant opportunities for investment. Several studies have provided estimates of this growth potential. The World Wildlife Fund (WWF, 2015; cited in Accenture, 2017) has estimated that overall global ocean assets, including ecosystem services, are worth 24 trillion USD and that a significant percentage of these assets will rely on healthy, productive and resilient oceans to maintain their value (European Commission, 2018). The Organization for Economic Cooperation and Development (OECD, 2016) conservatively valued the blue economy’s contribution to the global economy in 2010 at 1.5 trillion USD in gross value added.

The design, building and functioning of smart cities provides the opportunity to come up with effective solutions for optimal utilization and saving of energy, reduction of the consumption of non-renewable resources, control of environmental waste, ensuring sustainable development, optimization of the efficiency of urban systems, that leads to increasing the quality of life of the populations. The sectoral specialization of the blue economy is in accordance with its innovative potential and the priority guidelines for the development of scientific research and innovations for cities and regions in coastal areas.

The horizontal policy strengthens the innovation ecosystem in the cities and the regions, whereas the emphasis is placed on the development of certain thematic areas for smart specialization. At the same time, during the past few years, the terminology on the ‘circular economy’, the ‘restorative economy’ and the ‘blue economy’ have surged into common policy usage, all over the world. The general understanding considers them as economic systems that re-design traditional economic system of production and consumption around the circular and regenerative patterns of resource and energy use observed in mature ecosystems. The adoption of restorative economy needs not just policy measures but practical programmes to be cared by different companies to improve not just production system but also the distribution for achieving the regenerative patterns.

Promoting the blue economy requires access to affordable long-term financing at scale, but governments and coastal local authorities often have some deficiencies

when trying to push and promote the development. Sources of financing can include support for governance reform, ecosystem-based management of marine areas and resources, and other enabling conditions required for a blue economy. Correcting market and policy failures through the application of science-based integrated maritime planning and barrier removal instruments act catalytically to restore and protect coasts and to generate sizeable business activity and job creation activities.

## 15.7 Conclusion

When considering the blue economy aspects of the regenerative economy, an innovative approach for development of research and innovation strategies for smart specialization is required. It is based on the quintuple helix model which extends beyond the classical triple helix model and builds upon the quadruple helix model. The outlines of the sectoral specialization of the coastal areas and its cities' economy should be in accordance with the innovative potential for blue growth.

However, the environmental risks or losses in natural capital resulting from unsustainable economic activity in the seas and oceans are continuing to erode the resource base on which such growth depends. The stress and depletion of marine resources have been well-documented. Acidification and warming seas are causing widespread damage with 85% of fish stocks either over-exploited or exploited to the limit. Some estimates show the oceans and seas could contain one kilogram of plastic for every three kilograms of fish by 2025. Unlocking the full potential of a sustainable blue economy is good for the oceans and seas for economies globally. Sustainable blue economy investment and development must be aimed, from the outset, at the transition to a net-zero emissions world, using circular economy models.

The smart specialization strategies have to be developed in compliance with the EC and its Joint Research Centres directorate (JRC) guides and recommendations (JRC, 2016). They aim at increasing the degree of smart specialization through the establishment of some blue growth practices in cities and coastal areas to create an environment of high quality of life for its citizens and good governance.

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# Chapter 16

## From Restorative Building to Regenerative Economy: A Model-Theoretical Analysis on Bio-based Plastics for the Construction Industry



Daniel Friedrich

**Abstract** With the introduction of the Construction Products Directive EU305:2011, architects are more than ever required to select products with a high proportion of renewable raw materials. Only then will it be possible to internalise, hence to compensate, for environmental damage caused by technologies that do not conserve resources and are energy-intensive. Using a novel bio-based wood-plastic composite (WPC) as an example, this chapter shows that internalisation can be successful if conventional fossil plastics are “greened” by adding renewable biomass. The results show that this is only the case if the bio-content is not too high but exceeds a minimum value. The degree of sustainability depends on the assessment of the extent of damage to the environment and society. The optimal level of internalisation can then become allocatively efficient, meaning that the costs of avoiding plastics do not increase more than the damage costs decrease. The findings demonstrate that environmental protection can also be economically meaningful and potentially contributes to increasing social welfare in society. A paradigm shift towards restorative economy in construction should take this principle into account.

**Keywords** Bio-based plastic composites · Internalisation · Environmental damage · Abatement technology · Crude oil preservation

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## 16.1 Introduction

The European construction industry is one of the largest sectors of the economy. In 2017, it accounted for approximately 10% of the gross domestic product within the European Union (Statista, 2020). After the packaging segment, the construction sector consumes 10 million tonnes of plastic, making it the second largest consumer of fossil resources in the form of polymers. This represents about 20% of the total EU-wide plastics consumption (PlasticsEurope, 2020). The advantages of plastics are undoubted. It is durable, tough, easy to shape, and shows special properties that are hard to match by alternatives in construction applications (Youssef & El-Sayed, 2018). These include isolation against electricity, heat retention to increase energy savings and waterproofing. Another important property is recyclability. Through reuse, waste plastic can be converted back into new products of the same quality or lower performance characteristics, thereby significantly extending the entire life cycle of polymers (Hao et al., 2019). But also compared to packaging, the use of plastic in construction has clear advantages. While the former are mostly disposable materials that are either incinerated or recycled immediately after purchase, the question of the end-of-life use of plastics in the construction industry usually only arises after decades. Nevertheless, many building products are offered in a packaging on the market or delivered to the building site wrapped in a plastics foil. Thus, the use of plastic in the construction segment is not generally advantageous and the use of fossil-based polymers in short-lived packaging only makes sense if the packaging is collected and specifically taken for reuse as recycling. In Germany, for example, the recycling rate of bulky waste, such as furniture and inventory is 53%, electrical appliances are 100% recycled, and 99% of construction and demolition waste is recovered (Destatis, 2020). Obviously, efforts are already being made to recycle waste materials in general. However, these do not necessarily meet the criteria of a restorative economy, which consists in the use of renewable resources and not in the exploitation of limited raw materials even if this takes place in several life cycles.

It appears that, in contrast to other industries, the use of fossil resources in construction is comparatively less harmful to the environment only because products show a comparatively longer life span (Álvarez-Chávez, Edwards, Moure-Eraso, & Geiser, 2012). This is not to say, however, that this type of using increasingly scarce raw materials is fundamentally justified and should therefore be raised to status quo. Rather, it must be examined at each stage whether the current exploitation of fossil resources is justifiable. A continuation as before would still be acceptable if the linear use of oil, i.e., the extraction, application and degradation into individual components, which are then deposited in the ground as carbon or introduced into the atmosphere as carbon dioxide, did not lead to damages to the environment and mankind. On the other hand, the question arises as to whether the benefit of plastic as packaging or as a product in a component or building is still high enough if it is balanced against the environmental damage that arises simultaneously or afterwards. This net benefit would then often be too small to justify the current

application. This consideration therefore goes beyond the pure life-cycle analysis and increasingly doubts the current use of polymers even in long-life applications. Finally, the criticism is also justified that the refining of crude oil into plastics as today's standard technology and the loss of fossil resources deprives future generations of a potential. It is to be assumed that with progressive development, future technologies that use this source of raw material might be of far greater benefit to mankind than is the case today. Then the continuation of the current status quo, despite alternatives, would be all the more of a pure egoism of today's generation.

What a possible alternative looks like and whether it is then at all reasonable to substitute all plastics is to be discussed in the further course of this paper. The remainder is as follows: (1) first, sustainability principles will be explained, (2) then a new type of bio-based composite material will be presented, which could play an increasing role as a representative for greener technologies and (3) finally, this particular material will be used to show how an efficient avoidance of fossil-based plastics in the construction industry could look like.

## 16.2 Sustainability Principles

The literature on the goals of sustainability considers ecological and human capital to be worthy of protection in principle. Wackernagel et al. (1999) see the former as the maintenance of habitat, and Heckman (2000) understands the latter as the sum of human knowledge and skills in just this habitat worth protecting. It can therefore be assumed that the loss of eco-capital is accompanied by a loss of human capital. This can be explained by the fact that inductive research in particular is inspired by natural phenomena, meaning that observing nature expands the available knowledge. There are different views on how to maintain the eco-potential while humans use natural resources. The intensity with which such a sustainability strategy leaves eco-capital unchanged therefore determines the type of strategy. Consequently, a distinction is made between the weak sustainability principle and the strong one (Bjørn & Hauschild, 2012; Ryberg et al., 2018). This means that lost eco-capital is substituted in any way, e.g., oil consumption is offset by reforestation (Turner, 1993). It is easy to see that this only maintains the sum of capital, but not resource diversity. Ultimately, mankind cannot exist in an environment that is monotonous and homogeneous in its nature. In contrast, strict sustainability aims not only to maintain the quantity of total capital but to apply this principle to each species and resource, so that diversity is also maintained (Daly, 1991). This presupposes that human intervention in the natural cycle is regenerative, i.e., that the harvest is not greater than the output that results from natural growth. To stay with the example of reforestation, this would demand that deforested rainforest must be replaced by the same species at the same location and the felling of trees must not be greater than naturally growing back, so that the quantity of rainforest remains constant. In order to be able to exploit resources on a larger scale and to limit the damage from the loss of eco-capital, the concept of critical sustainability has been established (Ekins,

Simon, Deutsch, Folke, & De Grootl, 2003). This means that the only compromise to be pursued is the conservation and restoration of at least critical stocks of the same species. Anything beyond this may be substituted in whatever way possible. Here too, it is clear that this principle must not become the rule and should apply on a case-by-case basis.

The problem of the use of fossil resources by plastics can therefore at least follow the weak principle of sustainability, because a similar recovery of consumption is not possible since there is no regeneration. Hence, the only principle remaining is to minimise consumption. This can be achieved by applying avoidance technologies, as shown next using the example of Wood-Polymer Composites.

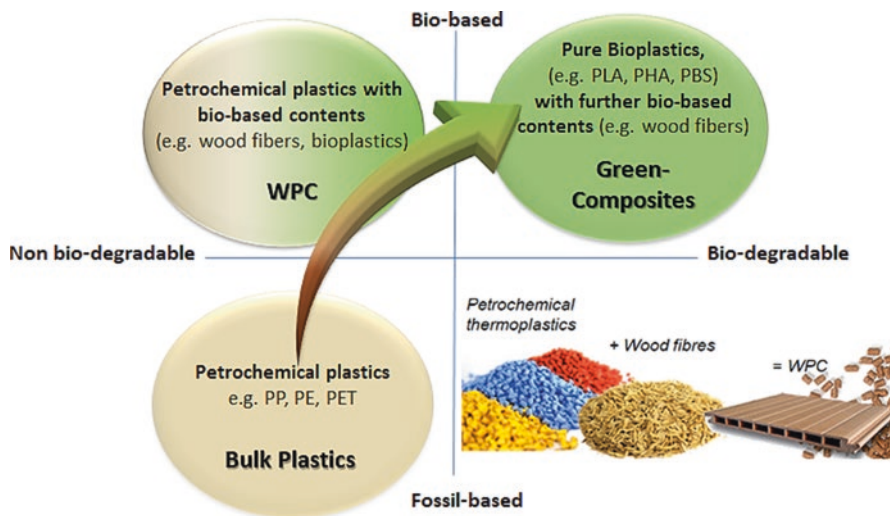
## 16.3 Alternative Technologies to Preserve Resources

### 16.3.1 *Bio-based Materials*

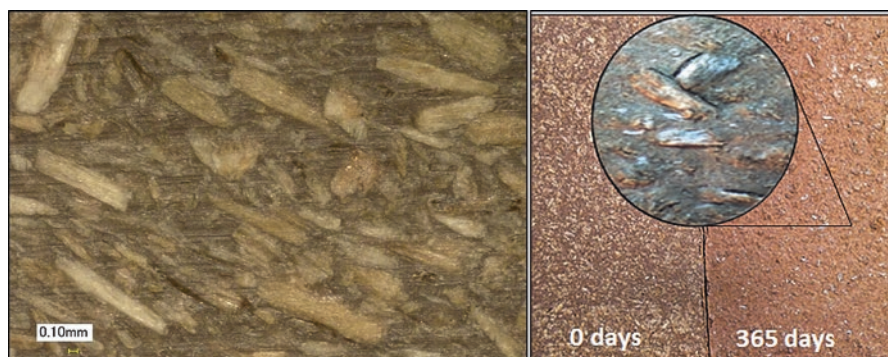
It is out of question that plastic, and the associated exploitation of fossil resources, is often used below its potential as it is the case with packaging, where polymers represent a rather convenient and cost-effective option for protecting goods from external influences, such as sunlight, moisture and mechanical forces, at least during transport (Hao et al., 2019). If the use of plastics was limited only to applications in which this material has no alternative, then resource preservation would be already well advanced. As a consequence, from falling demand, the costs for plastic would rise. Since plastic is currently a low-cost material, it is difficult for alternatives to compete in the market (Pal & Gander, 2018). If sustainable alternatives still managed to compete with more expensive plastic, then any further substitution by the alternative material would counteract a loss of eco-capital. The alternative material would thus have an internalising effect, as its use reduces environmental damage (Mason, 2012).

### 16.3.2 *Wood-Plastic Composites*

It is obvious that especially bio-based materials are internalising. If they are taken from nature under the strict sustainability principle, the application of the weak form of sustainability would be limited to a few exceptions. One such bio-based material is Wood-Polymer Composites, called WPC (see Fig. 16.1). This composite material still consists of fossil-plastic, in which, however, up to 80% by volume plant fibres are embedded (see Fig. 16.2, left). The latter is usually a wood fibre as waste material from the sawmill industry (Carus, Müssig, & Gahle, 2008). This fibre has an aspect ratio of 1:50, hence, it is a longer fibre which, in combination with the thermoplastic matrix, leads to a higher load-bearing capacity of the



**Fig. 16.1** Wood-Plastic Composites (WPC) as a transition technology towards purely bio-based plastics



**Fig. 16.2** Left: Wood fibres encapsulated in a thermoplastics-matrix; right: brushed WPC surface before and after one year of outdoor weathering

material, just like steel reinforcement in concrete (Monteiro, Calado, Rodriguez, & Margem, 2012). The matrix is usually polyethylene (PE), polypropylene (PP) or polyvinyl chloride (PVC). It can also be a recycled plastic.

WPC has been available in the construction sector for 20 years, and the main applications are decking and façade panels (Carus & Eder, 2015). In 2015, for example, 66,000 tons of WPC were produced in Germany (Statista, 2020). According to the author’s opinion, this bio-based material is also becoming increasingly interesting for the packaging industry. To stay with the example of the construction sector, in 2011, the EU Regulation No.305 (CPR, 2011), known as the Construction Products Regulation, was issued. In this regulation, the EU Commission

demands that construction products must also use environmentally friendly and renewable raw materials. A substitution of plastic-based construction products by WPCs would therefore also be in line with legal requirements. Nevertheless, this only makes sense if technical equivalence is assured. Here it becomes obvious that a replacement of plastics by wood or cardboard is only possible in well-selected cases. Especially in the building industry, construction elements are often exposed to weather, so they must be resistant to moisture. This works well for wood when it is surrounded by air and can dry out regularly (Tamrakar & Lopez-Anido, 2011). In the case of WPC, the wood fibre is embedded in the plastics-matrix and thus protected from both moisture and UV-radiation. The water absorption capacity of WPC averages 3%–5% and makes the material even suitable for façade applications. However, the fact that WPC contains biodegradable components may lead to the conclusion that it is not equivalent to conventional building materials in terms of durability. Indeed, investigations with artificial weathering or long-term tests under natural environments confirmed a significant load drop after only one year (Beg & Pickering, 2008). This is accompanied by a degradation of the polymer-matrix in the outer profile layers which translates into polymer chain scissions (Seldén, Nyström, & Langström, 2004). The short-chain polymers then reduce the load capacity. At the same time, the bond with the wood fibre weakens. The latter are eroded out and this degradation process then starts again in the polymer layers behind. The WPC material is thus gradually destroyed, which is associated with a reduction in cross-section and impairs the static load-bearing capacity in the component (Fig. 16.2, right).

According to studies by the author, the characteristic mechanical values would have to be reduced by at least 50% in order to be able to use them as design values in structural analysis (Friedrich, 2016). The final design value thus depends on the characteristic test result from the mechanical resistance test, assuming the flexural strength is the decisive criterion for the applicability of WPC in structural components, such as a façade panel. In this case, this characteristic value should be as high as possible so that after subtraction of material degradation due to ageing, there is still sufficient strength to satisfactorily guarantee the application for a predetermined service life, e.g., 50 years as cladding. In the case of WPC, the characteristic bending strength depends on the fibre content. The more wood fibres are embedded in the plastics-matrix, the higher the sustainability and thus the degree of internalisation of the material. The high fibre content also has a positive effect on mechanical strength, as this makes the plastic more loadbearing (Hung, Chen, & Wu, 2012). It therefore seems to make sense to embed as many fibres as possible. However, degradation increases with the fibre content, i.e., the degree of ageing-related deterioration is higher. From this point of view, it may not make sense to embed as many fibres as possible. On the other hand, the manufacturing costs of WPC rise, because the production speed of extruded WPC profiles decreases with increasing fibre share, i.e., fewer linear metres of profiles can be produced per time unit. This makes the fabrication of WPC elements more expensive, especially since capital costs are comparatively high due to the equipment-intensive production processes. Using too few wood fibres in WPC is not ecologically effective and too many wood fibres are

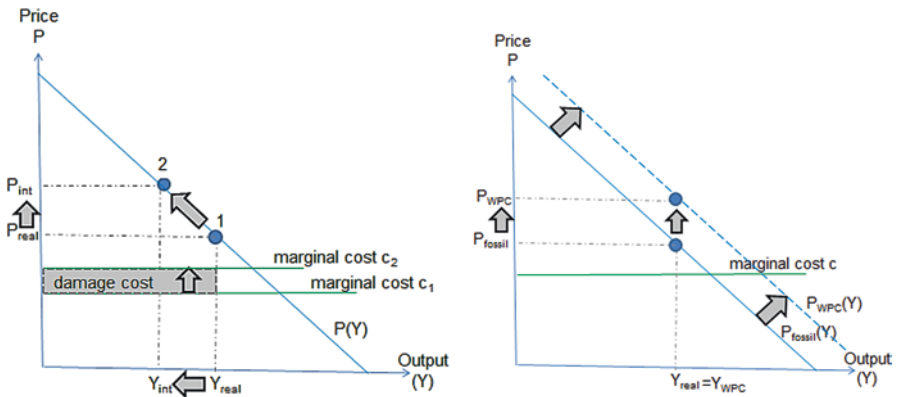


uneconomical. Hence, there must be an optimum where the wood fibre content is efficient, i.e., economical, and yet internalisation remains effective.

## 16.4 Macro-Economic Analysis Regarding the Effectiveness of WPC

### 16.4.1 Model-Theoretical Framework

According to neoclassical theory, the effects of economic factors can be modelled on the basis of a normative analysis. For this purpose, a graph is used in which the market demand  $P(Y)$  is represented as a straight line falling in  $Y$ , which is the quantity of the product (Xu, Cho, & Lee, 2016). If the production of the good causes damage to the environment or society (Fig. 16.3, left: grey area), then this damage should actually be paid by the producer, which is reflected in higher production costs, so-called marginal costs  $c$ . Such damage could occur in the case of oil consumption for plastics due to the exploitation of natural fossil reserves (Pal & Gander, 2018). After use of the plastic,  $CO_2$  would be released into the atmosphere and contribute to global warming (Strimitzer & Höher, 2015). In order for a producer to avoid this compensation payment, other materials can be chosen. However, these are most likely more expensive, since bio-based materials from renewable resources do not cause such damage. Assuming that a governmental regulator would force the producers to pay the compensation fees, e.g., through a  $CO_2$ -tax, as investigated in a study by Convery, McDonnell, and Ferreira (2007). The amount of this tax would then have to be at least equal to the proportionate damage costs in order to make producers indifferent in their choice of more environmentally friendly alternatives. If the producer previously produces with marginal costs of  $c_1$ , the optimal supply



**Fig. 16.3** Left: Internalisation of damage cost through reduction of output  $Y$  and price increase; right: Price-stimulating effect through change from fossil-plastics to bio-based plastics (WPC)

quantity according to Fig. 16.3 (left) is  $Y_{\text{real}}$ . It is optimal because it maximises its profit. In doing so, the producer will demand the highest possible price,  $P_{\text{real}}$ , if the market is willing to pay it.

If now production becomes more expensive, hence reaching a level  $c_2$  due to the punishment fee for pollution, then the producer would only offer  $Y_{\text{int}}$ , i.e., a smaller quantity. This results in less environmentally harmful goods being produced overall, which internalises environmental damage. For the market this has consequences, because now the producer will demand a higher price  $P_{\text{int}}$  to keep his profits stable. This should not bother him at first, because his business is still profitable. But this will not last very long, because consumers might look for alternative products in response to higher prices. If all oil-based plastic products are taxed, then the remaining alternatives should always be more environmentally friendly. The market will thus turn to these substitutes, increasing the pressure on producers to use renewable raw materials instead of paying the tax and freeing themselves from claims of pollution. Overall, the average bio-based products on the market will increase, which has a positive impact on the environment (Amacher, Koskela, & Ollikainen, 2004). The taxation of fossil-plastics in products is effective, i.e., it achieves its goal. However, it is also clear that crude-oil cannot be saved completely because, on the one hand, there are still no alternatives for some applications, which will make them increasingly more expensive in the long term. On the other hand, some companies can pay this tax without any problems because of their financial strength, as this tax applies to the entire industry. Nevertheless, the effect is noticeable and is currently being aimed for with the introduction of the CO<sub>2</sub>-tax in Germany. In this context, a more polluter-related taxation of less environmentally friendly products is more and more under discussion, as a so-called damage tax, DaVAT. This tax could be based on product-specific life-cycle analyses and should then encourage consumers to buy more tax-privileged, environmentally friendly products (Timmermans & Achten, 2018).

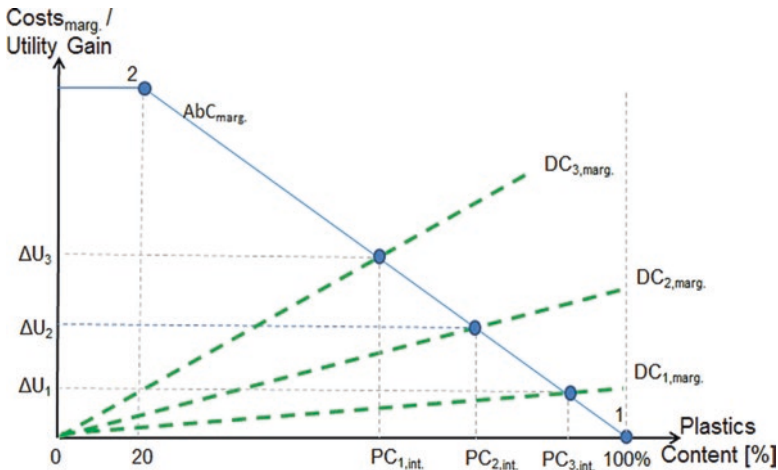
### ***16.4.2 Model-Fit with WPC Technology***

The example shows that internalisation can only work by increasing costs. In the case of WPC, a switch from neat plastics to wood fibre-reinforced plastics would also mean an increase in costs. And yet, as a transitional technology, WPC does have the potential to internalise the market for plastic products without state intervention. As explained so far, the transition to environmentally friendly alternatives must be attractive for the producer. This is the case if it at least maintains the previous profit or even increases it. WPC could certainly be an incentive for manufacturers. Klaiman, Ortega, and Garnache (2016) demonstrated in a consumer study that customers show a higher willingness to buy and pay if they are aware that they act in an environmentally friendly manner when making a purchase. According to Feucht and Zander (2018), eco-labels, and in particular on CO<sub>2</sub>-emissions, can encourage consumers to pay up to 20% higher prices than for less ecological

alternatives. Obviously, awareness of environmentally friendly behaviour alone is sufficient for the  $P(Y)$  curve in Fig. 16.3 (right) to shift upwards, i.e., to show higher willingness to pay on the market. This can be interesting for manufacturers, because sales increase with higher prices, even if the output decreases due to higher costs. This allows higher profits to be achieved. Klein, Emberger-Klein, Menrad, Möhring, and Blesin (2019) found that a higher willingness to pay is difficult to achieve for bio-based plastics as well, especially if they are visually indistinguishable from their counterparts made entirely of plastic. However, the advantage of WPC is that the wood fibres are clearly visible, especially when the surface is brushed (Fig. 16.2, right). This also explains the market success of WPC decking in recent years. This is all the more true when WPC has a high fibre content, for example over 50% (Fig. 16.3, left). Then it would not only save plastic and avoid  $\text{CO}_2$  emissions but also the existing emissions from the plastic still contained in the WPC would be partially compensated by the  $\text{CO}_2$ -sink resulting from the wood fibres. As a consequence, if the consumer is aware that WPC is included in the product, this would be equivalent to a curve-shift from  $P_{\text{fossil}}(Y)$  to  $P_{\text{WPC}}(Y)$ , which is accompanied by a price increase to  $P_{\text{WPC}}$  (Fig. 16.3, right). This can at least compensate for higher production costs resulting from the plastic transition. It is obvious that WPC also has an internalising effect because it substitutes plastics, even if it still contains a small proportion of it. Contrary to the tax, however, the market volume does not decrease, because the profit can remain the same despite higher costs. On the consumer side, the transition is not disadvantageous either, because a better conscience, known as the warm-glow effect, represents an additional benefit for the customer, which he or she purchases together with the product and will pay for additionally.

### 16.4.3 *Optimality Considerations*

Finally, the question remains about the optimal extent of bio-ingredients in plastics. Or, in the case of WPC, what is the optimum fibre content. As already explained, the manufacture of WPC profiles becomes more expensive with increasing fibre content due to lower production speed. On the other hand, a too small proportion is less economical, because the transition to WPC technology is associated with sunk costs from investment. Economics considers a change in technology towards environmentally friendly products to be worthwhile if the cost savings on environmental damage increase at least as much as the costs of the new technology. This means that for the optimal amount of internalising technology, the slope of the damage-saving-curve must be equal to the slope of the cost-curve when the new abatement technology is applied. This is shown in Fig. 16.4 for WPC, assuming that the wood fibre-content corresponds to the degree of use of the internalising technology “WPC”. This means that the more fibres embedded in plastics, the higher the degree of internalisation. Figure 16.4 represents an economic analysis and shows what the optimal internalising wood fibre-content depends on. The X-axis illustrates the proportion of plastics and, on the Y-axis, the marginal costs ( $\text{cost}_{\text{marg.}}$ ) of plastic



**Fig. 16.4** Economically efficient content of plastics in WPC for effective internalisation of environmental damage caused by plastics

avoidance are plotted, which corresponds to the production of WPC. This is described by the curve of the marginal abatement costs ( $AbC_{\text{marg.}}$ ), which decreases with increasing plastic content. Also shown are the marginal damage costs ( $DC_{\text{marg.}}$ ) to the environment through oil exploitation for plastic production. Marginal abatement costs ( $AbC_{\text{marg.}}$ ) at 100% plastic consumption are minimal, because no wood fibres are embedded and thus no WPC is produced (= Point 1). On the other hand, the marginal damage costs ( $DC_{\text{marg.}}$ ) to the environment are maximal. It can also be seen that in the case of a maximum proportion of wood fibres of 80%, which corresponds to the value of 20% plastic on the X-axis, the marginal abatement costs ( $AbC_{\text{marg.}}$ ) become maximal (= Point 2). Then the marginal damage costs ( $DC_{\text{marg.}}$ ) are also minimal. It should be stressed that WPC needs at least 20% wood fibres to be considered WPC at all. Figure 16.4 contains several scenarios of internalisation by WPC, shown as three different marginal damage curves,  $DC_{1,\text{marg.}}$ ,  $DC_{2,\text{marg.}}$ , and  $DC_{3,\text{marg.}}$ . Each of them intersects with the  $AbC_{\text{marg.}}$ -curve. The corresponding amount of remaining plastic content (PC) in the WPC is  $PC_{1,\text{int.}}$  to  $PC_{3,\text{int.}}$ . The following applies to these plastic contents: the degree of damage reduction corresponds to the degree of avoidance cost increase, since all curves are marginal values of the original cost functions. If even less plastic than  $PC_{\text{int.}}$  was to be incorporated, i.e., if the fibre-content was to be further increased, the avoidance would be too expensive compared to the damage savings. Therefore, the result is efficient.

However, it can also be seen from Fig. 16.4 that the steeper the marginal damage curve, the lower the proportion of plastic in order to internalise optimally. It is evident that the additional benefit  $\Delta U$  for the consumer, which is described as warm-glow, increases. Finally, it also becomes clear that it cannot be economically viable to substitute almost the entire plastic, because then the avoidance becomes too

expensive for society. This should only be the case if the environmental damage is rated extremely high.

The analysis makes it clear that WPC internalises ideally because the plastic content can be flexibly adjusted according to the extent of damage caused by plastic in nature. According to the author's opinion, currently about 30% of wood fibres (=PC<sub>2,int.</sub>) should already internalise optimally (Friedrich, 2018). However, in the future, with even more realistic estimates of the extent of damage, higher fibre-content will certainly be required. It is also understandable that this avoidance technology must be used consistently in all products containing plastics in order to develop its internalisation potential at all. If the average fibre content in all plastics applications were already 30% today, the effects from internalisation would certainly be noticeable.

## 16.5 Conclusions

The aim of this chapter was to show how new materials based on biomass help to reduce environmental damage from less sustainable materials. Plastics, which become an internalisation technology through the addition of wood-fibres, were used as an example. It was shown that it is not economically efficient to replace almost all plastic material, because then the transition would be too expensive. The socially optimal degree of biomaterial integration depends on the assessment of the extent of damage caused by petrochemical polymers. The higher the prognosis, the more natural fibres need to be embedded to compensate. Also, the optimum fibre-content increases with decreasing production costs with the new avoidance technology. This means that in the future, costs will continue to fall with higher utilisation, which will then lead to even "greener" plastic materials. The plastics transition in the construction industry must first be initiated, then the change towards a regenerative economy will gain in momentum. The technology already exists, the industry commitment and consumer demand are now required. This internalisation model can also be applied to other sectors, such as the energy industry, where the optimal internalising share of energy from renewable sources can be calculated in the same way.

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# Chapter 17

## The Use of Waste Sludge: Benefits to the Regenerative Economy in Bulgaria



Angel Sarov

**Abstract** This chapter's target is to accentuate on the benefits for the social-economic development, resulting from the wastewater governance. The wastewater treatment is the process of extraction of extra-resources, namely: residual biogas, used for heat and electricity; sand used in the construction; sludge and purified water, discharged into hydro-basins. Simultaneously, attention should be paid of the environmental challenges in relation to the circular economy. The sludge use should become a national policy with a direct governmental engagement, having in view that wastewater treatment plants and wastewater safety are strategic guidelines. Statistical information was used by Eurostat and the Ministry of Agriculture and Food and Forestry (MAFF)'s Agristatistics Department (2020). A brief literature review of publications on the topic is made at the outset. Thereafter, more light is placed on the regulatory framework in the EU and Bulgaria. The analysis continues with the situation so far, based on existing statistics on the quantities of sludge received and its utilization in agriculture in the European countries and in Bulgaria. Dependence and sludge effect on grain yield are determined on the basis of regression analysis.

**Keywords** Sustainable · Regenerative economy · Waste sludge · Agriculture

### 17.1 Introduction

In today's society, there are often controversies related to finding environmentally and economically balanced policies. The controversy is the result of the desire of policymakers to combine the goals of *economic growth* with those of *sustainable development, environmental protection, circular and regenerative economy* (United Nations, 2012, 2015, 2019; FAO & IFAD, 2019; European Commission, 2020). In order to achieve regenerative sustainability, it is necessary to ensure regenerative relationships that allow socio-economic and environmental systems to evolve

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continuously. In recent years, the concept of sustainable development has received a significant international response, being one of the two topics of the 2012 United Nations Conference on Sustainable Development (United Nations, 2012). Governments have agreed to outline the green economy as an important tool for sustainability and to stimulate economic growth, employment, reducing poverty, and maintain balance in the planet's ecosystems.

This chapter's target is to accentuate the benefits for the social-economic development, resulting from wastewater governance. Wastewater treatment is the process of extraction of extra-resources, namely: residual biogas, used for heating and electricity; sand used in construction; sludge and purified water, discharged into hydro-basins. Simultaneously, attention should be paid to the environmental challenges in relation to the circular economy. Statistical information was used by Eurostat (2020) and the MAFF's Agrostistics Department. A brief literature review of publications on the topic is made at the outset. Thereafter, more light is placed on the regulatory frameworks in the EU and Bulgaria. The analysis continues with the situation so far, based on existing statistics on the quantities of sludge received and its utilization in agriculture in the European countries and in Bulgaria. Dependence and sludge effect on grain yield are determined on the basis of regression analysis. Collecting information related to sewage sludge from treatment plants is a difficult and time-consuming process. The main problem is the identified discrepancies in the data provided by different sources. There is clearly an insufficient amount of information collected on sludge and their application in agriculture.

According to the Sustainable Development Goals (United Nations, 2015), agriculture is targeting policies related to environmental protection and conservation of natural resources. In this regard, sustainable agriculture requires politicians, experts, and practitioners to review the traditional agricultural practices known to date. They should balance both the increase in the economic viability of farms, on the one hand, and the enhancement of their social responsibility, on the other (FAO & IFAD, 2019). There are a number of systems for sustainability in agriculture: bio-economy, eco-economy, green economy, shared economy, circular economy, recovery/regenerative economy, etc. results (Bashev, 2016; Hetemäki et al., 2017; Brown et al., 2018; Kopeva, Sterev, & Sabeva, 2018; Kalmykova, Sadagopan, & Rosado, 2018; OECD, 2019).

The concept of a "circular economy is based on the view that prosperity" in agriculture does not mean only increasing the consumption of natural resources, but rather keeping ecosystems in balance with nature (European Commission, 2018; Mensah & Ricart Casadevall, 2019).

Regenerative agriculture is defined as a system of principles and practices leading to increased biodiversity, enrichment of soils, and improvement of ecosystem services. At the same time, yields, climate resilience, and community vitality are increasing (Walthall et al., 2012; FAO, 2016, Elevitch, Mazaroli, & Ragone, 2018).

The goal of regenerative agriculture is to improve soil quality, preserve biodiversity in farmlands and, at the same time, produce profitable agricultural products (Rodale, 1983). The regenerative systems in agriculture provide more efficient "ecosystem services and profitability for farmers" than the intensive production

model. To achieve this, the management model in farms should be rethought through the application of “individual regenerative practices within the current production model” (LaCanne & Lundgren, 2018).

In this regard, the utilization of sludge in agriculture is one of the options in support of strategies for the regenerative economy. The management of sewage sludge from the sewage treatment plants is undoubtedly one of the most sensitive and unresolved issues facing society not only in Bulgaria but also in the world (Di Fraia, Damian Figaj, Massarotti, & Vanoli, 2018; European Commission, 2006; Linderholm, Tillman, & Mattsson, 2012; Yapıcıoğlu & Demir, 2017; Zaharinov, 2011). At the same time, there is increasing interest among the scientific community on the socio-economic and environmental impact of this activity.

The wastewater recycling is a basic component of the circular economy. The wastewater treatment uses the extraction of extra-resources. After a three-step water purification remain the aforementioned biogas, sand, sludge, and purified water. Practically, the biogas could be used for heating and electricity, the sand – in building construction, the purified water – in hydro-basins. With regards to sludge utilization, there are several options related to the improvement of agricultural and non-agricultural soils. The sludge could be used also in forestry, recovery of disturbed terrains, e.g., mines, eroded areas, for fuel, and construction technologies.

In recent years, there has been an increasing need for a sustainable strategy for the management of this waste product. There is a great concern about limiting traditional recycling options, such as direct use in agriculture and others. At this stage, managing these processes requires complex solutions involving all stakeholders, not just treatment plants and sludge users. The utilization of sludge in agriculture should not be considered as the only opportunity to utilize the entire amount of sludge generated by treatment plants (Rada, 2017; Trzcinski, 2018; Turlej & Banaś, 2018; Usman et al., 2012).

## 17.2 Material and Method

The analysis is complemented by summarized information based on technological studies carried out, expert opinions and regulatory framework. The current situation has been taken into account using data from Eurostat (2020) on the amount of sediment formed in treatment plants in the European Union and Bulgaria. The development also uses statistical information from MAFF, Agrostatics Department. On the basis of the regression analysis, the effect of the sludge on the grain yield and the benefits for the regenerative economy in Bulgaria is sought.

In order to assess the effect on the regenerative economy of the cereals production and the utilized sludge in agriculture in Bulgaria, a regression model is tested. In this case, it is assumed that the mean yield is the dependent variable -  $y$ , and the independent (factor) variable is the sediment -  $x$ , i.e., it will be checked whether the average yield of the cereals changes under the influence of the sludge. The purpose of using regression analysis is to describe the function of the relationship between  $x$

and  $y$  using the function of correlation analysis and to determine the strength of this relationship.

The level of dependence between the average yield and the sludge will be verified by a linear function:

$$C = a + b.E + \varepsilon \quad (17.1)$$

Where:

$y$  – dependent variable equal to the average yield of the cereals crops;

$x$  – an independent variable indicating the amount of sludge recovered;

$a$  – free member;

$b$  – coefficient indicating the change of the dependent variable ( $y$ ) when changing the independent variable ( $x$ ) by 1;

$\varepsilon$  – random component.

### 17.3 Regulatory Framework

Directive 86/278 / EU “Environmental Protection Directive” is about the utilization of sewage sludge in agriculture, which is forbidden due to the lack of compliance with the specific requirements. However, the sewage sludge is not dangerous, if suitably used and managed, moreover, after meeting certain requirements, it would not be risky or its usage could even bring benefits. EU has a precise regulation on these issues, stating that sewage sludge is excluded from the category of hazardous waste: Directive 91/156/EU “Waste Base Directive”; Directive 94/3/EU; Directive 2000/60/EU on the landfill; Directive 2000/60/EU, describing the Community action framework, related to the water policy.

Bulgaria joined the EU as a Member State in 2007. Applying the requirements of European legislation in the field of environmental protection, and in particular waste management, Bulgaria also regulates the use of sewage sludge on agricultural soils in its territory.

The main document regulating the environment-friendly sound management and introducing the requirements of the Sludge Directive at a national level is the Regulation on the order and “manner of utilization of sludge from wastewater treatment through its use in agriculture” (Adopted by Decree No 339 of 14.12.2004., SG No. 112 of 23 December 2004). In 2011, the Regulation was amended and a number of amendments were made and the provisions of 2004 were amended in SG from 29/08.04.2011.

The review of the legislation shows that a very small part of the national legislative framework relates to the use of sludge for purposes other than agriculture (e.g., use for forestry or restoration of disturbed terrains). The incineration or disposal of sludge is also examined in the by-laws governing the incineration or landfill of waste. The by-laws on the implementation of the WMA, concerning indirectly the management of sludge in Bulgaria, are: “Regulation No. 4 on the Conditions and

Requirements for the Construction and Operation of Incineration Plants and Co-incineration Plants” (promulgated SG, issue 36 of 2013); “Ordinance No. 6 on the Conditions and Requirements for the Construction and Operation of Landfills and Other Facilities and Installations for the Recovery and Neutralization of Waste (Issued by the Minister of Environment and Water”, prom. SG 80/13/2013, (effective from 13.09.2013); “Ordinance No. 26 of October 2, 1996 for the reclamation of disturbed terrains, improvement of poorly productive lands, removal and utilization of the humus layer” (promulgated SG, issue 89 of 22.10.1996, amended and supplemented - issue 30 of 2002).

The Regulation No 6 of 2013 (State Gazette (SG), 2013) regulates the requirements of the European Waste Landfill Directive (EC, 1999). It prohibits the disposal of liquid raw sludge and implies an increasing need to create opportunities for the treatment and utilization of sewage sludge resulting from the requirement to phase out biodegradable waste destined for landfill by 2020.

The main subject of these recent amendments to the provisions of the Regulation is the changes related to the adoption of stricter limits for heavy metal concentrations. Other changes include the introduction of new precautions for the control of organic compounds, as well as the bacteriological and parasitological requirements that treated sludge must meet.

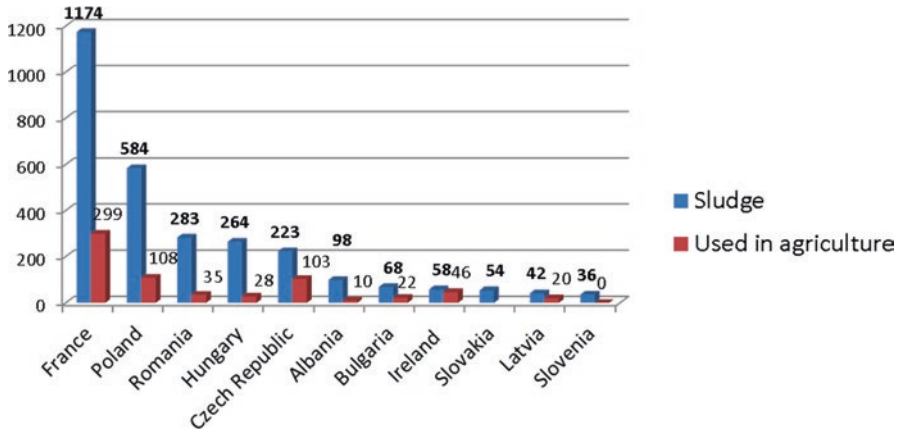
## 17.4 Results

The responsibility for the recovery of the sludge is a matter of national law. The trend of burning sludge for generating electricity and heat is increasing in major cities in Europe. In smaller settlements, the sludge is still plowed into agricultural land, but after its treatment to avoid risks to human health and soil and water protection.

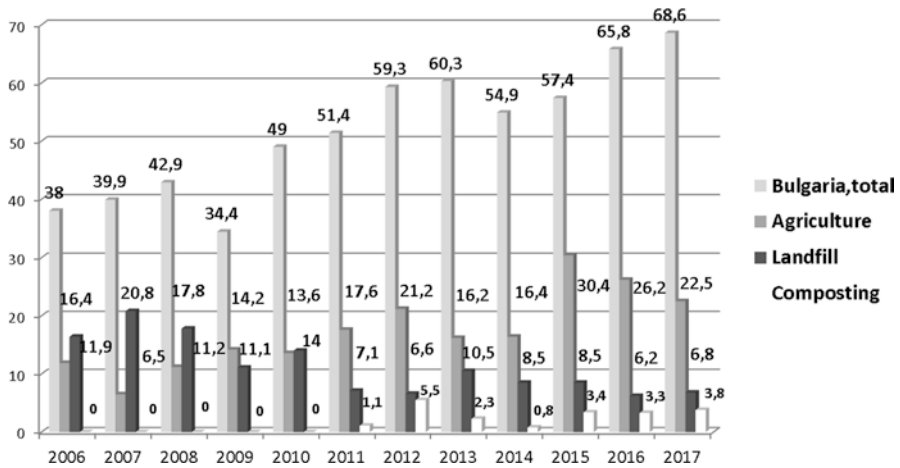
According to the Report of Executive Environment Agency in Bulgaria (2017), the recycling and recovery of sewage sludge should reach 65% by the end of 2020. At the same time, their energy recovery should reach 35% by the end of 2020.

In 2017, Ireland ranks first among European countries with nearly 80% of recovered sludge in agriculture, followed by Latvia with 48% (see Fig. 17.1). Although France is a leader in the generation of sewage sludge, its arable land is enriched by over 25% of the amount received. However, with the emphasis on sediment generation per inhabitant, Albania ranks first with 34 kg. dry sludge per capita and 3 kg/person utilized in agriculture for 2017. Hungary is next with 27 kg. dry sludge per capita total sediment and 2.8 kg. per person utilized in agriculture. In Bulgaria the distribution is 9 kg. total per person, of which 3 kg. are dry sludge in agriculture. Romania, as a neighboring country, has 1 kg of sludge per capita, related to 14 kg. total amount of sediment per inhabitant.

For the period 2006–2017, in the treatment plants in Bulgaria, there is an almost 80% increase in the generated sludge, which has changed from 38 thousand tons of dry substance to 68.6 t at the end of the period (see Fig. 17.2). At the same time, its



**Fig. 17.1** Sewage sludge utilization and disposal from urban wastewater (in dry substance (d.s.) in some European countries, thousand tonnes (2017). (Source: Eurostat (2020), Sewage sludge production and disposal)



**Fig. 17.2** Sewage sludge utilization and disposal from urban wastewater, in Bulgaria, dry substance (d.s.), thousand tonnes (2006–2017). (Source: Eurostat (2020) – Sewage sludge production and disposal)

utilization in agriculture is 33% on average. The highest amount of utilized sludge in agriculture is reported in 2015 – nearly 53%, followed by 2009 and 2016, respectively, by 42% and 40%. According to Eurostat (2020), the smallest quantity imported in 2007 was only 16%. For the period 2006–2017, the share of sludge deposition decreased three times, from 11.9 thousand tons of dry substance in 2016, it was limited to 3.8 tons in 2017. By 2020, the disposal of the sludge is required to be discontinued. After 2011, in Bulgaria, the alternative to the recycling of the sludge is its composting with bio-waste. The resulting high quality organic manure (compost) is of high quality and safe for the health of the population and the

environment. This process has a high degree of hygiene, stabilization, drying, addition of organic substances, and reduction of unpleasant odor. The existing composting systems optimize oxygen delivery through digital control, which accelerates the decomposition of organic components. Compost could be used effectively to combat eroded terrains (Figs. 17.3 and 17.4).

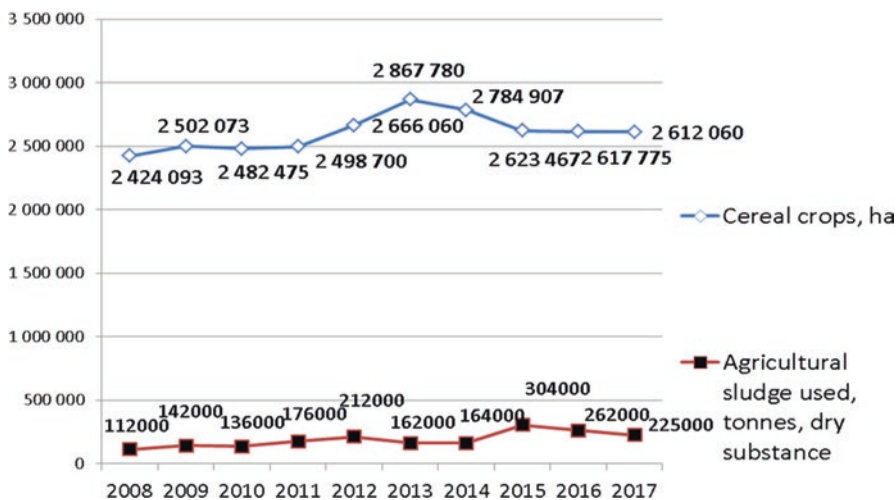
The coefficient of determination  $R^2$  shows what percentage of change in score is due to the factor. In this case, 3.6% of the increase in the average yield of the cereals can be considered to be due to the use of the sludge. The equation describes this relationship insufficiently. There are obviously other factors not included in the analysis. The correlation coefficient  $R$  (see Table 17.1) shows a weak relationship between the average yield and the sludge (0.189), i.e., it would not be appropriate to state that in this case the sludge affects the average yield of the crops, but rather the relationship is too weak. The value of Sig. F = 0.599 is greater than 0.05, therefore the linear model is not appropriate (see Table 17.2).

However, the results could be interpreted as follows: The free member  $a - 3025.5$  indicates what the average yield (kg/ha) of the cereal crops would be if no sludge was used in the cultivated land (Fig. 17.5). The coefficient  $b - 2.8272$  shows the change of the dependent variable  $y$  at the change of the independent variable  $x$  by 1 unit. Increasing  $x$  (in this case the sludge) by 1 kg of d.s./ha will increase the average grain yield by 2.83 kg/ha.

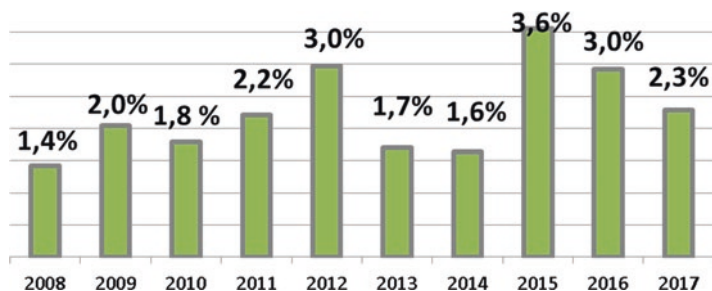
The regression equation is as follows:

$$C = 2,8272E + 3,025.5 \tag{17.2}$$

or Average yield = 3025.5 + 28,272 sludge.



**Fig. 17.3** Dynamics of arable land (ha), cereal crops and utilized sludge of dry substance (d.s.), tonnes in Bulgaria (2008–2017). (Source: Eurostat (2020) – Sewage sludge production and disposal; MAFF, Agrostatistics)



**Fig. 17.4** Percentage share of utilized sludge dry substance (kg) on the gross production of cereal crops in Bulgaria (2008–2017). (Source: Eurostat (2020) – Sewage sludge production and disposal; MAFF, Agrostistics and own calculations)

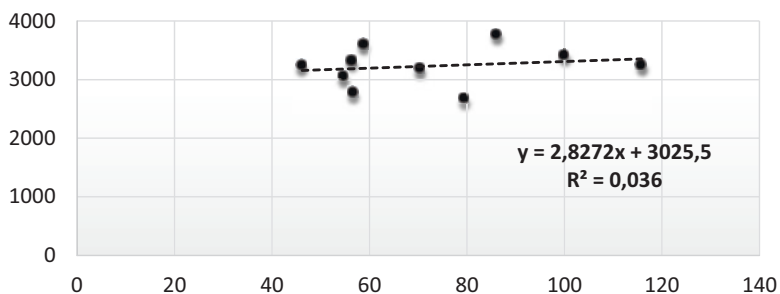
**Table 17.1** Model summary

Regression Statistics	
Multiple R	0,189,747
R Square	0,036004
Adjusted R Square	−0,0845
Standard Error	349,6538
Observations	10

**Table 17.2** ANOVA<sup>a</sup>

ANOVA	df	SS	MS	F	Significance F
Regression	1	36,529,3	36,529,3	0,298,789,128	0,599,552,484
Residual	8	978,062,4	122,257,8		
Total	9	1,014,592			

<sup>a</sup>Dependent Variable: RankRents



**Fig. 17.5** Correlogram of the relationship between average yield and sludge deposited. Trend model

## 17.5 Discussions

The various aspects and effects of sewage sludge recovery have been investigated in the scientific literature worldwide.

In a report from RPA, Milieu Ltd. and WRc for the European Commission, DG Environment (2008), an analysis is presented of the socio-economic and environmental aspects of the impacts of sediment. It is emphasized that not all impacts can be assessed at this stage. An assessment has been made of human health, the effects of emissions into the air, including bioenergy production. Palme, Lundin, Tillman, and Molander (2005) present “sustainable development indicators” for sewage sludge utilization and “wastewater treatment systems”. The results of the assessment of lifecycle risk economic indicators and uncertainty are used as inputs to classify the technical capabilities of sludge processing, using multi-criteria analysis. The results obtained reflect the economic, environmental, technical, and social aspects of the sustainable development of the sludge treatment system.

Özerol and Günther (2005) summarize that poor sludge “planning and management” can lead not only to “high health and environmental risks” but also to undesirable economic and social outcomes, nationally and globally. Singhirunnusorn, Sahachaisaeree, and Stenstrom (2011) focus on socio-economic factors as determining factors for the utilization of sewage sludge from sewage treatment plants. Singhirunnusorn et al., (2011) propose “an analytical approach for locally appropriate technology that integrates socio-economic parameters as a part of the decision-making process”.

Another group of authors (Maktabifard, Zaborowska, & Makinia, 2018; Smol, Adam, & Preisner, 2020; Zaharinov, 2011) draw attention to wastewater treatment plants, which “can be an important part of the circular economy for sustainability, thanks to the integration of energy production and resource recovery during clean water production”. This “can be done through the production of biogas and the recovery of energy” (Neczaj & Grosser, 2018).

At this stage, in Bulgaria, with few exceptions (Kopeva et al., 2018; Kopeva & Sabeva, 2018), there are no scientific publications related to the regenerative economy and the assessment of the socio-economic impact of sludge in general. The focus is on policies that prioritize environmental values. At the same time, the regenerative economy is in line with the recovery of invested resources. They are an invaluable asset and contribute to people’s well-being.

The regenerative system is associated with continuous self-renewal. It is a process that contributes to building relationships and is constantly supporting the development of socio-economic and environmental systems. In regenerative sustainability, synergies are created that continuously regenerate natural capital. In practice, this means more permanent crops, limitation of synthetic fertilizers, and diversification in crop rotation, animal husbandry systems, and the creation of functional natural areas. Integrating policies aimed at innovative management of agricultural practices, integrating the principles of biodynamics (Beluhova-Uzunova



& Atanasov, 2017) into the potential for restoring soil fertility, producing sustainable and healthy foods, and holistic governance to counteract biodiversity loss.

The publications available on the topic of sewage sludge include studies of individual elements in the technological process, in the management of technologies and the assessment of the environmentally friendly and efficient use of the sludge. In Bulgaria (Tsolova & Marinova, 2005; Baykov, Zaharinov, & Kaleva, 2013; Popova et al., 2017) have extensive research experience. The benefits of sludge for agriculture as a fertilizer and improver of the soil structure has been proved by numerous publications (e.g., Zaharinov (2011) states that sediments from “humification products” do not cause “serious” damage to the ecosystem). It is claimed that the use of sludge in agriculture is a cost-effective and environmentally friendly method. Sludges from wastewater treatment are known to contain organic and inorganic nutrients that can replace both mineral fertilizers and manure. Sludge naturally acts as a soil improver and promotes soil fertility. However, some European countries have introduced some sludge utilization organizations on agricultural land. So far, however, there is no serious indication that further restrictions will be taken in this area. It is useful to know that the presence of sediment in the soil further enhances its ability to retain water, permeability, and porosity that are indicative of good functional status (Chew et al., 2019; European Commission, 2001; Milieu Ltd, WRC, & RPA, 2008; Monteiro Faria, Célio de Figueiredo, Rodrigues Coser, Teixeira Vale, & Gehrke Schneider, 2017; Tsolova & Marinova, 2005; Zaharinov, 2011).

In this regard, the public should be aware that the treatment, disposal, and utilization of sludge in agriculture are carried out in accordance with the legal framework.

## 17.6 Conclusion

The utilization of sludge in agricultural lands is strictly regulated in the legislative system in Bulgaria and this process is strictly regulated in the Ordinance on the order and method of utilization of sludge obtained as a result of sewage treatment in WWTP. According to statistics, the impact of sludge on gross production is on average 2.5%. In this case, this is considered to be additional added value and, in practice, benefits in support of the regenerative economy. The correlation coefficient  $R$  shows a weak relationship between the average yield and the sludge (0.189), i.e., it would not be appropriate to state that in this case the sludge affects the average yield of the crops, but rather the relationship is too weak. It should be known that other factors, such as sowing material, geographical location, soil types, rainfall, humidity, agrotechnical activities, etc. influence the gross production.

When assessing the effects of sewage sludge from wastewater treatment on the regenerative economy, it should be known that soil, water, and climate are unified. In order to make a comprehensive assessment, the positive and/or negative impacts of all environmental factors should be included.

The analysis shows that there is a need for planning policies concerning the utilization of sludge in Bulgaria. This also raises the need for additional investment to find applications in the context of regenerative and bio-economy. Although sludge recovery is a global challenge, finding the right solution is often in the regional dimension.

Therefore, the utilization of sewage sludge in terms of a sustainable model of consumption and production will increasingly be on the agenda, which is a challenge for the regenerative economy. It could be affirmed, taking in consideration that wastewater treatment and wastewater safety are strategic directions for the future of society, that the sludge utilization should be considered as a national policy with the commitment of the government.

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# Chapter 18

## Circular Economy in Construction from Waste to Green Recycled Products in Israel: A Case Study



Zvi Weinstein

**Abstract** The chapter describes a policy of the State of Israel with the aim to cope with construction and demolition waste (CDW) through recycling, to be further used as green products. It is aimed at supporting the national economy and the recovery of the open public spaces that became places for illegal landfills, impacting the natural environment. Two major tools are used to achieve these aims: the first is the circular economy (CE), instrumentally led by the Ministry of Economy, and the second is the regulatory framework led by the Ministry of Environmental Protection. Both have the capacities to cope with, and support, the national economy and the environment. We argue that the way to achieve the full integration between the circular economy and the legal framework has still a wide gap, although big changes and advancements have been made towards reaching a comprehensive policy. Both Ministries are aware that it is a long process to achieve real changes after many years of environmental neglect due mainly to conflictual politics, economic interests, lack of budget and other government priorities. The means to achieve that goal include the use of the circular economy principles for recycling CDW into green and reusable products, on the one hand, and empowering the responsibility and accountability of local municipalities through regulation, on the other.

**Keywords** Construction waste · Illegal placement · Recycling · Green materials · Environmental regulation

### 18.1 Introduction

The chapter examines and analyses two key aspects of construction and demolition waste (CDW): the economic and the environmental. The introduction defines the two terms to enable establishing a framework for the following sections, including

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the economics of CDW and considering that Israel needs to supply new housing for the growing population.

In 2020, Israel celebrates its 72 years of existence with 9.2 million residents, while it is expected to double its population, in 2048, to 15.8 million. Hence, construction needs in Israel indicate that by 2030 more than 400,000 additional housing units will be built; and by 2035 approximately 1,120,000 new housing units will be added (Hasson, Kutok, Drukman, & Roter, 2016).

During the expected construction momentum, joined by many urban renewal operations, huge amounts of CDW will be produced, of which 95% could be recycled and returned to the construction and infrastructure sectors. Moreover, 2020 data from the Israel Planning Administration on Master Plan 14b in Mining and Quarrying signal a critical and expected shortage of clay, limestone, cement, basalt and sand (Ministry of Interior, 2012).

The present case study focuses on two faces of the same coin, i.e., economic and environmental. The coin represents the issue of construction and demolition waste. To achieve the goal of minimizing waste, both the economy and the environment should be taken into account in a building policy aimed at providing the best answers to all relevant stakeholders. This requires establishing a targeted and efficient mechanism able to take into consideration policy, operating functions, supervision, regulation and legal aspects.

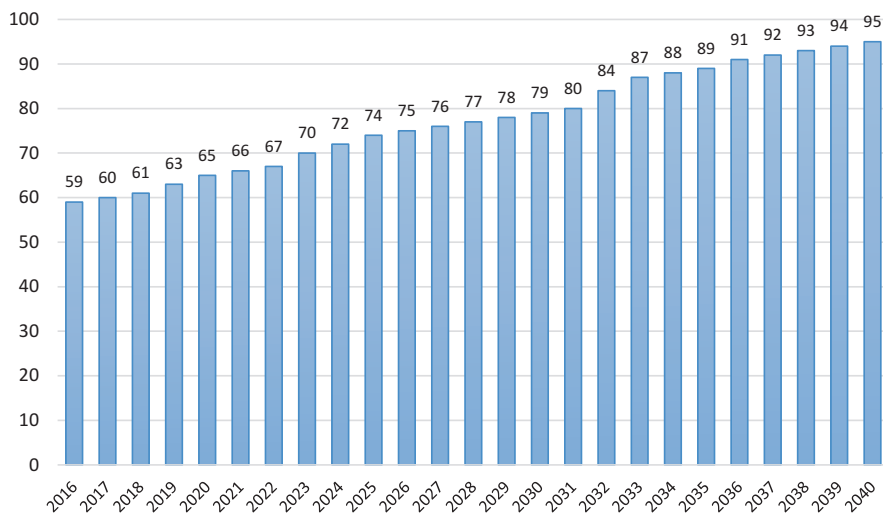
The economic side regarding CDW involves the central government's ministries, i.e., the Ministry of Environmental Protection (MoEP), The Economic Ministry, the National Infrastructures & Energy (MoE), the Ministry of Interior (MoI) and the Ministry of Housing & Construction (MoCH). The direct responsibility for CDW treatment is in the hands of the MoEP. The objective of this paper is to support cooperation of different ministries for a common interest, thus bringing success in one of the most complicated issues the State of Israel is currently faced with.

The building and construction domain in Israel plays a major role in the economic activity of the country and it is one of the fastest growing economic sectors in Israel. The total investment amount in the year 2017 reached 45 million Euros, which equals to 10.7% of Israeli Gross Domestic Product (GDP). The building sector employs 260,000 workers (Israel Builders Association, 2017).

The scope and size of these activities witness the huge amount of materials and resources consumed in the domain. Figure 18.1 presents data by the MoE regarding the forecasted demand of raw materials from 2016 to 2040.

“Business as usual” activities of the building and construction sector will cause extensive use of raw material mining, which are already scarce. The goal is consequently to size the benefits of implementing a circular economy model with the aim to decrease, at first, the scope of mining.

The environment aspects became a very significant factor in Israel in the last decade, raising the general awareness of citizens and of many organizations, such as NGOs or civic organizations, who adopted the vision of “quality of life” and sustainable environment, thus supporting a deep change in government policy and attitude towards open spaces, natural sites, climate change, renewable energy and nuisance caused by CDW.



**Fig. 18.1** Demand for raw materials 2016-2040e (million tonnes). (Source: Israel Ministry of National Infrastructures and Energy, 2017)

**Table 18.1** Estimated construction waste for 100 m<sup>2</sup> per building type

Sources of construction type	Waste quantity per 100 m <sup>2</sup>
Dwelling, public, offices	20 tons
Commercial, industrial	6 tons
Basements	3 tons
Demolitions	150 tons

Source: Edri (2010)

The chapter relates to both economic and environmental aspects of a circular economy and its benefits, as well as to the difficulties in implementation of a dedicated policy, highlighting both pros and cons.

The Israeli Ministry of Environmental Protection is in charge of all regulations and laws regarding waste. Collection of construction and demolition waste in Israel, unlike the collection of domestic waste, is not regulated by the local authorities. This makes it more difficult to ensure CDW is legally disposed of. CDW is collected only upon request – either by local authorities, or private companies. As a result, much of this type of waste is illegally thrown into open spaces causing environmental damages. As a consequence, a large part of the MoEP's efforts related to CDW are focused on its reduction by means of recycling, creation of authorized waste disposal sites and enforcement of laws to ensure legal behaviours.

Each year, the amount of construction waste reaches circa 7.5 million tons, of which 4.5 million tons are CDW and 3.0 million tons are excavating ground containing a major part of CDW (Tal, 2016). Table 18.1 shows the estimated amount of waste created as a result of a 100 m<sup>2</sup> building.



Construction waste is defined by the Maintenance of Cleanness Law (1984) and the Clean-up Law (1984) which include all types of waste and debris left over from construction and demolition activities. These materials (soil, rubbles, blocks, concrete, asphalt, tar and tar sub-products, bricks, tiles, ceramic, glass, insulation panels, wood, etc.) are mostly inert, though there are some that are dangerous, toxic, or flammable.

This case study follows the development goals of two Israeli Ministries – the Economy and the Environment – regarding CDW policies and investigate whether a joint resolution could succeed in achieving a comprehensive framework to be implemented in Israel. A second issue regards the hindered factors that prevent the realization of a sound policy able to satisfy all engaged stakeholders with respect to CDW.

The following sections describe the relevant policies developed in the period from the mid-1980s until today; the objectives and goals of the most recent regulations, as well as the possible alternatives leading to the choice made by the MoEP.

## **18.2 Method**

A case study is developed focusing on the issue of CDW and discussing how the central and local governments deal with it from two angles: the economical and the environmental. An analysis of the present state of CDW from the point of view of these two main aspects is presented and future directions to achieve the most effective outcomes with respect to this issue are introduced.

The available documents collected from the central government are analysed under these two perspectives. Relevant documentation includes planning laws, regulations and guidelines from both Ministries as well as other data. Sources and data have been categorized into sub-titles. In addition, two study tours have been made, visiting companies that successfully reuse CDW in the building sector, thanks to a recycling process in a circular economy approach.

Several interviews have been conducted with experts in the domain of CDW, at the Ministry of Economy and at the Ministry of Environmental Protection, as well as with owners of recycling enterprises. The case study used the qualitative approach and was performed during the period of January to June 2020.

### ***18.2.1 Approaching the Circular Economy***

In this section, we present a short description about the circular economy (CE), i.e., its meaning, principles and benefits with respect to construction and demolition waste (CDW). CE is seen as a tool to explain how to cope with scarce materials, and a system employed in many projects. It is an economic model aiming at growing the

effectiveness of resources and raw materials in the manufacturing process of products and systems along the supply chain (Tal, 2016).

A CE assumes that the linear economic model – based on production, consumption and growing amount of waste – is not able to exist anymore, due to the limited size of the resources our planet can offer, and in consideration of the destructive impacts on the environment. A CE is characterized by increasing exploitation and reusing/recycling of raw materials, and it acts according to a holistic process that integrates them through their life cycle (Eco-Finance, 2020).

The reuse of recycled materials derived from CDW is growing mainly in urban areas that have to satisfy the demand for housing and other constructions for the local population. In some densely populated areas with limited supply of natural materials, economics can play a key role in increasing the use of alternative raw materials (Hendriks & Pietersen, 2005).

The concept of CE goes from restorative to regenerative to create a life-long sustainability. Our environment has a limited amount of resources, and not always what we spend we return back to keep the equilibrium. Buildings, and the manner in which we design, construct and maintain them, have been significant contributors to the climate crisis the global population is witnessing, including Israel. Consequently, to keep a sustained environment we are committed “to do more good than less bad” (Brown et al., 2016: 47).

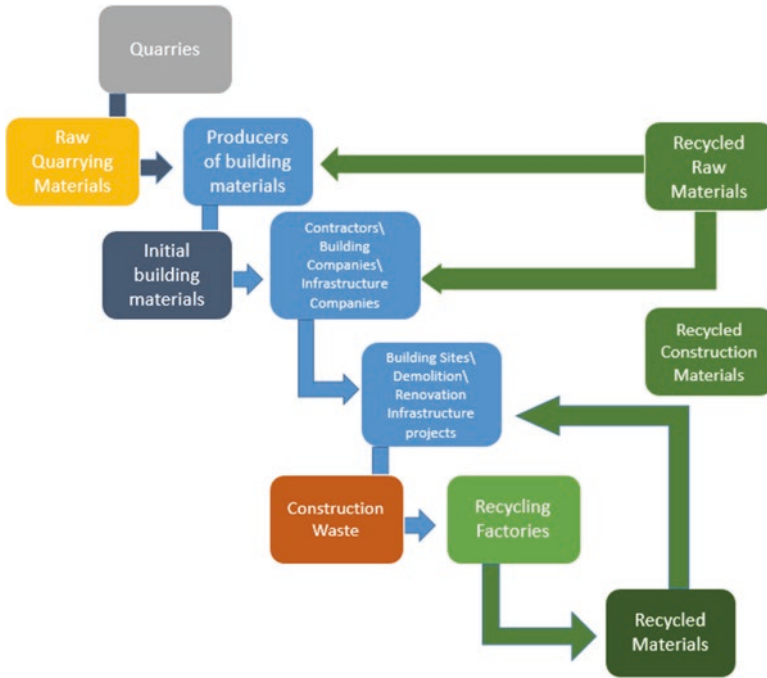
Building waste is a mixture of different quality materials that have been originally used to build various elements in construction, open space development or infrastructure. The position of the Israeli Ministry of Economy is that almost 95% of the building waste has the potential and possibility to be recycled and reused (Benita, 2018).

The environmental impacts of throwing waste in unauthorized sites cause damages in open sites and natural values, i.e., soil and water pollution due to infiltration of contaminants; creation of attractive places for multiple pests; air pollution with smoke and unpleasant odours due to illegal burning. There are several reasons why we need to recycle: to save significant amount of capital; to prevent damage to mining and quarrying areas spoiling the landscape; to decrease open spaces pollution; to reuse building waste, which is qualitatively equal to other building materials (Katz & Baum, 2011).

Figure 18.2 presents the components of construction materials participating in the process of circular economy model.

### ***18.2.2 Implementing the Circular Economy in Building and Construction***

There are several reasons why we need to adopt the model of circular economy in the building industry in Israel:



**Fig. 18.2** The model of circular economy, from mining & quarrying, to recycled construction waste. (Source: Eco-Finance, 2020: 5)

- The amount of materials used in the building sector is very large (65 million tons per year, as shown in Fig. 18.1).
- Demand for building materials is growing annually due to urbanization processes and population growth (Ministry of Energy, 2017).
- The size of environmental impacts is huge. The industrial construction factories (mining & quarrying, asphalt and cement productions), are responsible for one fourth of the national greenhouse gases (GHG) emissions (Ministry of Environmental Protection, 2018b).
- Resources become limited and price fluctuations are significant (mainly metals and natural minerals).
- Present construction systems are using resources which are not recycled.

Implementing circular economy in construction waste has to take a different point of view through a detailed analysis of the building process, the choice of the construction materials and the ways the products are used. The building, whether renovated or demolished, can supply materials for recycling. When examining the construction materials, there is a need to consider their composition features, their exposure and life length scale for different uses. Table 18.2 shows an example of transferring a construction waste material into new products and their uses. This is an example provided to the author during an interview with the Greenmix co-founder, Mr. A. David, on January 26th, David, 2020.

**Table 18.2** From waste materials to green products

Tier	Module	Output/Product	Used for
1.0	Sorting, crushing, sieving	Base	Sub layers.
		Subbase	
		Backfilling A 2–4	Roads reinforcement.
2.0	Sorting, crushing, sieving, rinsing	Rinsed sand	Sand for flooring. Raw material for construction products.
		Recycled aggregate (“sesame”)	Sub-flooring filling. Raw material for construction products.
3.0	Concrete production line based solely on recycled raw materials	Non-constructive concrete	Plasters.
			Light concrete.
			Self-leveling underlayment concrete.
			Controlled low strength material (CLSM).
4.0	Sorting packaging waste	Paper/cartons, metals	Send to specialized treatment facility.
		Wood	Tier 6.0.
		Polymers	Tier 5.0.
	Extraction of locked minerals	Minerals	Raw material for tier 1.0 and tier 2.0.
5.0	RDF & Gasification	Energy	The recycle process.
			Cement production.
6.0	Wood treatment system	Woodchips	Poultry farming.
		Wood pellets	Energy substitutes.
7.0	Purified sand by redundant health (from tier 5&6)	Fine sand	Plasters and adhesives.

Source: Author, with data from Greenmix, Benny & Zvika Group

### 18.2.3 Quantifying the Benefits of CE in the Building Sector

The main step to implement CE in the building sector is an effective management of the construction waste array. It is necessary when utilizing recycled materials instead of quarrying mining. The Eco-Finance consulting company, at the request of the Ministry of Economy has prepared three scenarios in that respect (Eco-Finance, 2020).

- Business as usual – Basic status, where only 40% of construction waste is recycled in comparison to an average of 89% as in the OECD (European Union, 2019)
- Scenario A – Partial implementation of CE at a rate of 75% of construction waste
- Scenario B – Full implementation of recycling up to 100% of the construction waste.

Landfills of construction waste without recycling and no operation for reuse, on the one hand, cause high costs for the economy, and for the landfill itself and, on the other hand, reduce the need for mining and quarrying. The resulting equation is: Landfill costs + recycling costs – saving costs of recycled materials = the cost to the economy.

Table 18.3 presents the costs of waste treatment and their division for cycling, landfill, external negative costs caused to the environment, and the cost of landfill in open spaces. The costs are calculated according to bids of the Ministry of Construction & Housing for waste disposal, targeted at developing new neighbourhoods. There are additional costs related to mining and quarrying of natural aggregates, and other external costs (difficult to quantify) caused by the operation of mining and quarrying, such as dust emission and air pollution, negative impacts on the landscape, lost ecological values and image of the region.

According to the calculation of the Ministry of Economy the results are: Basic scenario – 45,788,000 Euros; Scenario A – 19,578,000 Euros; and scenario B – 14,437,000 Euros.

Based on the calculations of Eco-Finance (2020), full implementation of CE in construction (Scenario B where 100% of CDW is recycled) compared to business as usual is expected to save (i.e., “economic efficiency”) a yearly sum of about 32 M Euros. While a partial implementation will save a sum of approximately 26 M Euros on a yearly basis.

The conclusion appears to state that as long as the CE ratio of implementation is higher, thus is the scope of saving both mining and quarrying expenditures and

**Table 18.3** Costs quantified under different scenarios (in ‘000 Euros) (converted from NIS at 1:4 Euros)

		Basic Scenario	Scenario A	Scenario B
		Business as usual	75% recycling in 2030	100% recycling in 2030
Variables	Cost per ton	Cost	Cost	Cost
Landfill	4	10,112	9657	3937
External landfill	1.25	3370	3172	1312
Recycling	8.1	24,666	45,937	61,250
Cleaning open spaces	15	28,606	–	–
Waste treatment total cost		66,754	59,387	66,499
Mining & Quarrying saving costs	(6.67)	(14,978)	(27,890)	(37187)
External mining & quarrying costs	(2.5)	(5991)	(11,156)	(14,875)
Mining & Quarrying total saving		(20,969)	(39,047)	(52,062)
Total cost for local economy		45,788	19,578	14,437

Source: Eco-Finance (2020)

economic efficiency. The major part of efficiency stems from saving as a result of decreasing scope of raw materials and the increased amount of recycled materials which causes much less CDW.

The following section is the complementary part of the economic aspects dealing with the construction waste activity. It presents the law regulations changes and the level of responsibility supposed to enforce the law to those who are involved in the construction waste processes under a “new deal” scenario. Both are aiming at changing and improving the problematic issue of construction waste in Israel.

### ***18.2.4 Policy Development of Construction Waste Treatment***

This section describes the policy development of laws and regulations passed by the Israeli Parliament (the Knesset) since the mid-1980s until these days in order to cope with the illegal disposal and the related environmental nuisances and economic losses throughout the country. These actions have been executed in several steps that are explained and summarized below.

The existing regulations consist of a number of laws and standards enforced in 1970, after the Planning and Building Regulations, accepted in 1965 (Planning Administration of Israel, 1965), ruling the applications for construction permits, as well as terms and fees to comply with all administrative norms. It was followed by the Cleanness Law, in 1984. The law introduced fines for dumping waste in the public domain, and called for establishing a limited number of properly managed landfills. A second step, called National Outlines Plan for Solid Waste (NOP 16), was approved in 1989. It was the first comprehensive attempt to regulate the locations of operational criteria for waste treatment and disposal sites, and in particular municipal waste. In 1993, the Government decided to close all unregulated waste dumps, which numbered some 500 at that time, including about 75 large landfills. These dumps were associated with a variety of environmental nuisances: risk of groundwater and soil contamination, air pollution, aesthetic blight, safety threats in extensive tracts of land. Additional steps began in the early twenty-first century and are being continued to date.

The treatment of CDW came up in the Israeli national agenda in 2003, following government decision number 2927 (Government of Israel, 2003). The Government decision initiated a clear policy of CDW and of the usage of recycled materials by public companies. The decision aimed at preventing redundant mining and quarrying, and securing expensive natural resources. The entrepreneurial building domain is mainly in private hands and, therefore, the economic interest represents a priority for its existence. On the other hand, the economic activity must be conducted according to the law and the CDW has to be delivered to the MoEP-authorized landfill sites. The Government decision left to the MoEP the responsibility to take the needed steps to implement the decision. As a result, the central local authority was asked to prepare a plan aimed at approving authorized legal sites, where the waste had to be delivered from the local municipality and, in addition, to set up sites

for waste recycling up to 50% of its capacity. In 2007, a landfill levy went into effect in Israel – Amendment 9 of the Maintenance of Cleanliness Law, The Clean-up Law (Knesset of Israel, 2007, 2010). The introduction of a levy is aimed at reducing the amount of waste sent to landfills by internalizing the external costs of landfilling in order to reflect the true price of burying waste. The funds collected from the landfill levy are deposited into a Maintenance of Cleanliness Fund to be used for the development and establishment of alternative waste treatment methods, such as recycling and energy recovery.

An important step was taken in 2009, when the MoEP began to lead a “recycling revolution”, which includes a separation of waste at-source, funding of recycling and recovery facilities, and an awareness-raising campaign. The goal is to increase recycling rates and to significantly reduce the amount of waste sent to landfills from 80% to 26% by 2030.

In 2018, a 2030 Strategic Plan for the Treatment of Waste was approved, allocating a budget of one billion Euros (MoEP, 2018). The plan is expected to result in making the waste market more efficient, reducing the landfilling of waste, increasing the rate of recycling, and reducing pollution and overall environmental risks.

Starting 1998, the directives of the Planning and Building Law (1970) instructed that local authorities must include in the building permits they issue to contractors an assurance that CDW will be disposed legally. In addition, residents must provide proof to the local authorities that the waste has been legally disposed, in order to obtain “Form 4”, a document that citizens must receive before they can move into a new or renovated home. In practice, though, these directives are not fully executed. Reports by the Israeli State Comptroller, in 2007 and 2013, found out that the Local Planning Committees have not been able to fulfil their functions (Israel State Comptroller, 2013), thus revealing a failure. In 2015, the Standards Institute of Israel issued a regulation that allows using recycled aggregates for infrastructures in accordance with the European Standardization (Standards Institute of Israel, 2015).

As a consequence, those who produce the waste, either tenants who renovate their homes or developers, normally get in contact with contractors, and deliver the waste to landfills or recycling sites (“gate fee”).

According to the MoEP, about 0.9 million tons annually, which is 25% of the total quantity of construction waste in Israel, are not transferred to legal sites, but are thrown in open public spaces. That practice is an illegal alternative to landfill and recycling, and its direct costs are relatively low.

The results of these illegal actions cause direct and indirect impacts, as described below.

Direct nuisances:

- Damage to open spaces and landscape values – both functional and visual
- Cost of handling cleaning of building waste from open spaces
- Government offices, local authorities and other public agencies invest a great deal of money in treating or preparing sites for construction. During the years 2010–2016, as part of the “Equal Environment” project, the MoEP has transferred to the local authorities a sum of 35 million Euros for cleaning hazardous

construction waste, as ranked according to four socio-economic classes (Central Bureau of Statistics, 2017). Building waste treatment refers to waste-on-site collection operations, recycling and transport of the materials to landfill site. The cost of treatment per ton ranges from 7.2 to 9 Euros (Eco-Finance, 2020).

- Loss of revenues from landfill levies – Calculating the loss of revenue is based on the fact that approximately 900,000 tons are generated each year. Since July 2007, a fee is imposed on construction waste in legal landfill sites. The levy estimation is calculated in accordance to reports sent to the MoEP by the recycling sites. The total sum is about ten million Euros.
- Fires outbreaks – Flammable construction materials in building waste, such as rubber, wood and tires. These events cause air pollution and nuisance due to smoke, odours and other toxic emissions that can cause cancer (Tal-Spiro, 2016).

Indirect nuisances:

- Risk of soil, run-off and ground water pollution – Construction waste might include dangerous materials liable to cause soil and drinking water contamination, or even seep into groundwater (Shenkar & Chen, 2011).
- Falling prices in the real estate market, and lower economic value of open spaces used for leisure and tourism.
- Loss of tax revenue – In the present state, disposal services of construction waste are managed as free market which features in cash payments. As a result, reports about transactions are lacking and taxes are not paid.
- Loss of raw materials available for reuse – Potentially, construction waste could be recycled at a “gate fee”, and reused in the building market. Due to illegal discharge, large amounts of raw material waste are lost, which could conversely be saved.
- Nuisance to health as a result of pests, invasive plants and animals, which could cause damage to biodiversity.

### ***18.2.5 Objectives and Goals***

The main reason for the need of a regulatory framework is due to the economic market failure in eradicating the illegal disposal of construction waste in open spaces, together with its economic, social, health and environmental damages. It became a top priority also thanks to the rising awareness towards keeping the environment safe in a bottom-up approach, with the wide support from civic organizations and the Ministry of Environmental Protection.

The MoEP has added new goals in regulating the building waste, as part of its annual programme. These goals are part of the Israel National Strategy (2010) on natural resources. Israel is short of natural resources like iron, coal, streams of rivers and more. Therefore, recycling has a high importance among different national strategies of all ministries. These goals are:



- Achieving 80% waste recycling
- Defining an inter-office policy of controlling the life cycle of raw materials embodied in building waste, as a recurring resource for long term sustainability of the construction and paving industry, resulting in reduced mining activities
- Extending the demand for recycling materials instead of mining new raw materials
- Establishing an information database for building waste production volumes
- Enforcing the use of recycled materials for firms and companies relying on public budget
- Reinforcing the social values related to the protection of the public quality of life, while protecting the environment through the intervention.

Similar to the economic part discussed above, the MoEP examined three alternatives with respect to the regulatory tool, its requirements and the mechanism it aims to achieve. The choice of the best alternative process was based on the existing knowledge, and the experiences gained using regulatory tools to deal with waste management.

The alternatives were reviewed and described considering their main principles, and the chosen one was discussed in detail. The analysis used the following list of variables and criteria for each alternative: benefits; regulatory burden; direct financial costs; implementation costs for the regulator; and public interests (Tal, 2018).

#### **18.2.5.1 First Alternative – The Zero Alternative – The Current Situation**

The existing situation consists of two main provisions: firstly, the Clean-up Law (1984) that prohibits that a person who builds or renovates from throwing waste in the open space. This is the general rule that applies to all producers of waste, and that enforces the disposal of waste to approved landfills and/or the recycling of it. Accordingly, the MoEP is adopting a number of enforcement strategies to avoid disposal of unauthorized building waste, including penalties, legal proceedings and forfeiture of trucks. In addition, as part of the current policy, the planning and construction regulations require that the Local Planning and Building Committees supervise that the construction waste is transferred to legal disposal sites. This regulation applies only to new construction or demolition of buildings for which a building permit has been granted.

#### **18.2.5.2 Second Alternative – Transfer of Building Waste Responsibility to Local Municipality**

The second alternative regulates the building waste treatment system by giving responsibility for waste disposal to the local authorities. As part of the proposed mechanism, developers and contractors are required to contact the local authority to

obtain the collection, evacuation and waste disposal services and are charged a fee for those services. The local authority performs the duty either by itself or through the publication of tenders for the employment of construction waste removal contractors to work on its behalf. The local municipality is charged for annual registration and reporting to the MoEP about waste quantities, the sites where the disposal is sent to for landfill or recycling. This reporting activity allows monitoring and control on the domestic and national markets (Ryvkin, 2020).

### **18.2.5.3 Third Alternative – Extended Manufacturer Warranty**

This alternative seeks to regulate the treatment of building waste through an extended manufacturer's warranty mechanism, as it is customary in Israel in relation to packaging waste, electronic and used tyres. According to this alternative, manufacturers and importers of construction materials are responsible to finance the collection and treatment of building waste, through recycling companies whose activities are funded in accordance with the type of construction materials they sell in Israel.

Local municipalities are required to set up a mechanism of CDW collection from building renovation sites as well as from newly built buildings and deliver the waste to a recycling company. Building companies, contractors and developers of the new construction have to finance the costs of collecting and transporting the waste up to the recycling site, while the recycling company has to finance the waste's onsite treatment. This alternative takes into consideration a decrease of illegal landfilling volumes. The MoEP would be able to establish more recycling companies that will be responsible for executing the law to contact various stakeholders and to fund the whole mechanism (Tal & Zagman, 2018).

## ***18.2.6 The Chosen Alternative***

The MoEP was due to examine the three alternatives for the regulator to cope with the issue of illegal construction waste disposal in open spaces and, through this tool, to establish a statutory framework where one entity is responsible for supervising the disposal of building waste.

The alternatives' analysis focused mainly on the major benefits resulting from each of them with respect to the problem described, and the purpose of the regulation. In addition, the analysis explains the regulative imposition and the direct financial consequence of that burden, as well as the costs imposed on the regulator itself.

Among the benefits, the MoEP has chosen the second alternative of building waste treatment, empowering responsibility to the local municipality. The key feature of this alternative is the creation of a national mechanism aimed at dealing equally with building waste generated both from renovation and new construction requiring a permit.

The main benefit expected from the implementation of this alternative is the prevention of the infraction of throwing building waste in the public domain, with an estimated benefit of 17 million Euros per year. In addition, today there are local authorities investing to enforce and supervise the illegal phenomenon of throwing waste in open public spaces. This alternative is supposed to supply the municipalities with financial resources for supervision.

In terms of regularity burdens, the alternative imposes to the waste producers whose building, demolition or renovation, is in a specific territory to contact the local authority, and be charged a fee for the service obtained from this call. For this alternative, there is no difference between the amounts of waste, be it a significant or a small volume. A bureaucratic cost is created due to the local authority obligation to establish a mechanism for that purpose. These loads are taken into account in the alternative and are embodied in a fee to be paid by the one responsible for the waste to the local municipality.

As far as direct financial costs are concerned, the producers of waste from renovation or demolition actions have to pay additional fees to cover different items, such as the supply of a container, its transfer to the gate site, the entrance to the site and the management and supervision performed by the local authority.

There will be no additional implementation costs for both the regulator and the local authority, since the above mentioned fees paid by the waste producer cover them all.

Regarding public interest, it is expected that this alternative has a positive impact on the environmental landscape value, since the abuse of throwing waste in open spaces is drastically reduced. As a result, all environmental nuisances are limited.

In terms of Impact on free occupation, it has been estimated that there are about 200 legal waste operators. In addition, there are several hundred operators working illegally. This alternative changes the whole free market structure. A possible solution for that problem is that the local government launches tenders to legally contract the operators.

### ***18.2.7 Discussion and Conclusion***

Two research questions are at the basis of the conducted study: (a) Can economic and environmental aspects be successfully combined through a comprehensive framework for construction and demolition waste policy in Israel? And (b) What are the hindered factors that prevent the policy's full implementation?

A variety of environmental aspects, whether direct or indirect, undoubtedly cause impacts on human quality of life. We can mention, for example, the lack of green open spaces, all kinds of pollution, diseases, landfill nuisances and climate change among the most relevant factors that influence our life. To overcome these problems, it is necessary to find out resources, including appropriate financing, which in most cases are in the hands of the central government and partnering stakeholders. Mutual interests, when facing national issues, must be effectively combined and integrated.

Based on the conducted analysis of the CDW situation in Israel, after years of laws and regulations to limit illegal disposal of waste, illegal landfills and “black markets” still exist, causing loss of revenues to both central and local governments. Moreover, considering the direct and indirect nuisances, as well as all the other negative impacts, the evidence confirmed a very difficult social situation, impacting a large part of the population. An urgent paradigm shift is needed, under two possible approaches: bottom-up and top-down.

The bottom-up approach can be seen as the result of local “green movements” in Israel, who put pressure on the national ministries – especially the Ministry of Environmental Protection and the Ministry of Economy – forcing them to take the necessary steps to reduce the negative impacts of CDW, and enforce control. The top-down line can be interpreted as the result of the collaboration between two leading ministries – the Ministry of Environmental Protection and the Ministry of Economy. Their decision to take real steps and change priorities comes as: an answer to the emerging housing demand of the growing population and especially of young couples; the need to preserve the “status” of the construction and building domains; and the objective to preserve the government’s long term budget.

This contribution has described relevant issues concerning construction waste and how Israel is coping with its environmental impacts using two lenses: economic and environmental goals. Two possible approaches have been discussed: the input of circular economy principles into the building sector, and new regulatory aspects adopted by law.

In both Israel and the Western world, attention is given to acting according to the circular economy principles for recycling high percentages of construction waste. The State of Israel is eager to adopt the European Union guidelines and implement the circular economy as in other countries in the EU (European Union, 2019).

The discussion above shows that the way to reach the point of satisfaction has to go a greater distance due to factors that hinder the goals to be achieved. These factors include rivalry and competition interests, too many actors, lack of budget, environmental civic organizations, government ministries, local municipalities, recycling firms, transportation companies in charge of delivering waste, owners of landfills and quarrying sites. Above all are obstructions, such as conservatism in the building sector and the anxiety of using imported recycled materials, a policy of a centralized economy and a vertical ownership of mining and quarrying, construction producers and building companies, developers and the citizen themselves. In other words, the current situation portrays a very complex state, which is not easy to solve.

Enforcement of waste regulations are not executed by all involved entities dealing with building waste. It seems that the race to saving costs and achieving as much economic gains as possible dictates the behaviour of many stakeholders engaged in the construction and industrial building sectors.

In spite of the above, most organizations support the tools of circular economy and the necessary regulations aiming at reducing damages for the society, the economy and the environment.

Taking into consideration the lack of important raw materials in Israel, which are necessary for the building and infrastructure sectors, and the benefits and cost

savings of the proposed steps in coping with the issues of waste, it seems that the change in attitude among policy decision-makers might be the last obstacle to integrate the circular economy and the regulatory frameworks to plan and build a cleaner and more environmentally conscious country.

One of the steps in progress is the establishment of an inter-organizational network platform that will serve as an inter-disciplinary knowledge centre of best practices in the field of construction waste to serve local producers and importers of construction materials and landfill sites, as well as a source for updated information about new recycled materials, new systems and guidelines.

Another important step is the Israeli Standard 118 regarding the “concrete, functioning and manufacturing requirements” for the cement amount and its degree of exposure (Standards Institute of Israel, 1962).

As of today, there are only 38 recycling sites in Israel. They recycle CDW up to 40% of the amount that reaches the site. This data is still insufficient, and it means that 60% of CWD is landfilled with the many environmental impacts and consequences this implies. By imposing new regulations, the Ministry of Environmental Protection can try to extend the enforcement through the empowerment of the local municipalities in charge of construction waste treatment in their territory.

The scenarios chosen by both the Ministry of Economy and the Ministry of Environmental Protection focus on aspects of costs-benefits, the contribution to the local economy, changing illegal landfills into leisure open spaces and future real estate areas to accommodate the population growth expected in 2030 and beyond.

In other words, the two ministries are trying to act according to world standards, paying great attention to the human aspects coping with environmental issues and strengthening the local economy.

To conclude, the necessary steps are pointing at ambitious economic and environmental sustainability goals, such as the entrance in the market of additional recycling entrepreneurs, a better local supervision on construction sites, the delivery of clearer and better information to stakeholders dealing with construction and demolition waste, the improvement of innovative technology, a higher consumption of recycled construction materials and the implementation of the ISO 14001 and 14004 standards aimed at environmental management systems (Standards Institute of Israel, 2004). These steps give us the answer to the question whether the combination between the two ministries – environment and economy – succeeded in the effort to bring positive changes. The lessons learnt from the examination and analysis of the case study are aiming far away. In other words, recognition, awareness, collaboration, integration of all relevant players starting from regulators, academia, research institutions, public companies such as entrepreneurs and consumers, private initiators, various industries, developers and builders, can help in achieving the full adoption of a circular economy in construction and demolition waste and the production of recycled green products. A significant employment of recycled CDW will certainly leverage the green building growth in Israel.

This ambitious goal seems possible if the above considerations succeed in encouraging and acting according to the following lines: a policy that aims at

innovation, quality goals, standardization, less bureaucracy, controlling and enforcement for planning and safety; appropriate financing that supports technological developments, investment in innovations and partnerships; levies concessions; assistance for physical infrastructures; access to government support in technological innovations; and, most of all, the creation of a Human Capital rich in vocational skills, and willing to invest in appropriate technologies.

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# Chapter 19

## Cultural Heritage, Tourism and the UN Sustainable Development Goals: The Case of Croatia



Željka Kordej-De Villa and Ivan Šulc

**Abstract** The chapter analyses the quality of managing cultural heritage sites in Croatia, particularly those inscribed to the UNESCO World Heritage List, which are under growing pressure of *overtourism*. The analysis was performed by using qualitative and quantitative data on visitors of the UNESCO heritage and the most important impacts of tourism on destination areas, compared to Sustainable Development Goals (SDGs) focused on tourism and heritage. The study investigates the state of safeguarding, protecting and valorizing cultural heritage in relevant documents and in practice, focusing on Dubrovnik as a case study area. The analysis revealed the insufficient plans for managing UNESCO World Heritage Sites in relevant documents and in the field, as well as lack of monitoring of tourism impacts. The selected cases in Croatia confirmed that the most common way for heritage valorization is within the framework of tourism (McKercher and du Cros, Cultural tourism. The partnership between tourism and cultural heritage management, Routledge, New York/London, 2009), where heritage is most often associated with sustainable tourism. However, desirable regenerative tourism, that repairs the harm that has already been done, is still far from the present situation and it will require much effort in its planning, designing tools for its implementation and its management to achieve it in the near future.

**Keywords** UNESCO World Heritage · Agenda 2030 · Overtourism · Sustainable tourism · Regenerative tourism

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## 19.1 Introduction

With 1.3 billion international tourist arrivals in the world in 2018 (United Nations World Tourism Organization/UNWTO/, 2019), tourism is inevitably a very important factor of economic, social and environmental transformation of the world. It is one of the most important consumers of natural and cultural heritage, contributor to their safeguarding and protecting as well as their re-use. Built cultural heritage, particularly the one on the United Nations Educational, Scientific and Cultural Organization (UNESCO) List of World Heritage Sites, is among the most important attractions for tourists, benefits from their interests and income, but also experiences the strongest tourism pressure.

UNESCO (2020: 1) defines heritage as “our legacy from the past, what we live with today, and what we pass on to future generations”. Heritage is usually divided into natural and cultural heritage, with cultural landscapes often taken as a separate category. In addition to its spiritual dimension and the role in the cultural identity of the community, cultural heritage also has its profound economic role (Afrić Rakitovac & Urošević, 2017; Benhamaou, 2003; Poljanec-Borić, 2017).

Cultural heritage is defined as material signs – either artistic or symbolic – handed on by the past to each culture and, therefore, to the whole of humankind (UNESCO, 1989). Cultural heritage is usually classified as: “tangible heritage (immovable cultural heritage, movable cultural heritage, underwater cultural heritage), and intangible cultural heritage” (UNESCO, 2020: 1). This chapter focuses on tangible cultural heritage in Croatia and, in particular, on immovable cultural heritage, such as monuments and touristic sites, which is explained from theoretical and practical points of view, with a selected case study from Croatia.

The present state of heritage protection in the world owes the most to the United Nations Educational, Scientific and Cultural Organization, which, in 1972, adopted the Convention Concerning the Protection of the World Cultural and Natural Heritage (UNESCO, 1972). The Convention promoted founding the UNESCO World Heritage List that was supposed to include the most precious and unique sites of natural and cultural heritage of the humanity, with universal value in the whole world. At the moment, a total of 1121 sites of natural, cultural and mixed heritage were on the World Heritage List (UNESCO, 2020). Beside protection on the highest level, UNESCO World Heritage Sites represent outstanding attractions for tourists and offer the opportunity to experience authentic natural or cultural heritage of a country.

The important role of tourism is explicitly visible in the most relevant document on global development, Transforming our World: The 2030 Agenda for Sustainable Development published by the United Nations (UN, 2015). In its 17 Sustainable Development Goals, the Agenda emphasizes creating conditions for sustainable, inclusive and sustained growth, prosperity and decent work for all, by considering differences in development and capacities within countries (UN, 2015). Nevertheless, tourism has a very important role in global, national and regional development

strategies, and it is treated as a desirable means of economic development and a contributor to social justice and environmental protection.

The research is based on secondary statistical sources and insights gained by review of relevant national policies and practices, as well as international documents, such as already mentioned, the 2030 Agenda for Sustainable Development (UN, 2015), Tourism and the Sustainable Development Goals (UNWTO, 2015), Policy for the Integration of a Sustainable Development Perspective into the Processes of the World Heritage Convention (UNESCO, 2015) just to name a few. Regenerative pillars and principles are based on Naboni and Havinga (2019), taking into consideration climate change, ecology and environmental issues, as well as human well-being. This book chapter gives an overview of present protection of cultural heritage, and on growing pressure of tourism on the UNESCO World Heritage Sites in Croatia. The main goal of this chapter is to analyse the quality of managing cultural heritage sites in Croatia, as well as to provide some insights and offer recommendations to policy-makers.

## 19.2 Tourism and the UN's Sustainable Development Goals

Tourism causes intensive economic, socio-cultural and environmental impacts in destination areas. The most cited are positive economic impacts of tourism – rise in income and number of jobs, as well as increase in general economic activity in the destination area. Taxes from income are directly and indirectly invested into development of infrastructure and public areas used both by hosts and guests. Particularly important are investments into safeguarding, restoring and re-using old and significant buildings, perceived as cultural heritage, that are actively used to increase appeal of cities for tourists. Recently, one of the most important areas of the research in this field is reconstruction and restoration of buildings and architectural monuments. The process of conservation encompasses maintenance, preservation, restoration and reconstruction (Luca, Šulc, Haselsteiner, Kopeva, & Brown, 2017). They have to be maintained and restored to sustain historic integrity and uniqueness in the form and material. These heritage buildings often get a new function with tourism, which contributes to urban renewal of previously shabby and badly maintained historical cores. Motivation of tourists is often deeply behavioural and they require active immersion into the local culture for their personal fulfilling and self-actualization (Pearce, 2005). Host communities benefit from preserved and often re-valORIZED culture, as well as from more dynamic and cultural life, generated by activities organized for tourists (Mason, 2003; Page, 2009; Williams, 2009). Therefore, heritage buildings get a new economic value through tourism.

UNESCO World Heritage Sites rarely fit the Butler's (1980) Life Cycle Model, according to which, tourism areas experience different stages in their development, ranging from exploration, development and stagnation, to potential decline or rejuvenation based on complete restructuring of tourism supply (Šulc, 2016). These sites, on the contrary, often skip decline and enter a new vicious circle that results in

further growth in tourism, particularly in favour of daily visits, *metropolization* of tourism (spread of tourism accommodation and services from the historical core into the urban region), and pushing other business and population out of the historical core. In the last stage, it results with overcrowding of core areas and replacing tourism businesses focused on overnight tourists on simpler services for same-day visitors (see Russo, 2002). These processes have recently entered tourism literature as *overtourism*, which represents the impact of tourism on a destination, or parts thereof, which excessively influences perceived quality of life of citizens and/or quality of visitors' experiences in a negative way (UNWTO, 2019). Negative impacts of *overtourism* can be present in various ways – as large crowds of people near main tourist attractions, traffic congestions, when tourists cannot view landmarks because of the crowds, when local tenants are *priced out* of the city due to renting to tourists, etc. (Responsible Tourism, 2020).

In order to minimize negative impacts of tourism, The World Tourism Organization (UNWTO) introduced the concept of sustainable tourism as “development that meets the needs of present tourists and host regions while protecting and enhancing opportunities for the future”. Soon, it becomes obvious that the principles of sustainable tourism are inadequate to address severe problems caused by tourism. As a result, the concept of “regenerative tourism” appeared. It is based on the notion of “regenerative design” presented as a dynamic process of participation, feedback and continual change over time (Lyle, 1994). The regenerative design is seen “both as a change in process and product, as well as a change in attitude towards our relations with environment” (Lyle, 1994: 7–8). Issues of transparency, local control, everyday practices, and democratic negotiations are essential elements for regenerative design. In addition to balance between consumption and production, regenerative design has to contribute to well-being and the whole process has to be politically transparent (Owen, 2007). The implementation of this concept in the field of tourism is complex and relevant. It proposes important guidelines on how to balance sometimes conflicting demands of development, growth and conservation of heritage. Regenerative tourism emphasizes the importance of our environmental impact, but also our relationship with the environment. It aims not just to do less harm, but to go on and restore the harm that our system has already done to the natural world, and by using nature's principles, to create the conditions of life to flourish (Pollock, 2019). Therefore, education and information campaigns are very important tools to introduce the concept in national policy. The relationship between tourism and cultural heritage evolve over time.

Tourism and heritage are explicitly included in four Sustainable Development Goals (8, 11, 12 and 14). As coastal tourism is still globally the most important type of mass tourism, Goal 14 “Conserve and sustainably use the oceans, seas and marine resources for sustainable development” treats it as an integral part of development strategies in small and island communities that highly depend upon healthy environment in tourism. Sustainable Development Goal 8 “Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all” is focused on economic impacts of tourism and it recognizes the tourism sector as an opportunity to increase employment. As World Heritage Sites are

important tourist destinations themselves, if managed properly, they have a great potential for inclusive local economic development, sustainability and strengthening social resilience (UNESCO, 2015). In order to meet SDGs, stakeholders should develop inclusive and equitable economic investments in and around World Heritage properties that make use of local resources and skills, preserve local knowledge systems and infrastructures and make local communities and individuals, including marginalized populations, the primary beneficiaries of these investments (UNESCO, 2015). Beside sustainable and responsible tourism, heritage destinations need to encourage economic diversification between tourism and non-tourism activities (e.g., craftsmanship associated with heritage conservation) and to reinvest part of the revenues from tourism in the conservation and management of heritage resources (UNESCO, 2015).

Considering that the World Heritage Sites are often located in or around cities, Goal 11 treats heritage as an integral factor of “making cities and human settlements inclusive, safe, resilient and sustainable.” It explicitly promotes protecting and safeguarding heritage in built (urban) environments and encourages investments into greener infrastructure (efficient transport, lower air pollution, clean energy, conserved heritage, open spaces) aimed for the residents, from which also tourists will benefit (UN, 2015; UNWTO, 2015). Urban development that integrates cultural heritage is more sustainable, diverse and inclusive; it helps to create green economies that enhance sustainability and helps in poverty alleviation. Re-use and restoration of heritage contribute to promoting regenerative initiatives and transition towards de-carbonization of local economies (International Council on Monuments and Sites, 2016). As tourism development and valorization of heritage require a quality monitoring and management, Goal 12 (Target 12.b) promotes sustainable consumption and production patterns by developing and implementing tools to monitor the impacts of tourism on sustainable development.”

In a broader sense, tourism (particularly based on heritage) can contribute to fulfilling all other SDGs. For instance, income tax from tourism can be invested in health care and services, aiming to prevent diseases, improve maternal health, reduce child mortality, etc., which are defined by Goal 3 “Ensure healthy lives and promote well-being for all at all ages” (UNWTO, 2015). Higher employment opportunities in tourism, particularly for youth and women, contribute to “Achieving gender equality and empowering women and girls” (Goal 5). Tourism can also encourage national governments to make their industry more sustainable, resource-efficient and clean, as a means for attracting tourism, and to facilitate sustainable industrialization, necessary for economic growth, development and innovation (UNWTO, 2015).

### 19.3 The Role of Tourism in Croatian National Economy

Tourism is a significant economic and export activity in Croatia and, since 2002, it has been steadily growing (The Institute of Economics, Zagreb, 2018). The share of tourism in GDP in the period 2012–2016 increased from 3.8 to 4.7 percent. In Croatia, in 2017, there have been 86.2 million overnight stays (which is 10 percent higher than in 2016), of which 80 million stays were of foreign tourists. In 2017, tourism created 9.5 billion euros foreign exchange revenues, which corresponds to a share of 19.4 percent of GDP. In 2017, tourism employed 99,467 persons, representing 7.2 percent of total employment. In the same year, tourism participated with almost 38 percent in total exports (The Institute of Economics Zagreb, 2018).

In 2017, 17.4 million tourist arrivals were registered. On average, in 2017, tourists spent 4.9 nights, which is slightly below the level in 2016 (5 nights). In general, the trend of shortening the average stay has been registered since 2000. On average, foreign tourists in Croatia stayed 5.8 nights, in 2000; 5.2 nights, in 2016; and 5.1 nights, in 2017 (CBS, 2018).

One of the important characteristics of Croatian tourism is a distinct seasonality. This is also revealed by the time distribution of the number of tourist stays per month. In 2017, almost 86 percent of the total annual number of overnight stays was performed between June and September, with July and August accounting for 61 percent of the total annual nights.

Adriatic Croatia is the most important Croatian tourism region according to tourist arrivals and stays. In the area of the seven coastal counties, in 2017, 95 percent of all stays and 87 percent of all arrivals in Croatia were achieved. To optimize tourism supply in Croatia, cultural tourism is seen as a great potential for tourism development. Definitions of cultural tourism are numerous. The most general definition of cultural tourism would relate to the specific interest based on the search and participation in new and significant cultural experiences, whether aesthetic, intellectual, emotional or psychological (Reisinger, 1994). The basic motive for traveling is a cultural attraction. But this motivation can be primary and secondary. According to the nature of the motivation in the typology of cultural tourism, we can distinguish between primary, incidental and unintended motivations. In addition to its spiritual dimension and significance in the cultural identity of the community, heritage has a significant economic role, too (Afrić Rakitovac & Urošević, 2017; Benhamaou, 2003; Poljanec-Borić, 2017). The economic valuation of cultural heritage is predominantly through cultural tourism. A key prerequisite for the development of cultural tourism is a cultural heritage.

According to the Survey of attitudes and tourist consumption in Croatia in 2017 (Institute for Tourism, 2018), 12 percent of tourists come to Croatia due to cultural sights and events. In the Development Strategy for Cultural Tourism from 2003, it is estimated that cultural tourism in total tourism participates with less than 8 percent. The first and only comprehensive research of attitudes and consumption of visitors to cultural attractions and events in Croatia was performed in 2008 for the Ministry of Tourism (Institute for Tourism, 2009). Average daily consumption of

visitors to cultural attractions and events on multi-day trips amounted to 34 euros on average. Research has shown that the vast majority of visitors are satisfied with their visit and stay in Croatia (according to Tomas, 2008, 48 percent of tourists visit experiences exceed expectations, and 47 percent of tourist visits was in accordance with expectations).

Tourists are satisfied with the quality of programs, the professionalism of the staff, and the tidiness, but are unsatisfied with the availability of information (before departure and in destination) and traffic signalization. Most foreign cultural tourists believe that Croatia has a rich cultural and historical heritage (84 percent) and connect Croatia with the richness of museums and galleries (71 percent). Between 50 and 60 percent of visitors identify Croatia with festivals and events and a destination that is suitable for cultural tourism. This is a significant insight that can help the tourism decision-makers. The existing large and unused cultural capital demands the openness of heritage protection policy towards the development of tourism, which assumes the interaction of all tourism stakeholders.

The problems of sustainable use of cultural tourism in Croatia are numerous. Lack of knowledge of local population and tourist coordinators in the field of cultural management is recognized as one of the most significant problems. There are also organizational problems during the preparation and implementation of projects. Although progress in this area has been made since 2003, there is still insufficient presence of cultural resources in the country's tourist supply, and some localities are still hardly accessible for a larger number of tourists (Ministry of Culture, 2003). It can be said that countries with a longer tradition of heritage protection have developed more appropriate models for tourist use of cultural heritage than transition countries. In Croatia today, there is a so-called hybrid or transitional model for the protection of cultural heritage, where the main sources of financing are public funds and monument rent (Poljanec-Borić, 2017).

It is estimated that Croatia has a great potential for growth of market demand of cultural heritage, but still the national authorities and entrepreneurs do not recognize this as a development opportunity.

## 19.4 Croatian Heritage on the UNESCO List

The aim of this section is to present UNESCO World Heritage sites in Croatia, as well as to present management models, levels of visiting and the issues they face.

The World Heritage List in Croatia comprises ten natural and cultural sites, out of which three belong to group of transnational sites. Natural sites are Plitvice Lakes (inscribed in 1979) and the transnational Primeval Beech Forests of the Carpathians and Other Regions of Europe (2017). Eight cultural heritage sites are the Palace of Diocletian within the Historical Complex of Split (1979), the Old City of Dubrovnik (1979), the Historical City of Trogir (1997), the Episcopal Complex of the Euphrasian Basilica in the Historic Centre of Poreč (1997), the Cathedral of St James in Šibenik (2000), the Stari Grad Plain (2008), the Stećci Medieval Tombstone

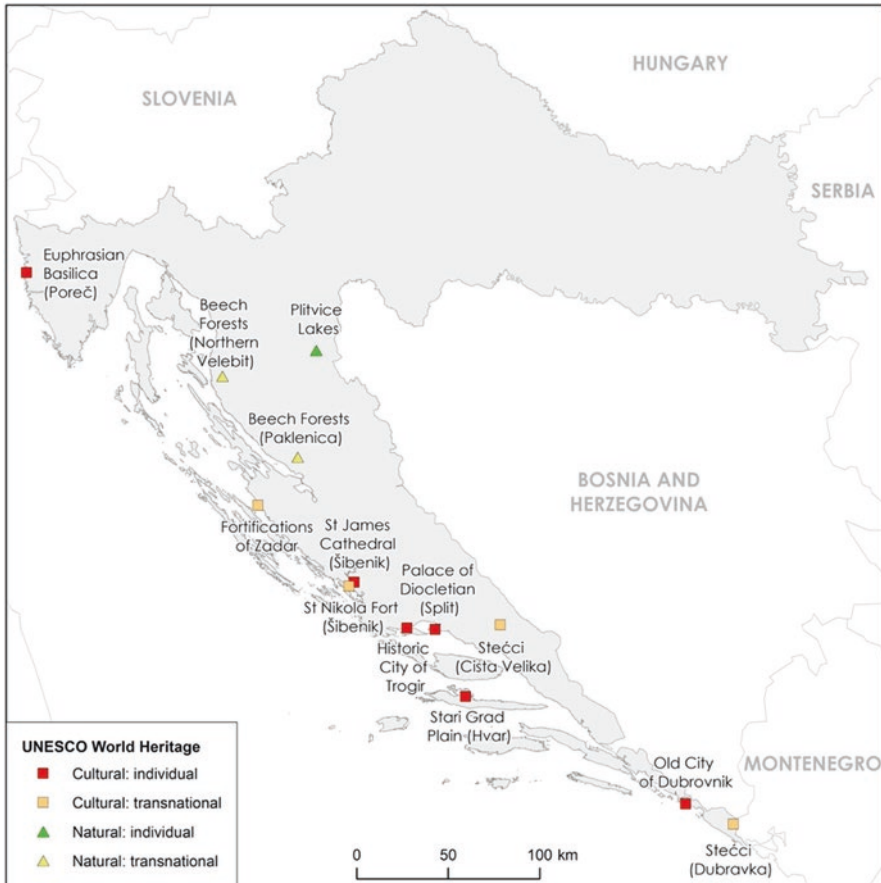


Fig. 19.1 UNESCO World Heritage Sites in Croatia. (Source: UNESCO, 2020)

Graveyards (2016), the Venetian Works of Defence between the 16th and 17th Centuries: Stato da Terra – Western Stato da Mar (2017) (see Fig. 19.1).

The Plitvice Lakes is the only single natural site protected by UNESCO in Croatia and it represents a unique phenomenon of karst hydrography and natural landscape.

Other UNESCO sites in Croatia belong to cultural heritage, featuring historical cores or individual buildings and building complexes in the coastal region of Croatia.

The Historical City of Trogir is a precious example of urban continuity on a small island located between the mainland and Čiovo Island. Another UNESCO cultural heritage site in Central Dalmatia is the Palace of Diocletian within the Historical Complex of Split (today the second largest city in Croatia), which was constructed as a typical Roman fortified city (*castrum*) by the emperor Diocletian (third-fourth century AD). In the subsequent centuries, the palace continued to

develop as a living city. The Episcopal Complex of the Euphrasian Basilica in the Historic Centre of Poreč in Istria represents a unique preserved early Christian sacral complex, constructed from the fourth to the ninth centuries. The Cathedral of St James in Šibenik (2000) is a remarkable example of pure Renaissance sacral architecture that witnesses exchanges in the monumental art between Dalmatia, North Italy and Tuscany in the fifteenth and sixteenth centuries. The Old City of Dubrovnik was inscribed to the UNESCO List of World Heritage in 1979 due to its historical core with preserved fortifications from the fifteenth century and its significance as a Mediterranean Sea power since the thirteenth century.

Beside single sites of cultural heritage, UNESCO protected two groups of transnational sites as World Heritage. In 2016, the sites Velika and Mala Crljivica, near Cista Velika in Central Dalmatia and St. Barbara in Dubravka, Konavle have been included to the transnational World Heritage Site of Stećci Medieval Tombstone Graveyards, along with 26 other sites in Bosnia and Herzegovina, Serbia and Montenegro. In 2017, the newly established transnational site Venetian Works of Defence between the sixteenth and seventeenth centuries: Stato da Terra – Western Stato da Mar included three sites in Italy, two in Croatia (Defensive system of Zadar and Fort of St. Nikola near Šibenik) and one in Montenegro (UNESCO, 2020).

## 19.5 Results and Discussion

### 19.5.1 *Management and Visiting of UNESCO World Heritage in Croatia*

Tourism has a very important role in the Croatian economy, with UNESCO World Heritage Sites and main promoters in tourism markets and attractions for potential visitors. These sites are managed in several different ways, but only few have own management plans, which points out the importance of heritage in political priorities on different government levels in Croatia. Lack of data on visitors in many heritage destinations makes monitoring and managing tourism impacts difficult and inefficient, ranging from an almost neglected Stećci to *overtourism* in Dubrovnik and Split). Here we discuss in more detail policies and management of UNESCO Sites in Croatia and impacts of growing pressure of tourism on UNESCO cultural heritage in Croatia, by presenting the case study of Dubrovnik.

UNESCO World Heritage Sites in Croatia are managed in several different ways, and they differ significantly in terms of their functions and level of visiting. National and nature parks are managed by their own public institution (*javna ustanova* in Croatia) and have special spatial plans, while natural heritage outside these parks is managed by public institutions on the counties' level (21 in Croatia), aimed at nature protection. The UNESCO cultural heritage in Croatia (except Stećci) is located within cities and, therefore, are managed by local administrative units, whose governments are in charge of managing the cities.



As regards the protection and management of cultural heritage, it is important to have a starting point based on the critical principles in this area, which have already been established and internationally accepted. Some of the key issues for the management of the world heritage are included in the Handbook for the World Heritage - Management of the World Cultural heritage (UNESCO, 2013). The basic principles of efficient management of the world heritage are: placing heritage concerns in a broader framework, recognizing the role in sustainable development, protection and management based on values and participation of stakeholders. According to this Manual, there are nine key elements that are common to all management systems: elements (legislation, institutions and resources), processes (planning, implementation and monitoring) and results (UNESCO, 2013).

The starting assumption is that there are all necessary elements in the Croatian policy, such as the legislative and institutional framework, as well as available resources. We are primarily interested in the management planning process, and whether there is a management plan for the UNESCO sites in Croatia. Formulating a management plan, implementing it and monitoring its implementation is essential for the good management of the world heritage. Preparation and implementation of the management plan enables systematic care and management of cultural goods, and helps to identify shortcomings of the existing management system.

Among the UNESCO sites, only the natural national sites have formulated the management plans, while the formulation of management plans for cultural heritage is still in progress. In December 2015, the draft of the Management plan of the historical centre of Split and the Basements of the Diocletian's palace were presented, but the document has not yet been adopted by the City Council. The contract for drafting the management plan for the city of Dubrovnik was signed in July 2019. The plan will encompass the period 2020–2025. The fact that there are no management plans clearly shows that heritage preservation is not high on the priority list of urban policies in Croatia.

Number of visitors of UNESCO World Heritage sites is very difficult to estimate, as most of them are located in public areas (e.g., cities), while only some objects require an entry fee and are not attended by all visitors. Even in those cases, statistical data are generally not available to scientists.

Therefore, the estimated number of visitors included registered number of tourist arrivals in the local administrative units in which the UNESCO sites are located and the number of cruise ship passengers in the cruise ports Zadar, Šibenik, Split and Dubrovnik (in 2018). Same-day visitors are excluded from estimations, as their arrivals to the destination is usually not reported, although they make quite a large share of total visits (e.g., Dubrovnik).

UNESCO World Heritage represented by historical cities of Zadar, Trogir, Split and Dubrovnik has mixed functions, ranging from a place for living, accommodation for tourists (hotels, hostels, apartments for rent, etc.), shops, restaurants, bars, to museums and other public functions (e.g., churches, cultural centres, seats of local government, theatres, museums, etc.). These are also the largest coastal cities in Dalmatia, famous for their sun and sea tourism. Cultural tourism based on UNESCO Sites overlaps with coastal tourism, and therefore it is impossible to

determine main motivation for visiting. Only some visit monuments that require a ticket (e.g., Dubrovnik City Walls (managed by the Society of Friends of Dubrovnik Heritage), Basements of the Diocletian Palace in Split and Split Walls (managed by the Museums of the City of Split), Kamerlengo Fort and the belfry of the church in Trogir). Dubrovnik is the most visited UNESCO Site in Croatia with 2,072,000 visitors, out of which two thirds are overnight tourists and a third comes on day trips from cruise ships (see Table 19.1). Beside historical street, the most famous monuments are the City Walls that were among the most visited tourist attractions in Croatia, with 1.3 million visitors in 2018 (Society of Friends of Dubrovnik Heritage, 2019).

The second most visited is Split with 1,646,000 visitors, with almost equal ration of overnight tourists and cruise ship visitors (see Table 19.1). However, historical monuments in Split are much less visited by tourists – only 247,000 visited the Basements of the Diocletian Palace in Split in 2016 (Slobodna Dalmacija, 2017). The Defensive System of Zadar is today a consistent part of urban fabric and it has a public function (as parks or public streets), which are available to everyone. The city itself recorded 725,000 tourists in 2018 – 558,000 staying in the destination and 167,000 from cruise ships (see Table 19.1), but only few actively visited the fortifications. Trogir is least visited among UNESCO heritage cities, with only 147,000 registered arrivals.

Individual cultural monuments on the UNESCO World Heritage List are also located in coastal cities (Poreč and Šibenik), where cultural tourism overlaps with much more intensive coastal tourism. The Euphrasian Basilica in Poreč and the Cathedral of St. James in Šibenik have kept their original sacral functions as seats of bishoprics, while the Fort of St. Nikola in Šibenik opened for public in 2019, after a two-year-long restoration, with the main purpose of visiting. Even though all three sites are available for visiting with an admission, statistical data on the number of visitors is not available. Slobodna Dalmacija (2017) has only a rough estimation that the Šibenik Cathedral is visited by 100,000 visitors annually. However, these sites are included in sightseeing by a much higher number of visitors, with potential market of at least 551,000 registered tourists in Poreč and 376,000 in Šibenik (90 percent of which are overnight tourists) (Table 19.1).

**Table 19.1** Number of visitors of cities with UNESCO World Heritage Sites in Croatia in 2018

Local administrative unit	Number of visitors	
	Overnight visitors	Cruise ship visitors
Dubrovnik	1,340,000	732,000
Split	859,000	787,000
Zadar	558,000	167,000
Trogir	147,000	–
Poreč	551,000	–
Šibenik	340,000	36,000

Source: CBS (2019) and MedCruise (2019)

### 19.5.2 *Tourism Pressure*

Despite exceptional value of heritage, positive economic impacts of tourism and predominantly good management of heritage sites themselves, most UNESCO sites in Croatia suffer from high pressure of tourism. Most of them face large crowds of visitors during the tourist season, particularly next to main attractions (e.g., Dubrovnik, Split), generated mostly by cruise ship visitors who have only a few hours in the destinations and are less informed on tourism supply. Overcrowding affects both local residents and tourists, whose experience is deteriorated by crowding together with other tourists in the same place and by waiting in long queues to enter the attractions. Furthermore, most destinations occasionally experience large traffic congestions, as streets and roads that had originally been planned for a smaller number of local users, are heavily pressured by numerous cars and buses with tourists. Those destinations often lack enough parking places on the outskirts of historical centres, as well, which contributes to *overtourism* (e.g., Poreč, Split, Dubrovnik).

On the other hand, due to high tourism demand, historical cores are gradually transformed into tourism enclaves. These processes particularly affect local residents, whose quality of life diminishes with large crowds of tourists, noise and lack of services for them. Furthermore, motivated by growing prices of real estates, they often sell or rent their properties and move outside the historical core and these properties are increasingly converted into hotels and other accommodation for tourists (particularly in Dubrovnik). Historical centres slowly stop being places of living and working and become open-air museums (*musealization*) with business and services catering only to tourists. In a later stage, services for all tourists give place to those that cater same-day visitors (usually from cruise ships), e.g., fast food and street food facilities, souvenir shops, etc. (see Russo, 2002). At the same time, large areas of former public spaces are largely given into concession to tourism businesses (e.g., terraces of restaurants or cafés) and they become unavailable for the local population and tourists.

Another huge problem that has affected the entire Croatian coast is illegal, abusive and/or anaesthetic construction of houses with accommodation for tourists, often oversized and unadjusted to vernacular architecture and cultural landscape. Although the UNESCO sites themselves are perfectly conserved and maintained, very close surrounding areas have been more or less severely affected or even degraded by these processes, particularly in Zadar, Šibenik, Split, Hvar and Plitvice Lakes. Those areas generally lack urbanist planning and appropriate organizations of transport, as well.

### 19.5.3 *The Case of Dubrovnik*

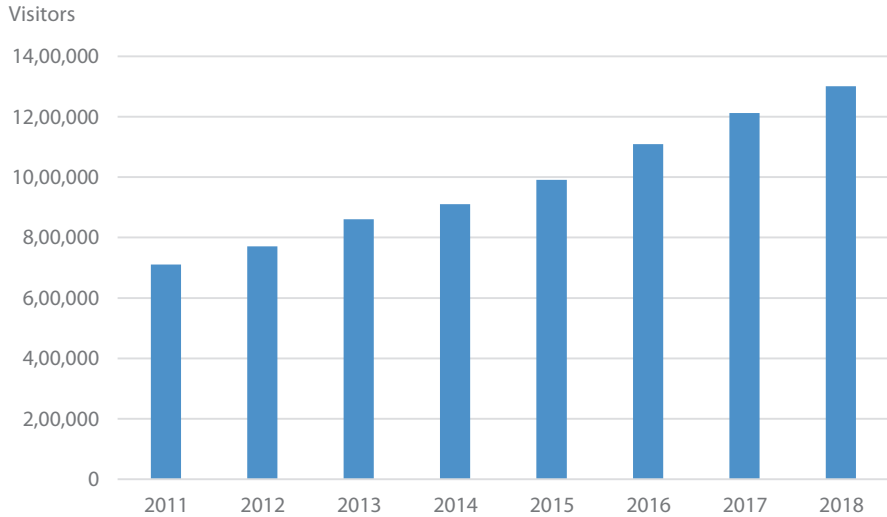
To get an insight into the dynamics of tourism and management of UNESCO World Heritage Sites in Croatia, we present the case of the Old City of Dubrovnik as one of the most famous tourist destinations in Croatia, with a population of 28,000 (CBS, 2011). It has an almost two-century-long tourism tradition and is one of few coastal destinations in Croatia that has recorded continuous tourism growth since the mid-1990s (Šulc, 2016; cf. Russo, 2002).

Dubrovnik is also one of the most important ports of call in the Adriatic and wider. For instance, in 2005, the city recorded 420,048 tourist arrivals and 1,665,732 overnight stays and registered 168 cruise calls and 121,148 cruise passengers (CBS, 2006; Port Authority Dubrovnik, 2019; Šulc, 2016). In 2013, the city reached the maximum in cruising tourism with 553 calls and 942,909 passengers (Port Authority Dubrovnik, 2019); while the overnight visitors made 646,295 arrivals and 2,173,539 overnight stays (CBS, 2014). After 2013, overnight tourism continued to grow and reached 1,139,725 arrivals and 3,484,667 overnight stays, putting Dubrovnik as one of the most visited destinations in Croatia in 2018 (CBS 2019). At the same time, the intensity of cruising tourism slightly decreased, with 414 cruise calls and 732,431 passengers (Port Authority Dubrovnik, 2019).

Considering that the Old City covers an area of less than 1 km<sup>2</sup> and used to host more than 10,000 people at the same time, the city has faced a serious problem of *overtourism*, for which cruising is usually blamed, as in many other cruise ports in the Mediterranean. After a cruise ship visits the Dubrovnik Port the visitors are transferred by organized shuttle buses to the Pile Gate, the western entrance to the Old City. Considering the large size of most cruise ships, such high number of visitors in the Old City at the same time causes large overcrowding in the historical core and traffic congestions in the Pile area, as many cars and buses are supposed to leave or pickup groups of visitors.

Most cruise visitors are less informed of everything that the city offers and have only a few hours for sightseeing, which is additionally reduced by waiting in traffic congestions. Hence, they tend to group next to main attractions (Stradun, Luža, City Walls) and cause congestions, which deteriorate the experience of all visitors (Fig. 19.2). Since their cruise package usually includes all meals on the ship, they make little use of restaurants and bars in the city, making very small economic benefits for the city, while their pressure on the historical core is huge. At the same time, certain segments of the Old City that are worth visiting remain almost empty even on peak days.

The case of Dubrovnik confirms previously described transformation of businesses, from those oriented on services for the local community towards services for overnight visitors (restaurants, bars, etc.) and, eventually to services for same-day visitors (fast food restaurants, souvenir shops, exchange offices ...). At the same time, prices of real estates have reached the sky due to large demand for flats and buildings that are converted into hotels and Airbnb accommodation, galleries, restaurants, etc. As less than 1500 people remained residents there, the historical core



**Fig. 19.2** Annual number of visitors in the period 2011–2018. (Source: Society of Friends of Dubrovnik Heritage, 2019)

has lost the character of a vivid city and has been transformed into an open-air museum, with a large difference between overcrowded streets in summer and empty streets in winter. Furthermore, tourism has pushed the prices so high that the real estates in the whole city has become unavailable to the local population and newcomers. Those who have not inherited a house or a flat can hardly afford to buy or lease a flat for a long term. Eventually, the population is pushed out of the city, which contributes to the urban sprawl in the whole urban region.

In 2016, UNESCO warned the city stakeholders to put the Old City on the List of World Heritage Sites in Danger. The reasons were growing pressure of (cruising) tourism in the historical core and the proposed greenfield project of a golf resort on the Mt. Srđ that would include construction of rather large buildings with apartments for rent to tourists and would change the cultural landscape of the city observed from the sea (UNESCO, 2016). UNESCO recommended to limit the daily number of visitors to the Old City to 8000 (Responsible Tourism, 2020), while main tourism stakeholders additionally decided to reduce the limit to maximum 4000 visitors a day. Even though the latter goal has not been accomplished yet, it demonstrates that the city authorities are well aware of the problem. They also partially limited cruising tourism, by making a schedule of cruise ships that visit the city, with maximum two cruise calls a day and a maximum of 5000 passengers per ship (Responsible Tourism, 2020). In 2019, due to large traffic congestions, the city authorities put restrictions on stopping cars and getting daily visitors on and off Thursdays and Saturdays (when cruise ships usually come to the city) and plan to ban private shuttle bus companies to transfer cruise tourists between the cruise port and Pile Gate, which will be organized by the city public transport service Libertas (Dulist, 2019). It is still too early to claim if the implemented restrictions will reduce the pressure

of tourism on the historical core or additional restrictions will be needed. However, these measures are not expected to influence significantly the quality of life of the population living in the Old City and to attract newcomers.

## 19.6 Concluding Remarks

The preservation of cultural heritage is the prerequisite for further development, while it is included in many social processes. Any damages will be manifested on quality of life of current and future generations. Heritage preservation should be integrative in its scope. It will be effective only if it is a part of the framework of entire public policy. It requires coordination of national and local stakeholders, in private and public sector. Implementation of the principles of circular economy to management of cultural heritage enhances development in accordance with UN SDGs. In addition, it could enable transition from sustainable to regenerative tourism. Implementation of restorative and regenerative principles in tourism (including cultural tourism) is still very limited and practically non-existent in Croatia. In more developed countries, it is considered as an alternative to sustainable tourism.

Therefore, we evaluate the management of cultural heritage based on the principles of sustainable use of cultural heritage. The relationship between tourism and cultural heritage develops over time. Based on the Handbook for the World Heritage – Management of the World Cultural heritage (UNESCO, 2013), the chapter identified that the basic principles of efficient management are still not fully implemented. This is especially true for incorporating the heritage in a broader framework of economic evaluation. Although some progress in balancing protection of cultural heritage and economic valuation is visible, it can be concluded that appropriate models for tourist valuation of cultural heritage are still missing. Lack of knowledge in the field of cultural management is recognized, therefore more research is still needed.

Formulation of a management plan, its implementation and monitoring are essential for the good management of the heritage. Lack of participation of all relevant stakeholders is evident, as well as organizational issues during the planning and monitoring process. Education and information campaigns are, therefore, crucial for mobilizing the non-governmental sector, citizens, etc.

In Croatia, management plans for world heritage are formulated only for natural heritage. Preparation of management plans for historical city centres are in progress, while plans for individual buildings and building complexes are still neglected. Relevant ministries (Ministry of Culture, Ministry of Construction and Physical Planning, Ministry of Tourism) and state agencies are responsible for this part of the process. Measures for the sustainable use of cultural heritage are also insufficient, and if they exist, they are sectoral and fragmented. Furthermore, the interaction between complementary sectoral policies (such as spatial, regional and rural) is weak and random and reflects insufficient cooperation between national authorities and other stakeholders. Elaborating different metrics for tourism statistics that will

support shift from quantitative to qualitative could be a part of solution for excessive *overtourism*.

European heritage cities that faced excessive *overtourism* have already introduced measures that can partially be implemented to heritage sites in Croatia. For instance, online booking with limited number of tickets for major monuments (e.g., Sagrada Familia in Barcelona or The Royal Path in Andalucía) proved to be efficient in limiting the daily maximum of visitors and spreading the pressure to the whole day. Programs of de-marketing, in terms of complete absence of advertising (e.g., Amsterdam) or changing image of the destination (e.g., Dublin) are yet to be tested. Venice implemented even more severe measures that include visitor tax in a form of ticket for visiting the city. These measures fit previously analysed SDGs that aim to develop tourism as generator of economic development and contributor to heritage protection, with strict monitoring. Increasing prices of accommodation and admission for main attractions are also used by many destinations, including Croatia, but the problem is these destinations is that it attracts those who can afford and not those who are the most motivated.

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# Chapter 20

## The Green Building Approach: Recent Initiatives in the Evolving Italian Scenario



Fabrizio Tucci

**Abstract** Several analyses and reports on sustainable design are pointing worldwide in the direction of what is known as the ‘Green Building’ approach: an integrated, multi-sectoral approach to the implementation of improvements that aim to increase levels of well-being, social inclusion and long-lasting development in cities, on the basis of most urgent aspects of environmental quality, efficiency and circularity of resources, in a climate change scenario. In Italy, in 2017, the ‘Future City Manifesto’ was launched as part of the initiatives of the Italian General States of the Green Economy in Architecture, aiming at mainstreaming the Green Building approach within the international Green City Network. The objective of this chapter is to present and discuss recent initiatives in the field of sustainable architecture and green economy in Italy, pointing at innovative processes, strategies, methods and tools in a Green Building approach, suitable to activate policy actions and foster significant results as regards future green growth and urban development.

**Keywords** Green economy · Green city approach · Sustainable architecture · Environmental quality · Green growth and development · Circularity of resources

### 20.1 Introduction

*Designing, building and dwelling* are words that constitute the essence of being human and citizens. They have been the subject of profound reflections by great intellectuals of the last century, who have left their indelible mark: from the foundations laid down in Martin Heidegger’s famous ‘Building Dwelling Thinking’ (1951), to the developments recently explored with the concept of *open city ethics*, by Richard Sennett’s in his recent book ‘Building and Dwelling’ (2018). A *sustainable* and *green* reading of these terms determines first of all a priority and an

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urgent necessity for every contemporary scholar and researcher to provide answers to the current problems by radically improving the environmental quality of the designing, building and dwelling categories of human actions. It also appears necessary to shift the attention, when designing and building, to strategies for:

- Regenerating and redeveloping existing assets, protecting land and improving resilience through climate adaptation and mitigation
- Improving energy efficiency and bioclimatic systems and incentivizing resource circularity
- Promoting the ecological conversion of cities, architecture and our way of living, producing and consuming through a new approach to dwelling
- Incentivizing the proactive role of all the players involved in such processes – from public authorities to commissioning clients, architects and qualified and specialized entrepreneurs
- Benefitting from the contribution provided by universities and state-of-the-art scientific research

so as to foster the pioneering technological and environmental approach to project design (United Nations Environment Programme (UNEP), 2017).

Out of the many pressing questions that demand an answer from every individual and citizen who cares about the culture of dwelling – in its multiple meanings –, and the conservation of the environment in which we live and of which we are an integral part, four questions particularly demand an answer. Why should we change the way we build and dwell in our built environment – particularly cities – in a sustainable and green direction? Why should we proactively and tangibly promote a commonly agreed methodological approach and scientifically founded strategies to achieve that aim? Why do we need to study the attempts and best practices that have been implemented over the past four decades at least – though this activity has intensified in recent years around the world? Why should we all contribute to speed up these green processes in the hope of securing a future for our cities? The reasons are to be found in some storytelling and, in a sense, grim statistics.

Over four billion people – out of the 7.8 billion alive today – live in the world's large urban centres, generating 80% of GDP but consuming 75% of the Earth's natural resources, responsible for over 70% of CO<sub>2</sub> emissions, producing 50% of the waste, using aqueducts that lose, on average, approximately 40% of their water, living in housing 70% of which is over 40 years old, consuming over half of the world's primary energy, experiencing the worst traffic and continuing to consume land. The world's top 600 cities are already home to 20% of the population, generating over 50% of the planet's wealth – a percentage that is growing – but living in conditions that are far from what we would term social well-being and of environmental quality. In Italy, 32 urban areas have illegal levels of air pollution because they exceed maximum levels of particulates, and our country is, moreover, the one with the highest number of deaths from pollution, relative to the population in Europe (Gesellschaft für Internationale Zusammenarbeit (GIZ) and International Council for Local Environmental Initiatives (ICLEI), 2012; International Energy Agency (IEA), 2018; Intergovernmental Panel on Climate Change (IPCC), 2018;

World Economic Forum (WEF), 2018; Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA), 2019).

The European Union is convinced that an approach to strenuously relaunch the priorities of urban ecological quality, sustainability and resilience is needed (European Commission (EC), 2016). This is also in consideration of the most recent developments in the green economy, understood as sustainable development, and in the circular economy as its fundamental basis (EC, 2017), in an era of climate crisis (Circle Economy, 2019). While focusing on increasing the ecological quality of cities is a decisive factor if we want to ensure the well-being of its residents, interaction among the green economy and architecture, urban planning and technological design culture offers a major opportunity to fundamentally enrich our knowledge and improve our approach to renovation and urban development if we want to improve social inclusion and promote local development and new forms of employment. This is because it allows us to reformulate architectural, technological and urban designs drafted ways, not to mention town plans, both from a strategic/planning point of view and from a technical/construction point of view (UN-Habitat, 2016).

The green economy is a general economic model that results in ‘improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities’ (UNEP, 2009) and, as far as this aspect is concerned, it boasts a wide body of work, particularly at international level, whose aim has been to promote high ecological quality as a way of boosting regeneration and relaunching the economy and society. It is not coincidence that ‘the ecological conversion of cities’ is one of the most important strategic themes that the Green Economy promotes, as shown by the many initiatives (United Nations (UN), 2016; Organization for Economic Co-operation and Development (OECD), 2017; UNEP, International Resource Panel (IRP), 2017; World Business Council for Sustainable Development (WBCSD), 2017) that identify actions and measures as key factors for a kind of ‘urban green growth’ that offers us the chance to improve the quality and sustainability of cities, that can provide a response to climate change, safeguard and enhance natural, cultural, social and technological capital, and regenerate and redevelop the many assets that exist in our urban systems, opportunities for investment, employment and, in a word, for planning a more desirable future.

The model, which is advancing on a European and international level, is called ‘green city’: an integrated and multi-sector approach to cities based on key aspects of environmental quality, resource efficiency and circularity, mitigation and adaptation to climate change. The green city approach has been recently wisely defined by The European Bank for Reconstruction and Development (EBRD) based on the International Council for Local Environmental Initiatives (OECD-ICLEI) methodology in 2017. Such model was also adopted as a basis for a green economy development programme in cities with the Economics of Green Cities Programme by the London School of Economics, LSE Cities, led by Nicholas Stern (Stern, 2015). In 2010, the integrated approach towards green city had already been adopted by the European Commission for the European Green Capital Award (EGCA), an

award which, by promoting the green city model, aims to support the advanced and sustainable development of European cities.

It therefore becomes essential to promote this green vision and publicize at all levels the important contributions and documents that are being produced, principally in an experimental and heuristic way, as the basis for constructing and developing a framework of priority strategies that, aware of the enormous variety and vibrancy of applications, can provide cities and architecture with guidelines, strategic benchmarks and tangible examples of how these strategies have been tried and implemented wherever they have been applied on the international scene over the past few decades, whilst always keeping the different scales – in an ascalar sense –, the various different disciplines – in a multi- and transdisciplinary sense – and the various sectors of knowledge and know-how – in an inter-sectoral sense – closely and inextricably linked (Antonini and Tucci, 2017).

## 20.2 Guidelines to the Processes of a Green City Approach in Italy

In Italy, this new approach has been supported by significant contributions. The relationship among the green economy, the green city and an adaptive design for the urban systems was the focus of the contribution of Sapienza University of Rome's Research Unit to the Italian Project of Relevant National Interest (PRIN) Research 'Adaptive Design and Technological Innovations for the Resilient Regeneration of Urban Districts during Climate Change', funded by the Italian Ministry of Scientific Research, in which this Operating Unit, based in Rome and coordinated by the author of this chapter, developed these themes during the period 2016–2019.

Furthermore, in coordination with PRIN research developments, in Italy, there have been important developments that led to the elaboration and presentation of the 'Future city' Manifesto (SGGE, 2017), proposed by a group of faculty coming from 20 Italian and foreign universities in 2017 coordinated by F. Tucci, in the framework of the General States of the Green Economy initiatives, and over the last year the development of this new approach has been boosted by the international Green City Network promoted by the Sustainable Development Foundation, institutions that the author of this chapter had the opportunity to coordinate in both instances.

The main goal was to encourage the development with respect to the relationship among the main principles that lie at the heart of the Green Economy and architectural and urban growth, on the one side, and regeneration and development, on the other. An internal debate was launched – through a direct confrontation with the international design practice – endeavouring to bring Italian cities closer to the development already achieved by other European cities, registering significant results in terms of *green* growth and redevelopment. In the '2017 Report on the state of the green economy in Italy', the Sustainable Development Foundation focused on the urban green economy, building on an analysis illustrating strategically

relevant trends in the administrative centres of the Italian provinces already in place. A commitment towards climate and renewable energy sources, the management of water resources, sustainable mobility and public administration's 'green' procurement was generally shown. The emerging framework is characterized by moments of light, with some excellent initiatives, and others characterized by shadows and delays. Through the adoption of an integrated approach towards the green city, it is possible to jointly tackle different aspects and problems, enhancing potential synergies and coming up with a comprehensive urban agenda for the Italian cities. The evaluation of some particularly important topics, such as urban regeneration, building and urban upgrading, air quality and circular economy, was consequently proposed. Territorial planning and urban management in Italian cities have traditionally obtained scarce results because they favoured, or allowed, decades of real estate expansion with low-quality constructions, particularly in the peripheral urban areas, and with high levels of soil consumption. Even though we are witnessing a generalized reduction of the latter in the last few years, in Italy soil consumption keeps increasing. Between November 2015 and May 2016, new artificial roofs invested 50 km<sup>2</sup> of the territory, a little less than 30 hectares per day (ISPRA, 2019). Moreover, the data analysis concerning the 14 Metropolitan cities shows how the total amount of soil consumption, referred to 2016, represents 21,4% of the national total, and constitutes an increment higher than the national average referred to the same year (ISPRA, 2019). High soil consumption, sprinkling and sprawling effects, recorded in most of the urbanized areas have caused the erosion of agricultural land, extended soil sealing and increased hydrogeological risk. Those phenomena required the employment of significant amounts of resources in terms of dedicated urban development works, and increased the time and cost of transportation. On the one hand, Italian cities bear a great potential, as we can also observe in a review of the key sectors; on the other hand, except for a few excellent exceptions, they lag behind and experience a hard time positioning themselves next to the leading group composed by the most advanced European and world cities (Tucci and Battisti, 2020).

A new approach to the drafting and management of design processes and priorities is motivated by problems – current problems that can no longer be ignored, as mentioned earlier – is inspired by a vision – based on key principles and objectives that have proved themselves to be able to upgrade themselves and be called into question on a regular basis – and is supported by a method – that can be linked to a framework of guidelines, strategies and measures/categories of actions that can offer a clear benchmark and at the same time are able to adapt to different circumstances, characteristics and needs.

So, what should we do next? What logical/cognitive steps should we now take in order to support a methodological approach? What requirements should we look for if we want to properly set up *green* design and building processes and orient sustainable, balanced and responsible dwelling?

No doubt that if we want to successfully introduce design answers to momentous problems of an environmental nature in the spheres of building and dwelling, in cities, architecture and the living spaces of daily life, then all the disciplines involved must join forces to tackle common objectives, all sectors of human activity must

cooperate closely and all scales of building and dwelling must communicate with each other (Stati Generali della Green Economy, 2017; Tucci, 2017).

The inevitable clash between so many different priorities can only be resolved by resorting to a vision, a plan and a way of completing improvement work that are founded on a deep-rooted awareness of the need for a systemic, as well as heuristic, view of action at the various different levels and sectors and drawing on different fields. A view that always focuses on coordinated action, where public authorities, commissioning clients, architects and contractors work together right from the beginning of the process. As well as limiting the impact on the environment, such an approach clearly has a strong social dimension: the user can be involved both during the design phase and the construction phase and, above all, during the management phase. An approach that also considers the importance of 'design for social innovation' can definitely encourage users to appropriate space, responding to the changes that families, workplaces and educational centres have undergone.

A multi- and inter-disciplinary, ascalar and inter-sectoral methodological approach will allow us to rationalize all aspects involved in different spheres of redevelopment and in process-, project- and product-based arenas, which are also inextricably linked, combining traditional and innovative methodologies. The well-being of users, the proper regard for places, the management of water, energy, bioclimatic and physical resources, the control of economic, social and environmental costs, the promotion and enhancement of natural, cultural, social and technological capital, all these are elements which should be constantly kept in mind (Tucci, 2018).

### **20.3 Materials and Methods for a Green City Approach**

During this working process and research phase, it has proved essential to fine-tune, at first, the methodological approach and the criteria and requirements used to adopt it and, later, the ecological guidelines and development strategies of *green* building and dwelling (Green City Network (GCN) and Fondazione per lo Sviluppo Sostenibile (FSS), 2018). This was needed in order to strengthen our awareness of the priorities and main challenges that cities, architecture and technology are asked to face. But, also, to objectively share our knowledge of the best practices that have been implemented the world over, working with scientific knowledge and taking a heuristic vision in the hope of finding innovative, environmentally and technologically aware design solutions. Those solutions that can prove sensitive to the differences of each context and adapt to the specific characteristics of each case, but that take their cue from the creation of a common strategic platform, in order to promote and implement a new urban, architectural and technological environmental policy.

Progress is being made thanks to the work of the above-mentioned national group of experts from the Green City Network and the General States of the Green Economy for architecture and urban planning, a group that has been working during the last year on a new phase that involves a further stage that will fine-tune an even more complex and in-depth system of best practices and draft a set of benchmarks

and innovative indicators designed to help assess and compare the measures adopted and the practices implemented.

That is why we must continue to develop an increasingly dense and active network of national contacts in order to foster the connection and sharing of information, a comparison with common strategic frameworks, the development of demonstration projects and the use of existing EU support programmes as part of a policy that encourages cohesion and research. All of the above is essential as part of a process to build and offer a strategic benchmark framework for guiding green-inspired regeneration in cities.

An extremely important aspect that influenced the structure of works and research operated while pursuing the above-mentioned objectives concerns the strategic fields and the relative measures that should be adopted, which are the recurring themes that the challenges that affect all cities in this day and age face as regards 'green' Building and Dwelling. Its purpose is to offer a planning framework of issues, guidelines, strategies and measures that is generally agreed in the scientific community and in practice at an international scale, systematically organized and made available to all, a framework that public authorities and architects should tackle broadly with regeneration work in their territories and contexts (GCN, 2018). (see Figs. 20.1 and 20.2)

The idea was to provide a range of solutions to be applied *sic et simpliciter* – indeed, it could not be possible to believe that such a thing can be done a priori – as the solutions should be found through a design-based approach, adapting common strategic courses of action to the different circumstances of each context and the specific nature of each case, on a case-by-case basis, thus keeping in mind, above all, the main characteristics of each location as regards environment, climate, social characteristics, economy, culture, size, etc. The 'tool box' metaphor is perfect: the tools are not the solution; they are the methods and instruments used to *repair* problems and find solutions. Hence, we could say that the work underway hopes to provide an initial tool box that can be implemented and expanded over time as experimentation increases.

## 20.4 Result and Discussion: Adaptive Actions of Regeneration Towards Green Cities

As regards the success of improvement work based on those objectives, processes and methods, the issue of urban and architectural regeneration is the key, a category that can orient all the most efficient and effective actions designed to achieve a Green City model. Today, urban regeneration is the strategic choice if we want to restore the appeal of our cities by efficiently using and reusing our existing built heritage and urbanized areas, thanks to the renovation of public and private buildings, improving urban quality, thus tackling such phenomena as decay,



GENERAL OBJECTIVES	GUIDELINES		
<b>FIRST GENERAL OBJECTIVE</b>	1.		AIMING AT URBAN AND ARCHITECTURAL QUALITY IN THE CITY
	2.		GUARANTEEING A SUITABLE AMOUNT OF URBAN AND PERI URBAN GREEN INFRASTRUCTURES
	3.		ENSURING GOOD AIR QUALITY
	4.		MAKING URBAN MOBILITY MORE SUSTAINABLE
ENSURING HIGH ENVIRONMENTAL QUALITY	5.		AIMING AT URBAN REGENERATION AND REINFORCING SOIL PROTECTION
	6.		EXTENDING UPGRADING, RESTORATION, AND MAINTENANCE OF THE EXISTING DWELLING PATRIMONY
	7.		DEVELOPING WASTE PREVENTION AND RECYCLING
	8.		MANAGING WATER AS A STRATEGIC RESOURCE
USING RESOURCES EFFICIENTLY AND CIRCULARLY	9.		CUTTING DOWN GREENHOUSE GASSES' EMISSIONS
	10.		REDUCING ENERGY CONSUMPTION
	11.		DEVELOPING ENERGY PRODUCTION AND USE FROM RENEWABLE ENERGY SOURCES
<b>THIRD GENERAL OBJECTIVE</b>	12.		ADOPTING MEASURES AIMED AT CLIMATE CHANGE ADAPTATION
	ADOPTING MEASURES AIMED AT CONTRASTING CLIMATE CHANGE	11.	

Fig. 20.1 General objectives and guidelines for green cities in Italy

## MEASURES / ACTION CATEGORIES

- Identification, protection, and valorisation of the cultural assets and the identity of places
- Definition of directions, criteria, standards to improve the architectural and urban quality of the built environment
- Valorisation of the antropic-cultural ecosystems of urban areas
- Promotion of a culture economy
- Promotion of a certain degree of homogeneity and equity in the urban environment quality distribution
- Promotion/valorisation of green infrastructure, of their multi-functionality and multi-purpose
- Promotion/valorisation of ecological corridors and green belts, according to the context and biodiversity
- Promotion/valorisation of parks and gardens, trees, green facades, and roofs, according to the context
- Promotion/valorisation of urban farming and short production chain systems, according to the context
- Scheduling of green maintenance/management
- Cutting down air pollution through the management and reorganization of urban system activities
- Cutting down air pollution through focused actions aimed at increasing green surfaces in the city
- Cutting down air pollution through traffic management
- Cutting down air pollution through regulation of industrial facilities in the area
- Absorption of atmosphere pollutants within the system territory-city-building
- Limitation of private car circulation in cities and promotion of public transportation circulation
- Increase of cycling and pedestrian networks through new or existing linear infrastructures
- Regulation of private car parking areas in public spaces
- Promotion of shared mobility through technological advancement, also using ITC ad ITS systems
- Incentivisation of electric, hybrid, and biofuel car use
- Densification of the urban fabric object of study, the urban “voids” and the “non-places”
- Hybridization of monofunctional areas through the introduction of functional mix, and mix of activities and use
- Renewal of residential and non-residential urban areas in decay or abandonment through physical transformation and functional recon
- Renewal of urban infrastructures in decay or abandonment, through physical transformation and functional reconversion
- Prevention of hydrogeological risks through the improvement of surface permeability, urban drainage networks, etc.
- Planning of diffused and continued public and private dwelling patrimony upgrading
- Planning of existing dwelling patrimony maintenance to improve its quality and extend its life
- Prevention of dwelling patrimony seismic risks, also through procedural and permit facilities
- Upgrade and reuse of the dwelling patrimony aimed at responding to new residential needs, most of all social ones
- Upgrade and reuse of the dwelling patrimony aimed at responding to new service and financial activity needs
- Employment of eco-compatible materials, nature-based, recycled-based, environmentally performative
- Prevention and reduction of waste production from building and living processes
- Separate collection and recycling of waste from living processes
- Separate collection and recycling of waste from building and demolishing activities
- Circular organization of the production-use-production processes
- Collection and reuse of grey and rainwater resources in buildings and open spaces
- Limitation of water consumption and efficient water use in buildings and open spaces
- Use of water purification networks with high purifying effluent's quality and mud treatment-recycling
- Promotion of diffusion and reuse of purified water and water from polluted sites' remediation operations
- Year-round diffusion and distribution to all citizens of potable, good quality water in sufficient quantity
- Acceleration of Deep Energy Renovation processes aimed at cutting down greenhouse gas emissions
- Adoption of performance-based design methods aimed at cutting down emissions
- Valorisation of the relationship between green (at different scales) and CO2 subtraction
- Valorisation of the relationship between sustainable urban mobility and greenhouse gas emissions' reduction
- Record of greenhouse gas emissions and evaluation of the economic, environmental, and social impact
- Energy efficiency and reduction of consumption in buildings and dwelling complexes, both public and private
- Application of passive bioclimatic solutions through natural ventilation and cooling systems
- Application of passive bioclimatic solutions through natural heating and lighting systems
- Adoption of smart automation systems, domotics, and building management to support energy performance improvement
- Adoption of design methods based on environmental Simulation and Modelling processes
- Use of energy production technologies from renewable solar sources
- Use of energy production technologies from renewable wind sources
- Use of energy production technologies from renewable geothermal sources
- Use of energy production technologies from other types of renewable sources, e.g., biomass, water, hydrogen, etc.
- Use of Smart Grid or Dynamic Smart Grid for the diffused and adaptive distribution of renewable energy
- Development of plans and/or programmes for resilience and adaptation to climate change
- Adaptation to heat island phenomena
- Increase of resiliency to heat waves
- Increase of resiliency and adaptation to droughts
- Adaptation to intense precipitation, thunders, and Pluvial flooding phenomena

Fig. 20.2 Measures/Action categories for green cities in Italy

functional decline and urban chaos, redesigning marginal spaces without consuming greenfield sites and reducing artificial land cover.

The strategic priority of urban regeneration, when inspired by a green city approach, is ecological quality, so as to ensure the sustainability and resilience of improvement programmes and projects at a time of climate change and dwindling natural resources (European Commission, 2016; Arup, 2015). Green city-inspired urban regeneration calls into question both its overly simplistic version – based on small actions that lack context, vision and the necessary ecological quality – and its generic version, which though based on wider economic, social, cultural, residential and infrastructural content is nevertheless inconsistent with, and fails to prioritize, urgent ecological challenges, and is therefore weak and qualitatively inadequate. In contrast, the green city-inspired urban regeneration model focuses on making the various connected aspects of high ecological quality the real priorities on which improvement programmes and projects should be based, adopting an integrated and multi-sectoral approach.

This, combined with the awareness that we now have – thanks to confirmation amply provided by research and greater knowledge as well as the consolidated experience of the best practices put forward and verified in many cities – that social objectives (the quality of well-being, safety, cohesion and social inclusion) and economic development (reviving and relaunching local economic activities and job opportunities) are inextricably linked to, and dependent on, ecological quality both in big cities and small towns, dependent on the liveability, appeal and the renovation and repair of degraded areas and buildings. Although we are forced to proceed by concentrating on separate parts, we need to work with an organic and consistent plan that aims to create high ecological quality.

To this end, we need to establish and update an overall town strategy and the guidelines for town planning, creating suitable occasions for participation and consultation, using the green city vision as our benchmark for urban regeneration projects and improvements, while establishing a list of recommendations in order to ensure the right level of ecological quality and make the most of possible combinations and synergies.

Among the first topics to deal with is the theme of halting land consumption. This is not just an outcome, it is a central aim of urban regeneration plans and projects, as part of a framework of measures designed to strengthen land protection and reducing artificial land cover, efforts that are consistent with the European objective of reducing greenfield consumption to zero. Land consumption reduces the availability of a resource that is scarce, essential and basically unrenewable. Cities that expand by consuming greenfield sites have a significant impact on their quality.

High land consumption, which we find in most urbanized areas, has had a negative impact on the landscape, leading to the loss of natural areas and farmland, erosion and soil sealing, increasing hydrogeological risk. Before embarking on regeneration projects, available urbanized areas and unused building stock should first be surveyed, such as derelict, abandoned and under-used areas: not just the usual former industrial estates but degraded urban fabric as well, unplanned fabric

featuring a combination of random functions, former railway infrastructure and infrastructure of other kinds, former small business premises and craft workshops, as well as degraded, abandoned and unused buildings, unauthorized or unfinished constructions that can be renovated if they are of a suitable quality or demolished if not.

If we want to achieve zero land consumption, we need to tackle the growing demand for urban development with an innovative approach to urban regeneration, adopting an integrated strategy applied to various different sectoral policies, designed to meet various needs as well as heighten the ecological efficiency of the urban network, resulting in social and economic benefits.

Another central issue concerns the lower greenhouse gas emissions. Today's climate crisis is having a significant impact on cities, an impact that is increasing, and cities must play a leading role in adopting mitigation measures so as to lower greenhouse gas emissions. Urban regeneration work should include the energy upgrading of entire buildings, combining active and passive solutions thanks to the use of innovative materials and technologies. It also needs to promote the use of systems that can assess the energy and environmental performance of buildings, building complexes and networks, as well as outdoor spaces in the urban environment based on indicators that allow us to highlight our priorities and the most effective solutions, restoring the role these systems once played as climate modulators.

We need to make the best passive technical solutions as widely available as possible so as to reduce energy requirements and improve living comfort: from natural ventilation and passive cooling systems to limiting solar radiation, from natural lighting to passive heating and the natural regulation of humidity. We need to reduce and manage energy demands using monitoring systems and intuitive interfaces for users; to promote forms of energy distribution and exchange between 'prosumers' using smart grids and by combining local resources, such as capturing the excess heat produced by manufacturing and tertiary activities in order to meet residential heating needs, or using dynamic modulation systems that change to suit different demands depending on the time of day, the season or even the time of year.

We need to analyse which renewable sources can be used locally and promote the best production technologies available, which can be integrated into buildings and cities in order to move towards a 'positive energy' model: active solar energy systems, mini and micro wind turbines, geothermal energy supply systems using either vertical or horizontal heat pumps, systems that run on biomass using suitable emissions-reducing technology or on biomethane produced from organic waste, fuel cell systems that can be used in urban areas, micro-cogeneration systems, trigeneration systems and the use of district heating networks, etc.

Finally, the reduction in the vulnerability of the built environment. Integrated strategies designed to prevent and reduce the vulnerability to extreme weather events must be identified and planned so as to improve resilience and mitigate their effects. Regeneration projects should draw on specific expertise regarding local climate characteristics in order to carry out technical analyses of the risk caused by climate change. They should stop soil sealing and increase the number of projects designed to reverse it. Nature-based adaptation solutions should be given pride of place both in urban regeneration plans and specific projects.

As regards problems caused by pluvial flooding, the increasing frequency of floods and, in general, the difficulty of managing water resources during emergencies, green and blue networks and infrastructure are extremely important both as microclimate moderators and when absorbing and retaining larger quantities of rainwater. For example, city squares or parks below road level can help accumulate rainwater during extreme weather events, and particularly intense rainwater can be channelled towards specially created areas, existing urban drainage networks should be monitored more closely and we should ensure that sewage systems – complete with spillway – remain isolated from the network of canals and rivers, even during intense rainfall.

Tools that can analyse and assess the ability to adapt to increasingly frequent heat waves and growing heat islands should be used. On the basis of such analyses and assessments, adaptive technical, administrative and design solutions should be included in urban regeneration and when renovating buildings and their outdoor spaces. We need to promote measures controlling the bioclimate of buildings, measures for shading and solar radiation control systems and measures encouraging natural ventilation and cooling and improving insulation using, among other things, innovative materials. It would also be useful to use and expand green infrastructure and improve cooling by employing, whenever possible, phreatic zones and surface water bodies.

Urban regeneration requires the implementation of projects designed to redevelop and enhance existing urban heritage, both historic, consolidated building stock as well as new buildings, which combine increased environmental performance with the improvement of design and architectural quality and benefits for the community, and that can ensure the creation of buildings that are pleasant to live in and inspire a heightened sense of belonging. If we aim to achieve high town planning quality when carrying out urban regeneration programmes, we have to protect and enhance the wealth of identity forming and historical values, cultural manifestations, know how, works and products that are typical of the areas concerned.

Such projects should be designed to suit the urban environment, particularly encouraging the integration of buildings with the open spaces near them, adopting a unified architectural approach. To this end, it is worth identifying guidelines, criteria, best practices, indicators and standards when drafting projects and assessments of the architectural, urban and environmental quality of urban regeneration programmes, while updating and improving existing ones.

When carrying out urban regeneration work, particular attention should be paid to redeveloping public spaces, both in central and peripheral areas, as they play a decisive role when creating urban quality: city squares, streets, porticoes, parks and gardens, playgrounds and pedestrian zones all have a significant effect on environmental and social quality.

As regards the problems associated with sustainable mobility in the areas included in regeneration programmes, the availability of pedestrian zones and/or zones that limit access to motorized vehicles, slow traffic zones, the availability of protected footpaths and cycle paths, public transport services and mobility sharing, not to mention infrastructure for recharging electric vehicles, are all essential.

The proper attention should also be paid to measures designed to reorganize areas of urban sprawl and ‘hybridized’ single-function areas with the creation of complementary and compatible uses, including spaces for collective use, in keeping with the principle of *mixité*, at the same time ensuring that land permeability is maintained and increased, and that ecosystem functions are restored and green infrastructure developed. When implementing urban regeneration programmes, social housing projects should not only meet the demand for homes, they should also guarantee residential well-being and social integration, supporting the development of resident communities by, among other things, designing shared and open collective spaces.

When carrying out renovation, restoration, reuse or maintenance work on existing public and private building stock, we should not only increase comfort, we should also improve energy efficiency, the efficient use of water and the proper ecological management of waste; keeping in mind the increased hydrogeological risk and the widespread areas at seismic risk, such improvements should be verified and combined, whenever necessary, with measures designed to reduce vulnerability and prevent such risks. We should also encourage the use of construction materials and components that boast a high ecological quality during their entire life cycle, products that can be reused or recycled.

In urban regeneration programmes, urban and peri-urban greenery, and particularly the development of green infrastructure, carries out an essential role. Everything from tree-lined avenues to vertical gardens and roof gardens, from public and private gardens to allotments and from parks to green belts significantly contribute to improving air quality and reducing pollution, mitigating and adapting to climate change, safeguarding water, managing surface water run-off and protecting the biodiversity of the urban environment.

We should support and promote nature-based solutions by focusing on green infrastructure, which can carry out a number of functions and ecosystem services. Such solutions also provide facilities for cultural activities, recreation and sport and support the well-being and health of residents. The development of green infrastructure as part of urban regeneration programmes not only requires the active contribution of public authorities, it should also involve the private sector (businesses, shops or even private citizens) that, as is already happening in some cities, can fund both the construction and the maintenance of urban greenery, both public and private (trees, hedges, gardens, balconies, vertical gardens and roof gardens on homes, shops and tertiary premises).

The implications for green city local development are quite interesting: support of a more suitable local development, promotion and development of technologies, green innovations and tools and strategies for the exploration, identification and application of green business and governance models, supporting identification and diffusion of new opportunities for green investments (GIZ-ICLEI, 2012).

As emphasized by the report ‘Towards a Green Economy’ (UNEP, 2017), green cities can effectively contribute to social inclusion and overall quality of life. The reinforcement of public transportation systems, as an example, can reduce inequality by improving service accessibility and contribute at the same time to the reduction

in traffic congestion, especially in peripheral areas. Cleaner fuels for transportation and energy production can reduce local pollution, which traditionally affect the weaker sections of the population. Traffic reduction and the improvement of security conditions of pedestrians and cyclists can sustain social cohesion. In fact, evidence demonstrates how children who live close to green areas are more stress resilient, less inclined to suffer from social disorders and have a higher self-esteem. Green areas stimulate social interaction and improve well-being. Moreover, according to UNEP (2017), the transition of cities to a green economy can create new job opportunities. Also, the EU Green Week 2019, dedicated to green jobs, underlined the high potential of new and good job opportunities generated by a green economy. Involving the private sector is equally important, through agreements aimed at promoting the social responsibility of enterprises involved in the race towards the improvement of cities and territories, making their actions and contributes to the green city transparent. Enterprises ought to be also involved in the promotion of targeted investments, services and other policy instruments, with the scope of improving cities environmental performance efficiently and sustainably in terms of costs, and maximizing economic and social benefits (Ronchi, 2018; Tucci and Battisti, 2020).

## 20.5 Conclusions

The guidelines/strategies and primary measures/actions categories generated by people and institutions towards a green economy and taken in the implementation of the international experimental initiatives would appear to provide incisive responses when it comes to making a practical, feasible change in the accepted approach to *thinking, building and inhabiting* architecture and the city, or what by now we refer to with a unified term of the *green city approach*. Because, as has been demonstrated, this is the true key to entering once and for all into a fully operative outlook from which to promote the *green economy* – and, therefore, the *circular economy* – as an economic model characterized by a search for ways in which to arrive at maximum levels of inclusion and social well-being, as well as the best possible ecological-environmental quality of dwelling.

To the extent that it proves to be based on substance, this will also lead to a new conception of building, in the ecosystem, interrelated sense of the term, taking in the regeneration and upgrading of sites, the use of renewable energies, the reuse of raw materials, the augmentation of energy and bioclimatic efficiency, the development of forms of resilience, mitigation and adaptation to climate change, along with the optimization of natural, cultural and social capital. All grounded in the formulation of specific procedures for the planning and design of technologies, materials, products and systems designed to promote and favour truly circular flows for the use and management of resources, so as to limit impacts on our biotic system and on the biosphere in general. The policies represented under the categories of recurring Measures/Actions that can be found in the two tables are probably only some of

those that a future rich in experimentation holds for us. Others may take shape following the activities of research and experimentation which are constantly moving ahead in Italy, as well as on the international scene. (Hausladen & Tucci, 2017)

The activities involved in the planning, design, implementation and management of the initiatives regarding the transformation of the architectonic and urban systems which are to be regenerated and upgraded, along with the activities involved in the preservation, safeguarding and optimization of historic or well-consolidated resources of construction and dwelling call for precise 'green-oriented' perquisites to be met, and for strategic guidelines to be pursued, in addition to which a framework must be established that proves adaptable, flexible, always ready to be challenged and rendered obsolete by the ongoing evolution of experiences, though it must also be scientifically grounded, in addition to offering good practices, meaning measures and the actions that can represent, for a technologically and environmentally oriented approach to planning, a practical reference for proper conceptualization and elaboration of the solutions to be tested and the results to be achieved.

Public policies have a key role in the path towards green cities, through direct involvement of administrations on all levels: municipal, regional and national. We can state that such path demands equally great attention to the use of available European funds and national and regional public funds, employable, in their totality or in part, to implement measures for green cities.

A green city project ought to be supported by suitable information tools, so as to be known and shared by citizens, and – as Edo Ronchi (2018) said in a recent interview – ‘we need to foresee punctual and recurring information and documentation tools to monitor activities, objectives, and results. It is also good to foresee broad consultation forms, which are nowadays possible thanks to digital technologies, aimed at stakeholders involved in projects and actions’.

We need to publicize improvement work that boasts high ecological quality wherever it has been tried, to publicize the measures that have been most successful given the contexts where they have been applied, promote an awareness of the key role that properly drafted design plays in environmental and technological aspects, aiming for a future in *building* and *dwelling* where buildings, neighbourhoods, urban districts and cities boast certified ecological, bioclimatic, energy and environmental functions that are part of the lifecycle of materials and, generally speaking, all manmade products. That is why we increasingly need to focus on the role of research, to support experimentation, innovation and the exchange of best practices, encourage the world of innovative start-ups, inform and train public authorities, professionals and entrepreneurs, foster companies that include green choices in their economic criteria, focusing, for example, on the efficient use of resources, material and energy savings and eco-innovative processes and end products.



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# Chapter 21

## Strategies to Promote Deep Renovation in Existing Buildings



Cristina Jiménez-Pulido, Ana Jiménez-Rivero, and Justo García-Navarro

**Abstract** Existing buildings play a central role in achieving EU climate and energy targets. Consequently, the building sector faces the complex challenge of finding effective solutions to manage both the conservation and renovation of this stock. Given that building energy renovation has the potential to reduce greenhouse gas emissions and achieve EU targets, the European Commission has developed frameworks and regulatory instruments to foster a deep renovation approach. However, progress in achieving the necessary transformation has been slow. The objective of this chapter is to identify strategies and actions that can accelerate the sustainable transformation of the building stock. We focus on the first renovation stage in which it is critical for accurate data to be collected and processed on the state of buildings to improve decision-making processes. By overviewing current policies and instruments, and new technologies and tools applicable to existing buildings, we explore open challenges and room for improvement to fulfil their potential. In this study, we have identified upgraded instruments and tools and new benchmarks, resulting in innovative strategies and actions as drivers for a sustainable transformation. From this perspective, we introduce how more ambitious approaches can lead stakeholders to develop strategies and apply actions towards a regenerative built environment.

**Keywords** Existing buildings · Accurate data collection · Assessment tools · Regulatory frameworks · Target-oriented actions · Regenerative approach

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## 21.1 Introduction

Buildings are central to our lives since we all spend more than 90% of our time inside them (EuroACE, 2020). How to manage existing buildings more effectively is one of the main challenges we currently face. Considering the role that the built environment must play to curb climate change, this challenge is particularly pressing for Europe, where most cities have been consolidated, that is, no more urban land is available. The starting step is to optimise resources and actions to guarantee building conservation. This needs to be followed by strategies aimed at improving building quality and energy performance. Upgrading the stock is of paramount importance in reducing the energy consumption and greenhouse gas (GHG) emissions of existing buildings, since their operation phase accounts for 70–90% of their entire impact on the environment (Mahmoud, Zayed, & Fahmy, 2019). According to the existing literature, one of the current major building management issues is scant knowledge of and information on the building stock (González, Zotano, Swan, Bouillard, & Elkadi, 2017) and its performance. This lack of transparent and comparable data on the building sector represents a major obstacle in taking the right decisions (González et al., 2017).

As the use of energy in buildings globally is expected to continue to rise under business-as-usual projections (Chalmers, 2014), innovative strategies to manage the built environment should be implemented. Furthermore, innovations applied to existing buildings should go hand in hand with the evolution of the construction industry. Although it is one of the largest industrial employers in the EU (EuroACE, 2020), the construction sector has not been traditionally considered an early adopter of technology. Given that other sectors are making great strides by, among others, using information and communication technologies (ICTs), the construction industry should consider how innovative tools and technologies could support positive changes in its business practices. Technological advances can be applied to foster improved energy performance in the building stock, for instance, or to optimise the renovation design process. Innovation could help the construction industry become more competitive and decarbonise (European Commission, 2018) with a view to an improved built environment.

Improving the built environment requires actions to accelerate a deep renovation of buildings. Comprehensive renovation of the building stock to lower its energy demand is required under the European energy performance of buildings directive (EPBD) (European Commission, 2018). Renovation not only extends the life of buildings but also raises the quality of living and working spaces, thus improving occupant satisfaction and comfort (Wright, 2018). By introducing an optional scheme called the Building Renovation Passport (BRP) to provide a renovation roadmap, the amending EPBD attempts to promote deep renovations and solve some traditional problems detected in building management. The decisions adopted when planning building interventions should be based on a previous diagnosis from reliable technical data to avoid uncertainties; nonetheless, this is not a common practice yet (Kolokotsa, Diakaki, Grigoroudis, Stavrakakis, & Kalaitzakis, 2009).

Therefore, appropriate inspections to assess the condition of existing buildings are vitally important in building stock management. Developing tools capable of supplying data of adequate quality and new systems supporting the technical assessment could anticipate the potential impacts existing buildings may have and guide technicians to find optimal solutions.

Innovation applied to building operation and maintenance processes has a clear potential to face the challenge of building stock preservation and improvement. However, there is no universal standard to extend the service life of buildings and, specifically, to increase building stock resilience, which can offer people better living and working conditions (Chalmers, 2014). This can be achieved through a strong benchmark in resilient features. Resilient aspects in buildings can be defined as a building construction that can “respond to change and to create lasting well-being for people and place” (Bhamra, 2015), and having the capacity to recover its overall required functionality. To the best of our knowledge, a common strategy to guide the required collection of data is not in place.

Exploiting the data collection of existing buildings successfully requires careful planning and understanding of the data to be mined (Wright, 2018). Neither are standardised systems in place for processing and evaluating the information collected on existing buildings. Some standards and certification systems have been developed, such as LEED (Leadership in Energy and Environmental Design, [www.usgbc.org/leed](http://www.usgbc.org/leed)), BREEAM (Building Research Establishment Environmental Assessment Method, [www.breeam.com](http://www.breeam.com)) or DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen, the German Sustainable Building Council, [www.dgnb.de](http://www.dgnb.de)), although applying them is voluntary, and their original focus was not on existing buildings. The reality is that existing building assessment tools neither explicitly consider resilient aspects of the building stock nor seek a restorative or regenerative built environment. Restorative buildings are those that can repair social and ecological systems to a healthy state (RESTORE, 2018). Regenerative buildings can go beyond their site boundaries through a positive interaction with their surrounding human and natural systems (Craft, Ding, Prasad, Partridge, & Else, 2017). By embracing a regenerative paradigm, a renovated building stock would find a balance and co-evolution between social and ecological systems (RESTORE, 2018).

Nevertheless, given the dimensions of the challenge, it requires a holistic and strategic approach to achieve the desired results: an improved and sustainable built environment. Building complexity demands a specific analysis and focused approach (RESTORE, 2020), capable of addressing the current challenge from a variety of perspectives and levels. The objective of this chapter is to identify strategies and actions that can accelerate the regenerative transformation of the building stock. Our analysis focuses mainly on the assessment phase, due to its relevance in ensuring a good decision-making process. We start by providing an overview of the main regulatory instruments and tools applicable to existing buildings. We then reflect on how the processes can be improved to provide the needed accurate data, which is imperative to guide more strategic and effective actions. By assuming that a creative and innovative vision allows us to shift from the resilience of the built environment towards its restoration or even regeneration, our ultimate intention is to

highlight effective strategies to address current challenges in the building sector and to promote a faster transformation.

## **21.2 Toward a Transformation of the Built Environment**

Based on the above, the built environment's current situation can be considered as generally accepted by the stakeholders involved. Experts agree that deep renovations of existing buildings have the potential to effectively reduce GHG emissions and curb climate change. Many stakeholders have already formed a global partnership and are strongly committed to adopting the 2030 Agenda for Sustainable Development that requires taking urgent action on climate change. Cities and existing buildings are elements of critical importance for that purpose. The 2030 Agenda contains 17 Sustainable Development Goals (SDGs) and 169 targets, outlined by United Nations Member States in 2015. Complementary to the SDGs, the Paris Agreement provides overarching regulatory frameworks, which are particularly relevant for the building sector as they target improvements in energy and resource efficiency (European Commission, 2019). Moreover, the European Commission published a roadmap in 2011 for moving to a competitive low-carbon economy in 2050, highlighting that the building sector could make a significant contribution to emission reductions (European Commission, 2011). The potential for cost-effective energy savings is so high that the building sector has become a priority area to meet climate and energy targets (BUILD UP, 2019). Blueprints shared on decarbonising the built environment are, therefore, a key aspect for achieving climate neutrality by 2050.

Moving forward and achieving those goals involves transforming commitments into standard operating procedures, and estimating the tools and resources required. Consequently, this section is structured into three subsections. Firstly, we examine the current building stock management situation in relation to regulatory instruments. Secondly, we explore the potential of assessment tools and rating systems to assist in building stock transformation. Thirdly, we highlight new technologies that could be applied to achieve targets. By analysing these three aspects, we provide a general picture of the built environment as a first step towards arriving at solutions to transform it sustainably. Some trends and possible actions have been identified from the analysis as better solutions to current problems, keeping the goals in mind.

### ***21.2.1 Regulatory Instruments: Policies, Plans and Standards***

Existing regulatory instruments in the European geographical context have been analysed. Most cities in Europe share common building conservation, energy inefficiency and quality problems. The European Union (EU) also provides a common regulatory framework that is later applied by Member States (MS). Apart from the

above-mentioned roadmap, launched in 2011, EU leaders adopted the 2030 climate and energy framework in 2014. In 2019, the EU and all MS adopted the European Green Deal, aligned with global commitments (2030 Agenda for Sustainable Development and the Paris Agreement). Central to the European Green Deal is the launching of the “Renovation Wave” initiative, which aims to promote a faster rate of building renovations, needed to improve energy efficiency and reduce associated GHG emissions. The EU Construction 2020 Strategy has also been defined to increase the sector’s competitiveness as it was developed to improve resource efficiency (European Commission, 2016).

The construction sector is a complex industry requiring a set of specific standards and regulations to meet shared goals. Figure 21.1 shows a timeline of key EU regulatory instruments affecting buildings. There is a large body of existing EU policies and measures that tackle emissions and other climate targets across all economic sectors (European Commission, 2011). Some policies also address the particular situation of buildings in terms of their consumption of resources including energy. A few examples are the Renewable Energy Sources (RES) Directive (2009/28), the Waste Framework Directive (2008/98/EC), the Energy Efficiency Directive (EED) (2012/27/EU), and the Energy Performance of Buildings (EPBD) (2010/31/EU). The last two directives are the most relevant for building stock renovation as their requirements play a crucial role in increasing its energy efficiency. The current EPBD sets a clear direction for the full decarbonisation of the European building stock by 2050 and provides tools, such as the BRP, to achieve it (BUILD UP, 2019). Although these regulations have had a positive impact on the energy performance of buildings since they came into force (European Commission, 2019), climate and energy goals are still far from being achieved. Further implementation efforts are, therefore, an urgent task to achieve the sought-after impact on building performance.

Each MS must take their responsibility towards improving the building stock seriously, adapting the targets to their particular situation (EuroACE, 2020) by developing specific plans to apply European regulations. Among other tools, the

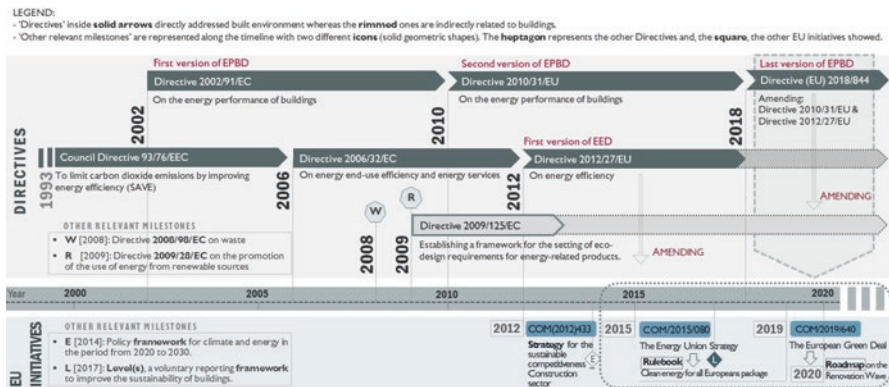


Fig. 21.1 Timeline of key EU regulatory instruments affecting buildings

EPBD requires all MS to establish a long-term renovation strategy to turn national buildings into a highly energy efficient and decarbonised stock by 2050. Going further, the EPBD encourages MS to facilitate the cost-effective transformation of existing buildings into nearly zero-energy ones. To support that transformation, additional instruments have been launched. For instance, the “Clean energy for all Europeans” package addresses some of the existing regulatory gaps in MS building legislation and tries to create a supporting framework for decarbonising the European building sector.

The complexity of the building sector demands a set of harmonised standards to ensure compliance with regulations and to guarantee a widely acceptable quality of existing buildings (RESTORE, 2020). Therefore, it is crucial to share a common technical language across all MS and to verify compliance with EU requirements and demands (RESTORE, 2020). EN Eurocodes (EN; harmonised technical rules) are a series of ten European Standards that are the reference codes for the design of buildings and civil engineering works. As some of the most used construction standards in Europe, their acceptance by MS and transposition to National Standards are mandatory. Besides EN Eurocodes, standards such as *ISO*, *DIN* or *BSI* are used in several building types. However, significant gaps still need to be addressed in renovation projects, including reliable assessments of the condition and performance of existing buildings. To fill these gaps, the European Commission has developed Level(s), a voluntary reporting framework that provides a common approach for measuring the environmental performance of buildings (Wright, 2018).

An integrated approach to take account of the Directives and standards on existing buildings is seen as necessary (Wright, 2018) and may contribute to achieving EU climate goals. This, together with promoting more ambitious renovation projects, holds the potential to truly guide building stock decarbonisation and thereby reduce its environmental impact and increase its quality. Policies and schemes for sustainable buildings should be clearly linked to the management of existing buildings and their conservation to achieve a more resilient and efficient built environment. By doing that, staged deep renovations could be planned after proper data collection, which is the way to guarantee better building operation management. We have also identified a need to use tools designed to assess the condition and performance of existing buildings through the collected data, together with the development of specific benchmarks and schemes for effective building renovations.

### ***21.2.2 Data, Assessment Tools and Rating Systems***

As seen above, practitioners and decision-makers need tools that enable them to evaluate existing buildings' condition. This would lead to improved decision-making processes on actions to be taken, which should be guided by measures for a more sustainable and resilient built environment. Starting with the diagnosis process when an existing building is inspected, such tools could assist technicians in



building operation management. It would be advisable for those tools to also be capable of considering the peculiarities of any given existing building, but under clear strategies to support the achievement of ambitious targets related to building stock performance as a whole (Olsson, Malmqvist, & Glaumann, 2016). Regarding the energy efficiency targets set by policies on buildings and how to meet them, the transparency of the tools to be used should be outlined and applied consistently. This subsection overviews tools currently used to assess existing buildings and to identify gaps and areas for potential improvement. We cover several tool types with a focus on the required collection and processing of data.

Two main aspects of existing buildings need to be improved to achieve the goals established for the built environment: (a) conservation actions to be applied to existing buildings to extend their life span; and (b) energy performance actions. Comprehensive and updated information, together with reliable mechanisms to evaluate these two aspects (a and b) would be very helpful to guide the needed building stock renovation. Several database and evaluation tools are used to assess buildings. However, addressing both aspects simultaneously could entail additional benefits for both the built environment and users, such as the improvement of indoor air quality.

High-quality data are needed to conduct proper assessments of existing buildings as a first step towards applying effective actions to improve them. Consequently, the amending EPBD makes explicit reference to building data collection (Article 10) as a necessity before applying outlined measures in renovations aimed at achieving targeted energy savings (European Commission, 2018). MS are currently developing their databases with building performance information. The European regulatory instruments also recommend regular inspections of existing buildings as another useful source of accurate data on them. Therefore, the widespread use of these databases needs to be promoted alongside the development of new mechanisms capable of providing reliable information on the conditions of existing buildings. A more in-depth knowledge of the building stock would strengthen the assessment of existing buildings for a better renovation process, thus contributing to the committed improvement of the built environment.

Regarding currently used assessment tools, EU regulatory instruments include a mandatory one to assess energy performance called the Energy Performance Certificate (EPC). MS have already established EPCs but, according to the EPBD, their transparency needs to be improved. To truly meet the objectives of an energy efficiency policy for buildings, clear energy parameters for calculations need to be applied consistently (European Commission, 2018). In our view, two additional shortcomings can be detected in EPCs: (1) the EPC does not provide information on the building's condition; and (2) the recommendations included as part of the certificate are merely limited to the building's improved energy performance without considering other possible improvements, and application is not mandatory. Concerning the first point, there is not even a mandatory evaluation tool for building condition assessments, shared by all MS (similar to the EPC for energy performance), based on clear standards that have not yet been set. The above-mentioned BRP is an attempt to address this problem, but it is an optional tool that is still being defined.

Apart from the covered mandatory tools, there are other rating systems for building sustainability evaluation, whose scope is much broader, but they are voluntary. Some of the most used certification systems, such as LEED, BREEAM and DGNB, have also been adapted for renovation purposes. These certification systems have different assessment attributes, evaluation models and ranking scale, so there are noticeable differences between them (Mahmoud et al., 2019). Additionally, many assessment tools addressing sustainability aspects can be found in the literature. Many were developed under funded research projects and also operate under several frameworks (Huovila, Bosch, & Airaksinen, 2019). Some other tools were developed especially for rating sustainability in existing buildings, such as the one designed by Mahmoud et al. (2019). However, none has currently gained either general or renovation-specific acceptance (Thuvander, Femenías, Mjörnell, & Meiling, 2012).

In light of the above, responding to the challenges involved in managing existing buildings can accelerate a sustainable transformation of the built environment. One of the main problems encountered in building conservation and renovation is a lack of knowledge of and information on the building stock and its performance (González et al., 2017). Although the body of knowledge is growing, it shows that data availability is still erratic, and that this lack of reliable data is a major obstacle when building sector professionals need to take the right decisions on existing buildings (González et al., 2017) to improve and decarbonise them. While existing mandatory evaluation tools seem partial and incomplete, voluntary ones are complex and often difficult to implement effectively for all existing buildings. Assessing the current state of the buildings after establishing sustainability goals for renovation projects would make the processes more targeted (Nielsen, Jensen, Larsen, & Nissen, 2016) and the tools more useful. However, only a few of the tools consider the building stock's resilient aspects (e.g. building condition evaluation) and guarantee its adaptation to changes in the economic, physical and social context. Furthermore, considerably fewer tools adopt a more holistic and ambitious approach (e.g. those embracing the regenerative paradigm).

### ***21.2.3 Innovative Tools and Technology***

From the elements outlined above, we identified gap analysis and data mining as tools that could provide guidance and some recommendations for a positive transformation of the built environment. Moreover, this should be accompanied by innovation to successfully fulfil previously outlined commitments, as suggested in the EPBD. The building sector should take advantage of opportunities, such as the development of new energy efficiency solutions, applicable to existing buildings, or the potential of using tools, such as building information modelling (BIM), to support the management of a building's performance. As further outlined below, not only can innovation make a notable contribution to the improvement of the building stock, but it could also trigger a positive transformation of the entire building sector.

Starting from accurate data collection, innovation applied to inspection techniques for existing buildings would allow experts to conduct an in-depth study of their condition and the state of conservation of their components. Technical inspections should be used as a source of reliable data. A proper and comprehensive diagnosis would avoid having to adopt building intervention decisions without a thorough analysis of technical data, as decision-making based on a technical report after only a visual inspection is still too common (Bortolini & Forcada, 2020; Kolokotsa et al., 2009). The development of new inspection technologies, together with the use of tools to process and interpret the data, could play a key role when applied to building operation and maintenance processes. Therefore, new technologies, such as automation and control systems, have a clear potential to preserve and improve the quality of the building stock.

Following the example of other sectors, the construction industry should benefit from the potential of ICTs and other new technologies by developing and applying them to existing buildings. It should also take advantage of the contribution to the construction industry's decarbonisation that can be achieved (European Commission, 2018) and the potential contribution to a better quality of the built environment. Many initiatives use technologies to improve buildings' performance and, even to explore their potential for regenerative design (Sonetti, Naboni, & Brown, 2018). For instance, the main objective of European projects – such as MOBISTYLE (2016), or InBetween (2017) – is to research and disseminate innovative ICT solutions for energy savings. Therefore, ICT is a prominent tool that could prove suitable for providing necessary reliable information on existing buildings. Ensuring that specific information from those tools is integrated and interlinked provides an opportunity to improve decision-making processes for existing building management and operation, and even renovation.

The most recent amendments to the EPBD suggest going beyond the application of ICT tools, pointing out that the full potential of technical building systems and building automation and control systems can be leveraged for improved energy performance outcomes (EuroACE, 2018). An additional concept, the smartness of buildings, has now emerged and it is closely related to the availability of ICT tools (Wright, 2018). The new concept of 'smart readiness' promotes smart-ready systems and digital solutions applicable in the built environment, for instance, features capable of responding to external conditions or systems allowing occupant-building interactions. Some of the challenges related to the smartness that need to be addressed are to make them reliable, private, and secure, affordable and user-friendly.

Since assessment is highly dependent on good data, the combination of techniques capable of providing appropriate information and innovative tools for better processing of the collected information can increase the capacity to evaluate existing building performance. Many defects in non-structural elements could be solved systemically, thus supporting the feasibility of developing new technologies capable of applying ICT data during the pre-design of renovation projects. New tools should then be connected to existing databases, facility management systems, simulation tools, and BIM models to the extent this is advantageous (Nielsen et al., 2016).

Ultimately, the development of support tools and procedures ensuring the availability of quality data can anticipate the potential problems of existing buildings and address them in advance.

### **21.3 Some Reflections on Innovative Approaches to Move Forward**

Strategic reflection is now needed to move forward because the reality is that the built environment is far from achieving its objectives. Despite the above-described tighter and more ambitious standards, the energy renovation rate in Europe remains around 1% per year, of which just 12% are deep renovations (EuroACE, 2020). At this point, it seems advisable to help European cities move from ‘business-as-usual’ to a ‘transformative’ mindset by promoting more effective actions on building stock. Since we are facing a complex endeavour, building renovation needs to be addressed from several perspectives and levels, including the revision of current frameworks, optimised data collections, better organised rating systems and interpretation processes.

By applying innovative approaches to conserve and renew the building stock, cutting-edge actions should be tested, and wider benefits must be measured. This needs to coincide with expanding the use of the above-mentioned databases to improve transparency and shared knowledge with a view to developing joint initiatives. More specific, target-oriented and affordable actions to overcome current technical and financial barriers could include streamlining procedures (Wright, 2018). Explicit calculation procedures and ease of use are crucial aspects in the overall sustainability appraisal process (Mahmoud et al., 2019). The use of new technologies such as IT platforms to hold information and link construction agents can also contribute to that end. We must not forget that the strategies need to encompass the challenges of the built environment and cities, thereby considering health and social issues, liveability, sustainability and climate change simultaneously. We believe that these actions can achieve more impact by embracing strategies to promote restorative renovation projects.

To guide the reflections, we focus firstly on gaps and some room for improvement detected in the current tools and systems. Secondly, a brief overview is provided of some pioneering initiatives and cutting-edge actions that could be applied to the building stock to increase its renovation rate and overall quality.

### ***21.3.1 Specific Frameworks and Assessment Tools for Existing Buildings***

The main voluntary assessment tools used, along with others found in the literature and developed as part of several research projects, operate with multiple indicator systems. This high number of indicators makes them difficult to implement (Huovila et al., 2019). Indicator systems need to be harmonised and aligned with international commitments (e.g. EPBD aims, or the Sustainable Development Goals, SDGs). The EU is meeting this need by developing the Level(s) Framework, robust indicators based on existing tools and standards to establish a basic common language around sustainable building (Wright, 2018). This task is complex, and it is not yet completely developed. For the sake of simplicity, the framework could be developed to address a range of scenarios with a design based on specific contextual needs and requirements.

The earlier the assessment of existing buildings, the higher the potential to effectively influence their life-cycle performance (Pombo, Rivela, & Neila, 2016). Therefore, more systematic assessment mechanisms could make a positive contribution to the building stock. However, there is no common protocol to follow during inspections to assess a building's condition. Used as a benchmark for technicians and other stakeholders involved in building management, frameworks and rating systems – focused on specific tasks within the scope of work – could increase the quality of operation and maintenance services. For instance, frameworks developed to guide the needed inspections of existing buildings and diagnose their condition, from the perspective of the built environment targets, would ultimately contribute to improving the results of the renovation works.

The overview of existing instruments that can be applied in building stock transformations is a valuable starting point to address the development of these new frameworks and focused assessment tools. However, more ambitious approaches must also be tested to deal with today's great challenges. For instance, a restorative approach could be used to drive renovation projects with more impact in their surrounding area. More concretely, these kinds of projects could apply to nature-based solutions, such as green roofs and walls providing insulation and shade for buildings. Renovation embracing some restorative measures would contribute to reducing the energy demand, but also to regenerating the city environment (European Commission, 2018). Therefore, by adding restorative solutions to the set of indicators included in new frameworks developed for building management, the sustainable built environment transformation could be accelerated.

When interventions are carried out on existing buildings, the decisions about building materials or constructive system solutions are critical and have a strong impact on existing buildings' adaptability, durability and, consequently, their resilience. Data are crucial for taking good decisions and these should be supported by a reliable assessment of the existing building condition. An appropriate analysis of the state of buildings determines their cohesion in terms of construction together with the safety and serviceability of the structures (Sesana, Rivallain, & Salvalai,

2020). Designers need to deal with the diversity of the building stock, varying typologies, age, occupancy, etc., to plan appropriate deep renovations. Their decisions on renovation processes to solve the problems detected depend on obtaining a reliable diagnosis of any degradation processes. Therefore, a systematic assessment based on collected data would enable informed decisions during the renovation process.

If the construction sector wants to fulfil the requirements of the built environment set by EU directives and international regulatory frameworks, innovation and emerging technologies should be employed to improve building stock management. As already mentioned, there are technologies that can be applied to systematise the maintenance process of existing buildings. Indeed, tools in the field of heritage have been recently introduced, for instance, Building Information Modelling for heritage (Heritage-BIM) (Historic England, 2017). Using specific rating systems and new benchmarks, the innovative assessment processes referred to above could then be combined with new technologies to maximise the effectiveness of data collection and interpretation. Then, more comprehensive and relevant data could be achieved by taking advantage of the interoperability of the different database and the capability of the new technologies, provided that the database design is appropriated. Instead of the usual visual inspection assessment, advanced evaluation tools can be used as an example of technology that can provide a good basis. The support of technologies applied to building inspections can improve not only the quality of data collection but also the precision of the diagnosis.

Strategies and tools that enable improved decision-making processes during the assessment stage must be developed to support the achievement of ambitious building stock performance targets (Olsson et al., 2016). From our perspective, this is a good starting point for a more sustainable and resilient built environment. Exhaustive and detailed diagnoses of the condition and performance of existing buildings are needed to design customised interventions as part of ambitious projects. The best suited projects would also enable budget control for retrofit works, one of stakeholders' major concerns, and an important barrier to sustainably transform the built environment. The systematisation of works to solve problems and issues in existing buildings are already generally feasible by applying ICT data to evaluation tools or to the pre-design of renovation projects.

### ***21.3.2 Strategic Actions on Existing Buildings***

The management of existing buildings should include the combination of technical maintenance and a quality assessment of the entire building, including regular energy audits. Damage or defects in existing buildings can compromise their structural performance, their energy efficiency and indoor air quality. Furthermore, the consequences of those defects are not merely technical, as they can also cause users to suffer health problems, and waste resources and energy. BRP could become an appropriate instrument to address existing building management in the holistic manner suggested, since this instrument can gather all relevant building information

in one place, along with a long-term roadmap to plan deep renovations. Indeed, the European Green Deal relies on the use of individual BRPs as a central tool to make the EU Renovation Wave a success (EuroACE, 2020). However, since BRP is voluntary, its successful implementation depends on the involvement of all stakeholders and strategic actions to boost its use.

One possible strategic action that can be taken to extend gradually the use of the BRP is its implementation only in particular building elements instead of the full system. BRPs could be divided into minor parts because the building elements have their own particular features and dynamics. For instance, the façade is the most challenging element of buildings since it concentrates many of their problems across their lifetime; therefore, it deserves specific attention. Furthermore, as a connecting element between the interior and exterior, façades exert a key influence on two aspects: the energy efficiency of buildings and the comfort level of their spaces. Considering that there are 60 billion square meters of façade surfaces in MS (ENVISION, 2015), a specific chapter on façades of BRPs could also be a strategic instrument to address both aspects at the same time, and be used as a trigger point. After a proper characterisation of the building's façade, this instrument could be used to establish behaviour patterns and improve maintenance. This requires a well-defined framework that can guide the long-term roadmap front-end solutions for this to function.

In addition, cities need strategic interventions to help them move from 'business-as-usual' to a 'transformative' mindset. Strategic renovation works on "early adopter" buildings, chosen for their replicability and scalability, could be brought forward. Looking to increase the exponential impact of deep renovations, some works could inspire other urban areas to activate the same process. The EPBD encourages MS to carry out energy efficiency renovations by adopting a cost-effectiveness or disruptive perspective. Experience shows that the range of cost-optimal interventions includes envelope renovation, which is also quite representative and can help inspire confidence among stakeholders involved in building renovations. It can also be seen as a first step in developing renovation guidelines based on these experiences, in other words, a digital repository or 'library' of standardised solutions to be adopted during similar renovation processes (Wright, 2018). In this regard, authors such as Delmastro, Mutani, and Corgnati (2016) proposed defining building archetypes (Reference Buildings) as a first step to identify buildings in compelling need of renovation. This approach could be supported by the strategic instrument previously proposed as part of BRP tool. It should also provide an estimation of the expected energy savings after façade renovations as starting point, and wider benefits, such as those related to health, safety and air quality, for the entire building.

Over recent years, there are new trends in buildings towards a more user-centred design (Morton, Bull, Reeves, & Preston, 2019). Research shows that improving and broadening user engagement has the potential to foster more action acceptance and impact (Morton et al., 2019). This should be seen as another strategy towards promoting deep renovations, since the influence that users' behaviour has on the energy consumption of buildings has been proved (Fabbri, de Groote, & Rapf,

2016). Therefore, user engagement can be a key issue for better building performance after well-designed renovations, together with the increase in indoor air quality. Users should be considered and informed about how higher comfort levels and well-being can improve their health with user-friendly tools. As a result, user-centred designs could support renovation works and increase the renovation rate. Furthermore, renovation processes that embrace building users could arrive at innovative solutions, such as new technologies that enable a better interaction of buildings and their users by adapting building operations to their needs. Therefore, user-centred design can also be a way to promote innovation in the building sector, while the building's energy efficiency and overall performance are improved.

Besides users, new strategies should be considered to guide renovation processes through co-created methodologies capable of including all stakeholders involved in building renovation. Co-creation can be used to refer to an act of collective creativity, where designers and other stakeholders work together in the design process, favouring desired changes to occur (Paone & Bacher, 2018). By adopting a bottom-up approach, supported by new technologies (e.g. ICT solutions) and smart features, co-creation processes could be applied to overcome some constraints identified in building management and renovation. To reduce subjectivity, for instance, methods such as the *Analytical Hierarchy Process* could be used to develop a *Decision Support System* that embodies stakeholders' relative preferences of multiple key criteria (functionality, cost, aesthetics, etc.). Gamification mechanisms could also be applied to facilitate renovation processes because they can increase stakeholders' interest. Since gamification can be an effective way for reducing energy consumption (Sanders & Stappers, 2008), this could be used to overcome the lack of knowledge and awareness, another barrier that practitioners usually mention. Ultimately engaging all relevant stakeholders through such participative experiences seems an effective way of ensuring acceptance of measures adopted to achieve energy efficiency and quality targets.

Given that policies need to be accelerated for climate action and to transition to a sustainable built environment, several strategies should be explored. By identifying intervention cases, target-oriented actions could be adopted and work on the building stock phased to scale up its deep renovation. The new BRP's attempt to integrate and interlink building information and a roadmap seems to be a good starting point. Prioritising building façade interventions can be proposed as a possible trigger for promoting building interventions, with a view to seeking replicable best practices. Innovative measures on existing buildings and actions adopted for new synergies within projects and stakeholders have the potential to encourage other buildings and urban areas to adopt a similar approach. By taking advantage of experimental actions, existing buildings' renovations can be approached differently to increase effectiveness and stakeholder engagement. Practitioners and decision-makers would benefit from the key role that new technological solutions can play in building management towards a systemic transformation of the construction sector (Volt & Dorizas, 2018) and the improvement of the built environment.



## 21.4 Conclusion

The deep renovation of buildings that are currently in a bad condition needs to be accelerated to avoid the enormous damage that problems in the building stock can cause on the environment, and to increase occupants' well-being. Two main paths can be identified to successfully manage the building stock while guaranteeing its renovation: (a) developing appropriate technologies to collect and process relevant data; and (b) assessing buildings by using adequate rating systems (e.g. energy performance, building condition, etc.). Additionally, the use of ICTs and other technologies during renovation can improve the decision-making process, guide the design of retrofitting solutions, and maximise environmental and social benefits. The successful implementation of technology and the use of innovative tools require appropriate actions, strategies and approaches.

Based on current regulations and plans, there is an agreement on the “big picture” of building stock management issues, and the needed transformation of the built environment. However, the transition to a sustainable built environment has so far been slow and we are far from achieving the objectives. In an attempt to accelerate this transformation, new tools and strategies can be applied to the building stock. Our shared reflections on how to improve the effectiveness of the measures adopted and on how to trigger the renovation of the building stock highlight more ambitious approaches, and innovative strategies and actions. Tailored rating systems and assessment tools can help improve renovations and even prioritise actions. Regular assessments performed during the operation stage of buildings also prevent building users and other people from being endangered. Therefore, both exhaustive and detailed diagnoses of the condition and performance of existing buildings are needed as a starting point to design customised interventions and increase the building sector's competitiveness.

The strategic measures put forward in this chapter include focusing efforts on building façade actions. This is because we encourage taking advantage of the impact that actions on this building element can have, both on user comfort and on the city environment, as it is also a determining factor in the energy performance of the buildings.

Building management supported by technology could guide the building transformation processes, thus enabling control of a pressing stakeholder demand: budget control during renovation works. As the transformation needs to be accelerated, further studies are needed on how the impact of these actions could be enhanced by adopting more ambitious approaches. One action has been identified here as the most promising: implementing restorative measures for renovated buildings. For instance, introducing the restorative perspective into new frameworks to evaluate existing buildings would enable us to estimate and consolidate the potential of renovated buildings.

Optimising processes that are part of the renovation of the building stock requires changes in cities led by a more ambitious vision to curb climate change and promote a regenerative built environment. Cities with resilient buildings and restored spaces

will become more liveable, environmentally friendly and able to offer improvements in users' health and productivity.

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# Chapter 22

## Investigating, Implementing and Funding Regenerative Urban Design in a Post-COVID-19 Pandemic Built Environment: A Reading Through Selected UN Sustainable Development Goals and the European Green Deal



Maria Beatrice Andreucci and Antonino Marvuglia

**Abstract** Before the world was impacted by COVID-19, progress towards the 2030 UN Sustainable Development Goals (SDGs) was already uneven, and a more focused attention was needed in most SDGs' target areas. The pandemic abruptly disrupted plans and efforts towards urban transition, in some cases reverting decades of progress. The concept of resilience changed in 2020 and having to face severe health issues combined with increased socio-economic challenges in a climate change scenario, cities must urgently explore on how best to combine environmental goals with economic recovery and social justice, modifying on-going plans and initiatives, while re-arranging priorities. Acknowledging the impact that the pandemic will produce, for the years to come, on processes and initiatives towards a regenerative economy, this contribution describes most recent strategies aimed at urban transition in Europe, and critically discusses available options with respect to implementation and funding, within the framework of selected UN SDGs. Our conclusions challenge the ability of our modern society to put in practice the needed urgent actions, and call for a paradigm shift to prepare Europe to deal with climate disruptions, activate transition to a healthy and prosperous future within the planetary boundaries, and scale up solutions that will trigger transformations for the benefit of people and the environment.

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## 22.1 Introduction

The public health and economic emergency we are currently living in is the worst the world has experienced in a century. Since 22 January 2020 and as of 15 November 2020, 54.486 million cases of COVID-19 (according to the case definitions and testing strategies in place in the affected countries) have been reported, including 1.319 million deaths (Johns Hopkins University, 2020). The sanitary emergency is affecting every country, including high-income nations in Europe and North America. Globalization and the devastation of wildlife habitats facilitated the fast spread of viruses around the world. The pandemic has put governments in front of difficult choices, having to balance between protecting public safety and well-being and saving national economies. Eventually, the prospect of a large number of deaths and of the collapse of health systems have left countries with no other reasonable choice but to impose draconian measures (including citizens' lockdown and shutting down many economic activities), which have drastically affected the lifestyle of millions of people. This has led to a global economic downturn with massive job losses, and major impacts especially on vulnerable groups. Although COVID-19 and climate change are both rooted in the same "business as usual" economic development and urbanization model – already proven to be fatal for humans – governments have addressed them as separate and unrelated phenomena and have therefore insufficiently responded to them. This is a significant hindrance for the world's aspiration to achieve the UN 2030 Sustainable Development Goals (SDGs) (United Nations (UN), 2016).

Progress towards the achievement of the SDGs was already slow before the outbreak of the pandemic, but COVID-19 is now worsening the situation, further producing severe negative impacts on most SDGs (Berchin & de Andrade Guerra, 2020), so that it seems likely that many of the 169 targets will not be met by 2030 (Naidoo & Fisher, 2020). Preliminary research on the impacts of COVID-19 on cities mainly relates to four major themes: (1) environmental quality; (2) socio-economic impacts; (3) management and governance; and (4) transportation and urban design (Sharifi & Khavarian-Garmsir, 2020).

It is now urgent a widespread endorsement of the necessary commitment to the active search and experimentation of solutions to the world's biggest challenges, ranging from combatting and eliminating poverty and reducing inequality to dealing with climate change, health care, and capacity building.

With the outbreak of the COVID-19 crisis, emerging issues and related questions with respect to mainstreaming regenerative urban design, sustainability, and climate

neutrality arise spontaneously: *How did societal challenges and related priorities change in the post-COVID scenario? Should the attention paid to UN SDGs change as well? How much do innovative research and funding frameworks to boost regenerative urban design already take those changes into account? How can addressing the challenges of climate neutrality through the European Green Deal help with respect to a post-COVID achievement of the 19 UN SDGs?*

The following sections describe funding frameworks and critical pathways towards regenerative urban design in a changing built environment post-COVID-19 – such as “Innovative Urban Assets and Infrastructure”, “Circular and Just Urban Economies”, and “Climate Neutrality” – aiming at offering critical perspectives taking into consideration the above dilemmas as well as the much-awaited funding frameworks, such as Horizon Europe and the European Green Deal.

## **22.2 Responding to COVID-19 within the Wider SDGs Framework**

Cities are engaged in an epochal conflict to cope with the COVID-19 pandemic and its long-lasting impacts. All over the world, this frightening virus is threatening cities and communities, jeopardizing public health, as well as the economy and the very fabric of our society. Over 90% of COVID-19 cases are recorded in urban areas, with the world’s most densely populated slums suffering the hardest effects. Even before the pandemic outbreak, due to rapid urbanization, four billion people (i.e., more than half of the world population) in the world’s cities faced the effects of worsening air pollution, scarce infrastructure and services, and uncontrolled urban sprawl. Progress towards the 2030 SDGs was already uneven, and a more focused attention had already been acknowledged as needed in most areas. The pandemic abruptly disrupted plans and efforts towards many of the SDGs and, in some cases, reverted decades of progress (UN, 2020). Even if none of the SDGs has remained unaffected by the consequences of the pandemic, the SDG 1 “No Poverty”, SDG 3 “Good Health and Well-being”, SDG 8 “Decent Work and Economic Growth”, the SDG 11 “Sustainable Cities and Communities”, and the SDG 13 “Climate Action” deserve now particular attention, not only for the effects already produced by COVID-19 but mostly in consideration of all possible urgent actions that should be put in place at different scales. At the same time, far from undermining the case for the SDGs, the magnitude and uneven impacts of COVID-19 have demonstrated that cities need the 2030 Agenda, the Paris Agreement on climate change, and the Addis Ababa Action Agenda, emphasizing the urgency of a coordinated and comprehensive international response and recovery effort, based on sound data and science and guided by the Sustainable Development Goals (UN, 2020).

UN-Habitat, the UN agency for housing and urban development, is working with national and local governments, helping them in preventing, facing, responding to,

and recovering from the COVID-19 pandemic. The UN-Habitat COVID-19 Response Plan aims to:

- Support local governments and community-driven solutions in informal settlements
- Provide urban data, evidence-based mapping, and knowledge for informed decision
- Mitigate economic impact and initiate recovery.

The UN-Habitat's COVID-19 Policy and Programme Framework provides, in turn, guidance for global, regional and country-level action.

A rigorous assessment is of paramount importance in order to design, monitor, and adjust the multiple performances required in urban re-developments, specifically referring to two primary trajectories (risks reduction and resources management), and six dimensions (*air* – pollutants emission, ozone depletion, urban heat islands –; *water* – flooding, storm water, domestic water, wastewater –; *land* – soil sealing, soil consumption, land use, land cover, urban heat islands, droughts –; *natural capital* – habitat, biodiversity, natural cycles, ecosystem services –; *resources* – reduction and efficiency, circularity, zero waste, renewability, food production –; and *people* – community resilience, health and well-being, welfare).

A key overarching objective would be the one of regenerating economic activities, without simply restoring old irresponsible patterns of environmental quality degradation. In this respect, social and economic emergencies impose an increased international collaboration and mutual support towards the most exposed and vulnerable communities.

In many SDGs' indicators, timing matters enormously to save lives and ecosystems, and to put in place effective governance. The issue of SDGs is tightly interlinked with the issue of resilience and the timing of the resilience. In other words, looked from the lenses of regenerative sustainability, a paradigm shift towards sustainable urbanization, based on post COVID-19 "response, recovery, and reset" in a climate change scenario, ultimately translates into a consistent call for a "regenerative" urban transition.

As a matter of fact, the COVID-19 pandemic has debunked any common belief that the Global North (Ashford et al., 2020) has the full capacity to tackle global challenges and has further stressed the need for mutual learning and adaptation in all countries towards a more sustainable and just world.

We need a "just" climate transition which is able to protect the poor and the most vulnerable people and which is not disconnected from our pandemic response. This would not only invert the tendency of the climate disaster we are already witnessing, but would also minimize the risk of new pandemics breaking out.

The new Coronavirus certainly affects every person and community, but it does so unequally. It has even further aggravated existing inequalities and injustices. Inequalities are present in all urban societies and introduce further complexity in managing pandemics (Acuto, 2020). Although sharper in unstable settlements, inequalities are not limited to the Global South (Ashford et al., 2020). Nearly two



billion people worldwide have reduced or no access to acceptable sanitation, and more than 150 million people are considered homeless (Satterthwaite, 2000).

Nonetheless, although desirable, it is not guaranteed that we will be able to leverage COVID-19 as an opportunity for healthy economic recovery, stronger community building, and more explicit considerations of urban equality. The digital response to what is probably the most “information-intensive” public-health crisis of modern times has initiated a deep digital change by boosting teleworking, web-based communities structuring, virtually delivered services, and 3D printing of essentials (Acuto, 2020). The role of information and communication technologies (ICT) in fighting against the spread of the pandemics is very important. One can, for instance, think about the role of contact-tracing mobile apps, which are able to alert people who have been in close contact with someone that shortly after has been tested positive to the virus, although they have been often criticized because of allegedly endangering citizens’ privacy (Rowe, 2020). However, ICT also carry the risk of being very dangerous in spreading a sort of other disease, which has been defined as “infodemics”, referred to as an excess of information – some accurate and some not – that makes it difficult for people to find reliable sources and trustworthy guidance when they need it (Pan & Zhang, 2020).

The very face of our cities is likely to change quite significantly in the years to come, with the pandemics having only accelerated the change that in many cases was already slowly but steadily happening. Transport infrastructures, public transportation means and public venues of all kinds (even streets) might have to be retrofitted in order to prevent overcrowding. This is likely to drive a regenerative urban transition, and ultimately transform our cities and communities, hopefully in better and more resilient ones.

We should also be vigilant in making sure that government funds are allocated to decentralized renewable energy production, because this would be a meaningful start of the implementation of the European Green Deal and would create new critical jobs within the post-COVID-19 economic crisis. At the same time, we should be active in providing universal healthcare, extending social protection, and free education to reach all vulnerable populations, and giving the necessary priority to the realization of affordable housing (Mastrucci, Byers, Pachauri, & Rao, 2019) and multifunctional urban green blue infrastructure.

A change in the governance structures and business models is required, and the city’s perception can be improved by co-designing inclusive public spaces, as well as different ways for people to engage and interact with technology and nature (Landman, 2020).

### **22.3 Implementing Regenerative Urban Transition**

In recent years, a rapidly growing number of cities have already started to design and implement strategies and policies aiming at environmental sustainability, green economy, and green growth.

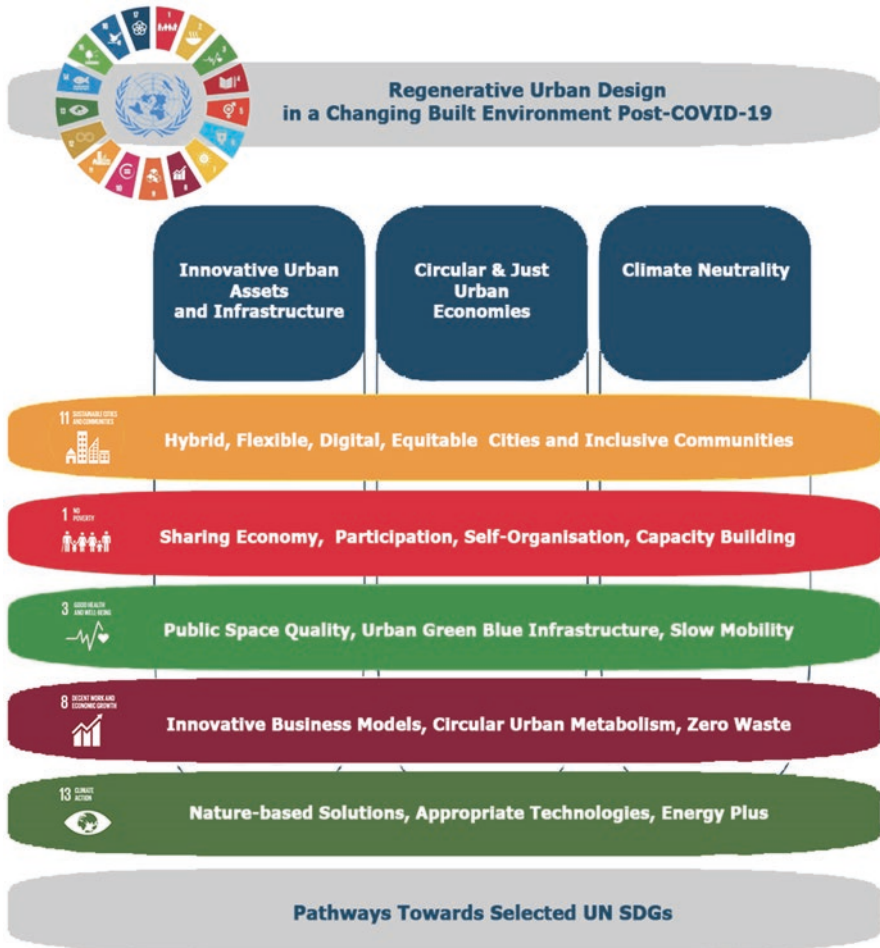
The European Green Deal (European Commission, 2018) represents a framework for policy initiatives with the overarching aim of making Europe resilient and climate neutral by 2050. The plan is also to update existing laws and regulations on climate, and introduce new rules boosting the circular economy, building restoration, biodiversity protection and enhancement, sustainable farming and innovation.

Three action clusters – and their interrelationships – can in particular be identified as prioritized sectors along the Green New Deal for sustainable urbanization, here defined as: Innovative Urban Assets and Infrastructure; Circular and Equitable Urban Economies; and Climate Neutrality. We have chosen to explore and discuss in the following sections how these three modular building-blocks of SDGs achievement, and related integrated actions, can guide a regenerative urban transition, and frame medium-term strategies towards more resilient and equitable societies (see Fig. 22.1).

### ***22.3.1 Innovative Urban Assets and Infrastructure***

Cities will never cease to need large-infrastructures; however, sometimes small-scale infrastructures, such as cycle lanes and bike sharing, or techno-ecological systems (Bakshi, Ziv, & Lepech, 2015) for climate change adaptation (SDG 13) and thermal comfort (SDG 3), can also play an impactful role in an urban area, benefiting both people and the environment (SDG 11). Appropriate technologies (Schumacher, 1973) should be considered as means to shape sustainable behaviours, and improve the daily life of the city's inhabitants, while innovations should be co-created and co-designed by and for the citizens, observing the principles of universal design and usability by people of all ages and capabilities (SDG 1). In this respect, a new role has emerged in the highly digitalized society of the developed countries: the role of “persuasive technologies”, such as mobile apps and gamification tools to induce citizens and service users to adopt more virtuous and sustainable behaviours (Huber & Hilty, 2015; Cellina et al., 2019; Ming-Chuan, Tsai-Chi and Hsin-Ting, Ming-Chuan, Tsai-Chi, & Hsin-Ting, 2020). On the other hand, collaborative initiatives like urban living labs (Bulkeley et al., 2016) and participatory planning tools (Nyerges et al., 2016; Voytenko, McCormick, Evans, & Schliw, 2016) have arisen and became operational, showing their potential in helping decision-makers towards making shared choices and realizing inclusive projects and initiatives.

However, regenerative transformation of urban assets and infrastructure will not be achievable by relying only on technologies, or providing more sustainable service offerings alone; it will progress only through a fundamental rethinking of space and the re-organization of all daily activities, addressing different urban settings at various scales, from building and open space to neighbourhoods, and up to the inter-city scale, while taking into account how people move, work, live, recreate (JPI Urban Europe, 2020). For these reasons, this concept offers a clear focus for a holistic, people-oriented and challenge-driven perspective for distinct aspects of the



**Fig. 22.1** Regenerative Urban Design in a changing built environment post COVID-19: Pathways towards selected UN Sustainable Development Goals. (Adapted from JPI Urban Europe, 2020)

“doughnut economy” (Raworth, 2017) (SDG 8), and the overarching ambition of regenerative cities according to a wider Smart City and Community concept (Hauser Hand, Weber, & Bluestone, 2017).

### 22.3.2 *Circular & Just Urban Economies*

According to the Ellen MacArthur Foundation’s definition (2015), a circular economy provides multiple value-creation mechanisms, and is based on three principles: (1) conservation and enhancement of natural capital (SDG 3); (2) optimization of

resources by reintegrating materials, components, and products into nature, or valorizing them into other supply chains' resources, fighting resources depletion and material scarcity (SDG 1); and (3) reinforcing systemic value by identifying and designing out negative externalities (SDG 13). The Ellen MacArthur Foundation also identifies six business actions to support the three principles mentioned above: Regenerate, Share, Optimize, Loop, Virtualize, and Exchange, i.e., the "ReSOLVE levers" (Ellen MacArthur Foundation, 2015).

Circular economy is a motor for sustainable growth (SDG 11), the creation of good health (SDG 3) and decent jobs (SDG 8) and, at the same time, it is able to protect the environment and its natural resources supporting climate adaptation and mitigation plans (SDG 13). The shift from a linear urban metabolism to circularity, through integrated transformative and equitable actions, represents a critical contribution to the achievement of a regenerative and inclusive urban transition, by supporting the restoration of attractive built environments ultimately founded on livability and well-being (SDG 3), as well as implementing urban design principles able to deliver high quality and healthy public spaces (SDG 3).

### 22.3.3 *Climate Neutrality*

The European Green Deal traces pathways to climate change neutrality and sustainable development, supported by significant investments in green technologies and innovation. It includes the first EU Climate Law with a legally binding target of net zero greenhouse gas emissions by 2050. It also embraces a new and revised European Union (EU) Adaptation Strategy (European Union, 2020).

The EU has been an early pioneer on climate change adaptation. The 2013 EU Adaptation strategy created impact at multiple scales by mainstreaming adaptation through policies and funding instruments. The EU Member States have adopted comprehensive adaptation strategies and plans. The EU made sizeable investments in making cutting-edge climate risk information accessible, usable and useful (SDG 3). The new EU Adaptation Strategy will be even more ambitious in terms of better knowledge, better climate risk management (SDG 13), and better urban solutions (SDG 11).

To achieve energy transition in cities, it is essential to increase energy systems integration and improve energy performance to levels that go significantly beyond the ones established in current EU building codes, as well as reaching a Europe-wide deployment of Positive Energy Districts (PEDs) by 2050 (European Commission, 2016, 2018). The PED approach aims at progressing the flexibility dimension of urban districts within the (renewable) regional energy system, as well as minimizing the energy and ecological footprint of people, goods, and services. The district scale is supposed to boost economic sustainability (SDG 8), and develop synergies (e.g., efficiency deployment, flexibility, integration), through equitable and inclusive governance in distributed resources (SDG 1), and a considerable involvement of stakeholders and communities in urban planning and

implementation (SDG 11). Mainstreaming Climate Neutrality for cities and citizens implies that the development should follow four guiding principles, namely: (a) quality of life (SDG 3); (b) inclusiveness (with special attention to energy affordability and prevention of energy vulnerability) (SDG 1); (c) sustainability (SDG 11); and (d) resilience and security of energy supply (JPI Urban Europe, 2020). Districts and neighbourhoods will not be able to produce more energy than they consume without the design of new mobility solutions, and more circular use of resources. Sustainable energy systems and smart mobility solutions must consequently be prioritized, and cities should adopt circularity in order to secure health and well-being within the limits of planetary boundaries. New mobility solutions necessitate innovative energy technology and systemic design thinking (JPI Urban Europe, 2020). By system (or systemic) thinking it is meant the analytical approach by which the attention is shifted from the study of single events to the study of the systems from which they emerge (Meadows, 2008a). This means no longer looking simply at causes, effects, and mutual relationships but reasoning instead in terms of emerging patterns, structures, and the so-called *leverage points*, i.e., places within a complex system (a corporation, an economy, a living body, a city, an ecosystem) where a small shift in one thing can produce big changes in everything (Meadows, 2008b). Leverage points, therefore, are very important when seeking to produce a change within interconnected ecological, social, and economic systems (see also a link with the Nexus approach recalled in Sect. 4).

Similarly, Climate Neutrality implies a correct consideration of user behaviour and lifestyle (SDG 3), balancing the goals of cost efficiency and green growth (SDG 8), with affordability of housing and energy poverty reduction (SDG1). These three key priority clusters – Innovative Urban Assets and Infrastructure, Circular & Equitable Urban Economies, and Climate Neutrality – imply the adoption of visionary integrated approaches that support each other, as well as provide solutions to most of all the other urban critical challenges, thus revealing multiple interlinkages with the priorities set by the SDGs and the higher significance of community resilience in a post-COVID-19 scenario. The three clusters can be considered synergistic multiscale strategies aiming at supporting the climate neutrality and other sustainability achievements in cities, mostly in consideration of their increased physical, functional, and socio-economic vulnerability. Some common ground across the three clusters suggests that priority should be given to the regeneration of existing urban areas through innovative and participatory urban governance models, based on following up inputs provided by residents and inhabitants during design, implementation, and post-occupancy phases.

## 22.4 Benchmarking and Monitoring the Implementation and the Results of Policies and Interventions Aimed at SDGs

As already mentioned above, the enormous disruption of social, economic, and health spheres of the global society caused by the COVID-19 pandemics, directly threatens human well-being and mankind's life, jeopardizing the sought-after achievement of the United Nation's Sustainable Development Goals (Zhou et al., 2020). The 17 SDGs and related 169 targets aim to promote a global agenda for sustainable development to be achieved by 2030. The UN SDGs global indicator framework includes 244 indicators, nine of which appear under two or more different targets, resulting in 232 distinct indicators.

Specifically, SDG 3 "Good Health and Wellbeing" aims to "ensure healthy lives and promote well-being for all at all ages" (United Nations General Assembly, 2015). SDG 11 explicitly focuses on Sustainable and Resilient Cities and Human Settlements and gathers 14 of the 244 indicators.

Beyond the compelling principles that lay behind the UN SDGs, the question we ask ourselves now is: *Is there a way to reconcile the reorganization of our society after the dire damages caused by this frightening pandemic with the pursuit of the UN SDGs?*

This is certainly not an easy question to answer, but beyond any doubt, the paths towards community recovery and regeneration of our built environment after such an epochal crisis cannot overlook the complex symbiotic interrelationships that affect our economic and social system. In other words, the post-pandemic rebirth of our society is deeply anchored on the foundations of the "Nexus approach" (Bai et al., 2018). This requires a multi-disciplinary approach which overcomes governance silos and goes even beyond tracing linkages between water, food, and energy systems, but extends them also to sectors like infrastructure provision, inequality, and resilience, as proposed by Bai et al. (2018). A planner or a policymaker who embraces this comprehensive approach is aligned with the good principles of regenerative development and design (Robinson & Cole, 2015), which has "whole systems thinking" as an intrinsic feature (Mang & Reed, 2012).

### 22.4.1 *The Importance of Disaggregated Spatial Indicators in Integrated Planning*

Thinking more specifically about cities, where 68% of the world population is expected to live in 2050 (United Nations, 2019), it is now acknowledged that integrated planning and multi-sectors governance is absolutely needed to create healthy, sustainable, and equitable cities (UN, 2017; Lowe, Whitzman, & Giles-Corti, 2018; UN General Assembly, 2015).

Integrated planning requires the adoption and monitoring of indicators able to encompass the entire pathway of city's life shaping: from urban systems policies – defined as the most *upstream* determinants of health (Marmot & Bell, 2012) – to the more *downstream* pathways that regulate physical and mental health risk exposures of citizens, such as traffic, air pollution, physical inactivity, social isolation, safety, and unhealthy diets (Giles-Corti, Lowe, & Arundel, 2020).

The link between sustainable development, climate change, and human health is recognized by the scientific community, as well as at institutional level, with the World Health Organization (WHO) having recognized health as a distinctive marker of sustainable development (WHO, 2017), and the role of city planning in creating the conditions for good (and bad) health (WHO, 2008).

The critical role played by cities in achieving the SDGs, was recognized in the UN Habitat's New Urban Agenda (NUA) established in 2016 (UN, 2016), which recognizes the importance of quantitative and qualitative monitoring and regular tracking of progress towards cities' sustainable development (UN, 2018).

In 2017, an indicator framework to measure progress on implementing the 17 SDGs and their targets was endorsed by UN member states. This framework has then been refined specifically for cities by UN Habitat in its *Action Framework for Implementation of the New Urban Agenda* (UN Habitat, 2017). This Action Framework goes beyond Goal 11; it proposes 85 target indicators from other SDGs which have urban-based targets, of which 48 from the UN SDG global indicator framework, and 37 city-specific indicators from the City Prosperity Initiative (UN Habitat, 2015).

Giles-Corti et al. (2020) outline a conceptual framework describing pathways through which urban systems policies (i.e., city planning decisions) shape urban design and transport planning actions, and daily-life choices, thus ultimately affecting health and sustainability. They underline the importance of disaggregated spatial indicators to measure inequities in opportunities and map inequitable access to infrastructures and services, as well as the outcome of city policies on the health of inhabitants (amongst other things). "Socio-spatial equity" is in fact one of the urban challenges identified by Babí Almenar et al. (2021), pointing out that many of the case studies reviewed by the authors describe a lack of adequate distribution of living systems in urban areas (Wu et al., 2018; Anguelovski, Connolly, Masip, & Pearsall, 2018; Shen, Sun, & Che, 2017, with a consequent unbalanced distribution of their characteristics promoting health (in other words, evidence of environmental injustice).

Indicators allow benchmarking and monitoring the implementation and the results of policies and interventions. According to Giles-Corti et al. (2020), most of the SDGs and NUA indicators associated to city planning and health would allow for spatial disaggregation, although this is strongly conditioned by local data availability. With this aim in mind, therefore, they underline the importance of standardization of indicators and data collection. Going in this direction, the International Organization for Standardization (ISO) and the World Council on City Data (WCCD) have put their set of city services and quality of life indicators in relationship with the SDG-related indicators. ISO 37120:2018 (ISO, 2018) is supported by

additional standards, focusing on smart cities (ISO, 2019a) and resilient cities (ISO, 2019b). However, the ISO and WCCD approaches do not leverage the importance of spatially disaggregated indicators. This limits its usefulness for city planners and fails to unveil health inequalities as advocated by WHO (2010).

Very interestingly, Giles-Corti et al. (2020) finally remark also that, despite the importance of city planning to reach several SDGs, there are no specific city planning indicators for nine of the 17 SDGs, which is a signal of the fact that the strategic importance of spatial planning for the achievement of those goals is overlooked. Importantly, they highlight how the UN's SDG indicators framework ignores critical *upstream* indicators (like regulatory policies, or interventions and investments) that are likely to determine whether the SDGs are actually achieved. Conversely, the NUA indicators framework, which properly measures several urban design and transport planning interventions, omits important *downstream* indicators (for example, the ones measuring injury and health outcomes) that assess the results of policy implementation.

Investing in data and information technologies will be, therefore, instrumental to recover from the COVID-19 pandemic and accelerate the implementation of the SDGs (UN/DESA, 2020).

## 22.5 Funding Regenerative Urban Transition Through Horizon Europe

The European Commission has been paying for three decades significant attention to urban dimensions and sustainable development as real cornerstones in its funding strategies, and this trend seems to continue through the forthcoming Horizon Europe Framework Programme. The Programme aims at giving Europe a new push to a global positioning. Horizon Europe is supposed to be the biggest and most ambitious EU Research Innovation programme ever. It would possibly build on the success of Horizon 2020 and would improve it further by fostering a stronger support to breakthrough innovation through the European Innovation Council, by creating greater impact through Research and Innovation (R&I) missions and by streamlining partnership opportunities (Gabriel, 2020).

The EU research and innovation framework programme (2021–2027) aims to strengthen the EU's scientific and technological bases and the European Research Area (ERA); to boost Europe's competitiveness, innovation, and job creation capacity; and to respond to citizens' priorities and sustain our socio-economic model and values. The Commission set up a budget in excess of € 100 billion for Horizon Europe.

The Commission had already identified six priorities for the period 2019–2024:

- “A European Green Deal”: Striving to be the first climate neutral continent
- “A Europe fit for the digital age”: Empowering people with a new generation of technologies
- “An economy that works for people”: Working for social fairness and prosperity



- “A stronger Europe in the world”: Europe to strive for more by strengthening our unique brand of responsible global leadership
- “Promoting our European way of life”: Building a Union of equality in which we all have the same access to opportunities and
- “A new push for European democracy”: Nurturing, protecting, and strengthening our democracy.

Three pillars – Excellent Science; Global Challenges, and European Industrial Competitiveness; Innovative Europe – and four specific key strategic orientations (KSO) have been defined (September 2020) to frame the R&I contribution to EC political priorities:

- KSO 1 – Promoting an open strategic autonomy by leading the development of key digital and enabling technologies, sectors, and value chains to accelerate and steer the digital and green transitions through human-centred technologies and innovations
- KSO 2 – Restoring Europe’s ecosystems and biodiversity, and managing sustainably natural resources to ensure food security and a clean and healthy environment
- KSO 3 – Making Europe the first digitally-led circular, climate-neutral, and sustainable economy through the transformation of its mobility, energy, construction, and production systems
- KSO 4 – Creating a more resilient, inclusive and democratic European society, prepared and responsive to threats and disasters, addressing inequalities and providing high-quality health care, and empowering all citizens to act in the green and digital transitions.

The aim is to create a strong bridge between R&I and EU policy priorities, and give directionality towards the UN SDGs across six clusters:

- Cluster 1 – “Health”
- Cluster 2 – “Culture, Creativity and Inclusive Society”
- Cluster 3 – “Civil security for society”
- Cluster 4 – “Digital, Industry and Space”
- Cluster 5 – “Climate, Energy and Mobility”
- Cluster 6 – “Food, Bioeconomy, Natural Resources, Agriculture and Environment”.

Great attention is paid to the impacts (i.e., long term targeted effects on society, the environment, the economy and science, enabled by the outcomes of EU R&I investments) that will be produced. In particular, KPO 3 “Making Europe the first digitally led circular, climate-neutral and sustainable economy through the transformation of its mobility, energy, construction and production systems” relates to four (out of a total of 15) impacts; namely: Climate change mitigation and adaptation; Affordable and clean energy; Smart and sustainable transport; Circular and clean economy; and four clusters: Cluster 1 (Health); Cluster 4 (Digital, Industry, and Space); Cluster 5 (Climate, Energy, and Mobility); and Cluster 6 (Food, Bioeconomy, Natural Resources, Agriculture, and Environment).

Specific “missions” will be planned in the framework of pillar II “Global Challenges and European Industrial Competitiveness” (drawing from other pillars). Horizon Europe will define mission’s characteristics and governance elements. A “mission” is a portfolio of actions across disciplines intended to achieve a bold and inspirational and measurable goal within a set time frame, with impact for society and policy-making as well as relevance for a significant part of the European population and wide range of European citizens. R&I missions will better relate EU’s research and innovation to society and citizens’ needs, with strong visibility and impact.

Particularly relevant with respect to the SDGs previously identified appear two out of the five missions already identified in June 2020:

- “A Climate Resilient Europe – Prepare Europe for climate disruptions and accelerate the transformation to a climate resilient and just Europe by 2030”. Targets by 2030: prepare Europe to deal with climate disruptions, accelerate the transition to a healthy and prosperous future within safe planetary boundaries, and scale up solutions for resilience that will trigger transformations in society; and
- “100 Climate Neutral Cities by 2030 – by and for the citizens”. Targets by 2030: support, promote, and showcase 100 European cities in their systemic transformation to climate neutrality by 2030 and turn these cities into innovation hubs for all cities, benefitting quality of life and sustainability in Europe.

Each mission would involve one or more of the following:

- Launch specific calls in Horizon Europe and other programmes. These calls will encourage creativity and bottom up working from the proposer.
- Identify specific actions to change/improve policy context, which are critical for missions’ success, such as framework conditions.
- Make use of the appropriate partnerships.
- Mobilize structural funds to the alignment to mission goals.
- Establish the appropriate links with national programmes.
- Influence the international agenda, combining efforts with similar third country programmes.

When ready for investment, cities will be able to apply for a variety of instruments/funds/facilities mainly involving European Investment Bank (EIB) funds. Already, in the past (2012–2018), EIB contributed with estimated urban lending in excess of € 150 Billion, out of which nearly 20% was invested on climate mitigation actions through Natural Capital Financing Facility and Municipal Loans. Other instruments, such as the Connecting Europe Facility, provide guarantees and bonds, whereas the European Energy Efficiency Fund (a Public-Private Partnership with international banks) equips cities with market-based junior debt, mezzanine instruments, guarantees, equity, leasing structures, and forfeiting loans. Moreover, in response to the coronavirus pandemic, the EIB quickly deployed a support plan to help meet the most urgent financing needs of regions and municipalities. Recognizing, through dedicated funding, the key role of cities and regions in mitigating the pandemic’s effects while supporting the local economies will hopefully

enable a faster urban transition and allow more equitable and inclusive implementation of regenerative initiatives.

## 22.6 Concluding Remarks

Achieving in ten years, within European cities, what Europe plans to achieve in 30 years, is a huge challenge that requires a systemic transformation for acting on the global climate emergency, and for delivering co-benefits that will improve the health, well-being and prosperity of citizens. This transformation seems possible, because technologies and innovative solutions for sustainable energy, transport, food, water, dwelling, and material systems already exist thanks to R&I programmes developed over the last decade, and mostly considering the initiatives that will soon be made available, thanks to Horizon Europe and national R&I programmes. Green technology prices and market conditions are moving fast towards climate-friendly investments and will continue to strengthen incentives to regenerative transition. The European Green Deal, including a revision of EU directives for 2030, and the reinforced role of the EIB will thus further strengthen this trend.

In conclusion, COVID-19 has exposed our society to its biggest admission of fragility in decades, but has also presented our community a unique opportunity to rethink, replan, and redesign. However, a main dilemma remains: *Will we make use of these lessons to plan and decide for a better future? Will the most developed countries respond positively to the call for a revolutionary change in their business operation, curbing tax avoidance and reducing investments in military defence* (Naidoo and Fisher, 2020)?

This ending contribution to the RESTORE Final Book does not seek to establish what is likely to happen, but instead to make a case for “conditional optimism” about our resilience capacities, and to flesh out the reasons why one might confirm SDGs being a critical pillar of a regenerative approach to architecture and urbanization aiming at integrated transformative benefits. By this forward-looking message, it is meant that, if humanity successfully navigates the technical, ethical, and political challenges of developing and diffusing powerful transformative actions, the achievement of 2030 UN SDGs will certainly have an enormous and potentially very positive impact on health, well-being and quality of life.

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