Speculative tinkering on circular design materials through 3D printing

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Abstract

Despite the spread of new circular materials and digital technologies, designers' awareness of how to practically implement them is not fully achieved yet. Therefore, new ways to foster digital craftsmanship skills and experiential knowledge should be implemented. This contribution aims to reflect on digital technologies, especially 3D printing, in speculative design approaches with circular materials through the development of the materials library from the FiberEUse research project. This "materials and product library system" is an adaptive experiential tool that goes beyond merely collecting physical materials samples. It also includes possible products, speculative applications, and non-textual content, merging physical and virtual learning experiences. Its physical section comprises a materials library with flat samples of the materials and a product library with applications or cut-offs of some meaningful details of products.

By analyzing the library's development path, three incremental phases emerge in terms of interaction with circular materials and 3D printing for speculative approaches: experiencing materials, technology, and products. The first phase aims to preliminary explore the potential and qualities of materials through traditional craftsmanship skills. The second phase deal with the first experimentations with the technology, understanding the limits and influence on the expressive-sensorial qualities. The third phase is oriented toward new applications, investigating the possible outcomes from a formal point of view. As a synthesis, the tinkering process emphasizes the active role of experiential tools in spreading the use of circular materials and digital technologies, helping acquire new skills through an experiential approach. It also adds a further level to the exploitation of materials libraries, paving the way for new possible uses, i.e., distributed replication, participation, and implementation. As a result, materials libraries assume a more active role in the experiential knowledge transfer even during their development, representing a practical path to building new skills. Hence, a new model of materials libraries may emerge as a replicative learning and speculative design tool.

Author keywords

Circular economy, Materials library, Additive Manufacturing, Materials experience, Experiential learning.

Introduction

Fostering new responsible ways of production and consumption is becoming increasingly important from an environmental, economic, and social point of view. Among those, Circular Economy (CE) models have demonstrated to help in encouraging sustainable practices by preserving the resource flows and values as long as possible (Reike et al., 2018). Considering the design and production of new goods and products, switching to sustainable materials and technologies is recognized as a possible strategy for implementing cleaner practices, as well as circular economy practices for design (Sumter et al., 2021). Among those, the use of new waste-based or recycled materials and digital technologies, i.e., 3D printing, is gaining attention within the design research and practice, helping to establish new bottom-up, collective, and practical design experimentations or tinkering activities with materials (Despeisse et al., 2017; García-Ruiz & Lena-Acebo, 2022; Parisi et al., 2017; Rayna & Striukova, 2021; Veelaert et al., 2020). Within this context, digital fabrication tools have mainly been studied at the intersection with CE, resulting in different strategies and approaches to put its principles into practice, i.e., through repairing, distributed economies, upcycling, and recycling initiatives from local waste streams (Colorado et al., 2020; Despeisse et al., 2017; Mikula et al., 2021; Oyinlola et al., 2023; Ponis et al., 2021; Sauerwein et al., 2019; van Oudheusden et al., 2023). Moreover, the discipline of material design is demonstrating its crucial contribution to spreading the use and knowledge of new materials linked with digital technologies, especially by experiencing materials and envisioning them into concrete artifacts through speculative design approaches (Clèries & Rognoli, 2021; Galloway & Caudwell, 2018; Kretzer, 2021; Pedgley et al., 2021). However, designers' awareness of using these new circular materials and sustainable technologies is not fully achieved yet (Pedgley et al., 2016; Romani et al., 2021). Therefore, new ways to foster digital craftsmanship skills and experiential knowledge should be implemented in the next years. A possible way is represented by experiential tools, especially materials libraries, aiming to facilitate the knowledge transfer of unquantifiable practical contents, i.e., expressive-sensorial qualities and skills (Akın & Pedgley, 2016; Nimkulrat, 2021; Wilkes & Miodownik, 2018).

This work analyzes the use of digital technologies, such as 3D printing, in speculative design approaches linked to real exploitations of new circular materials. The analysis is based upon a reflective practice approach focused on the design and development path of a "materials and product library system", the materials library of FiberEUse, a research project on composite materials from recycled glass and carbon fibers. This new library merges a physical and a virtual learning experience through different media, i.e., physical samples, product cutoffs, and visual supports. It allows speculating on new possible applications by experiencing and tinkering with its different content. After introducing the case study, the work briefly detects three incremental phases of interaction and engagement with circular materials and 3D printing: (i) experiencing materials; (ii) experiencing technology; and (iii) experiencing products. Each of them is linked to a part of the materials library, as well as physical contents and possible interactions with the experiential knowledge. The experiential approach to the materials library helps in envisioning and speculating on new plausible applications through a practical approach. A fourth phase is then outlined as a possible way to foster the transfer of new digital skillsets and attitudes amongst designers and practitioners, which means (iv) experiencing the path to the materials library development. The tool assumes an active role in transferring these new digital craftsmanship skills as a participative learning and experiential tool to be locally replicated, modified, and implemented, including the development process in the learning activities.

Methodology

This work relies on the approach of Reflection-in-action, or reflective practice, in the research area of materials design (Clèries & Rognoli, 2021). Practical experimentations and projects are used as inquiry tools to reflect on practical issues and create new theoretical knowledge (Goldkuhl & Sjöström, 2018; Reich, 2017; Schön, 1992). As part of the Research Through Design (RTD) methodology, the role of design experimentations, artifacts, and products is to conceptualize and generalize through reflections to be collected during and after the practical inquiry itself (Friedman, 2008; Horváth, 2016). From literature, similar practical approaches in design research have been theorized by different scholars. Each approach usually emphasizes different aspects linked to the use of artifacts and practical inquiry tools within the design research discipline, i.e., as "designerly ways of knowing", tacit knowledge and reflective practice, or deriving embedded rules from prototyping (Cross, 1982; Friedman, 2008; Schön, 1992). In this work, the development of the Materials Library is considered a Reflection-in-action activity since it could be seen not only as a product to be properly developed and designed but also as a research path to be analyzed to build new knowledge. Hence, the whole design process of the tool may be seen as a practical inquiry that helps in understanding the use of speculative design approaches linked to the knowledge of digital technologies and new emerging materials, such as 3D printing and waste-based materials. Nowadays, Materials Libraries are seen as wider systems whose aim is not only to support materials selection by showcasing physical samples and sharing technical data.

In this work, Materials Libraries are intended in two different ways: as experiential tools to foster and speculate on the use and knowledge of emerging materials and technology or as practical design experimentations to generalize some theoretical knowledge. The first meaning is briefly resumed through the selected case study and represents the aim of this tool as a product and/or system. The second one corresponds to the methodology of this contribution, allowing for reflecting on the possible speculative experiences that may be encountered by interacting with Materials Libraries and digital technologies. The authors were directly involved in the design path of the library, resulting in a first-person approach to the design experimentation. In this way, the reflections during and after the inquiry were used to theorize on the topics of this contribution. In detail, reflections were collected by considering the structure and taxonomy of the tool during its use in a demo presented at the Milan Design Week 2021, as well as internal workshops to the project's partners, i.e., waste suppliers and designers of the products.

Speculative tinkering with materials

Using materials libraries creates a possible path to envision new applications and physical artifacts through an experiential approach. In other words, these tools represent a valuable option to foster speculative design approaches. According to Galloway and Caudwell, Speculative Design represents a meaningful way to ask new questions and generate plausible scenarios to tackle complex issues in design research (Galloway & Caudwell, 2018). In addition, speculative approaches may also be exploited in the research areas of materials design and Design for Additive Manufacturing, leading to practical experimentations and interactions with emerging materials (Bauer, 2019). To this end, designers and researchers are directly involved in the process of tinkering and experimenting with new materials formulations and process parameters, creating a range of physical output that materializes their practical work. From literature, this approach to materials is also known as Material Tinkering, a "practice of direct, creative, and iterative experimentation on materials" emphasizing the physical act of manipulating matter (Parisi et al., 2017; Rognoli & Parisi, 2021). During the experimentation process, the different material samples may foster the generation of new alternative scenarios and words, as well as applications, resulting in speculative actions (Rognoli et al., 2021; Rognoli & Ayala-Garcia, 2021). The tinkering activity is, therefore, embedded with speculative design approaches, defining proper "speculative tinkering" practices. Within this context, speculative tinkering is meant to envision new applications and scenarios through the iterative manipulation of emerging materials and technologies, often including other socio-ethical topics such as sustainability.

Case study: FiberEUse Materials and Product Library System

The case study focuses on designing a Materials Library to showcase materials and possible applications from the recycling and reuse of glass and carbon fibers from waste and products at their end-of-life, such as construction structures, wind blades, and aerospace components. The practical exploitations within the library also want to foster the integration of new waste-based materials through examples in real contexts, for instance, from industries or design practitioners. The new Materials Library is meant to spread the knowledge related to these new solutions, including different contents and materials samples. The experiential tool developed within FiberEUse widens the concept of materials libraries by including materials samples, new products, possible applications, textual and non-textual content. The "Materials and product library system" is divided into two main parts, the Physical Library and Virtual Library, merging the concepts of tangible/virtual fruition, as well as local/distributed use (Romani et al., 2022). This tool can be used during the different phases of the design process, making more accessible the knowledge of emerging materials and technologies through flat samples, cutoffs, pictures, renderings, and numerical data. The virtual part is visible at https://fibereuselibrary.com, while the physical one can be freely used on request. Only the physical part would be considered for the sake of this work, which is divided into two main parts. The first one, the Physical Materials Library, collects flat materials samples according to the finishing, kind of waste, and concentration (Fig. 1a). The second part, the Physical Product Library, showcases cutoffs and parts from physical products using the new materials. The Physical Product Library (Fig. 1b) was developed through a new spatial taxonomy, resulting in different three-dimensional tetrahedral structures, where each sample is defined by a position within a four-variable coordinate system. Each structure represents a different waste, material, and process, i.e., glass fibers, carbon fibers, and different 3D printing processes, and the vertexes are linked to the four selected variables of the structure. In this way, different variables, such as process parameters, finishing, or shape complexity, may be compared and experienced through the physical parts, which are linked to a specific position of the spatial system, allowing comparisons and qualitative assessment. Each sample of this section is then part of a specific tetrahedral structure, and it is represented by four different coordinates, one for each selected variable of the specific spatial structure. For instance, a sample of the structure "3D printed glass fibers" has a defined layer height, number of perimeters, surface finishing, and shape complexity, corresponding to the four variables at the tetrahedron vertex (Romani et al., 2022). Hence, the system allows to showcase and compare different combinations of the four variables, showing more possibilities in terms of new applications to envision.

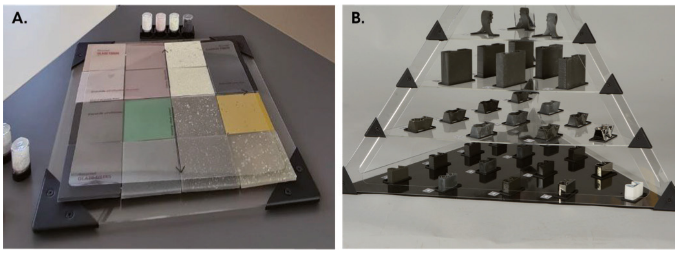

Figure 1. Tangible part of the materials library (physical part): (a) insight of some structures of the physical material library and (b) physical product library.

Experiencing Materials Libraries

Considering the interaction, tinkering with circular materials and 3D printing, three different incremental phases to foster speculative tinkering emerge from the analysis of the library's

Figure 2. Incremental phases in interacting, experiencing, and tinkering with circular materials and digital technologies through materials libraries.

development path and final design. As shown in Fig. 2, tinkering with materials through 3D printing results in: (i) experiencing materials; (ii) experiencing technology; and (iii) experiencing products. Each phase is linked to a physical part of the materials library and specific technical and experiential knowledge, progressively envisioning new plausible applications.

Experiencing Materials

The first step in fostering speculative tinkering deals with materials and their preliminary exploration through tinkering activities. The phase of Experiencing Materials (Fig. 2, phase 1) aims to begin the exploration of their properties and qualities by interacting in an immediate way, trying to reduce the mediation and influence of external tools or processes. Hence, the first attempts to investigate their physical properties and expressive-sensorial qualities are usually performed by directly handling materials and tuning the first formulations. To this end, more traditional approaches and techniques from crafts are generally used. Although the influence of processes cannot be removed as a variable in shaping and interacting with materials, crafting helps in limiting their influence, focusing on the variations of the materials themselves. Experiencing materials also means interacting with them not only in structured ways but also encouraging fuzzy interactions, structuring the tinkering activity by narrowing down the practical activity, i.e., focusing on a specific material or a specific set of qualities. This phase helps in detecting some possible paths to organize iterative tinkering, as well as paving the way for the next steps. Considering the case study, this phase resulted in the production of some sets of flat samples, which were then selected to be part of the Physical Materials Library. Hence, this section of the Materials and Product Library system represents the final output of this phase, and their users can experience the results of this tinkering activity. They can also begin their path with these materials, starting their speculative path by understanding the materials as they are and acquiring some basic experiential knowledge to be used in their envisioning path.

Experiencing Technology

The second phase in fostering speculative tinkering focuses on the experimentations and practical trials with the technology, considering the impact of the process in shaping materials. The phase of Experiencing Technology (Fig. 2, phase 2) wants to continue the exploration of the previous step by experimenting with the influence of the manufacturing process through hands-on activities. The experimentation may be performed through sampling, trying to define some set of samples that highlight possible modifications on the qualities, either seen as opportunities or limits to their real implementation. In this case, digital processes can progressively replace traditional prototyping techniques, which can be used to support further investigation and tinkering, i.e., finishing and post-processing. In this case, tinkering with the process by tuning the possible settings allows the practitioner to work in two different ways. First, it helps in defining the optimal parameters to obtain meaningful samples, which can then be used as a reference for developing new applications. Furthermore, they can also help detect different expressive-sensorial qualities that cannot be completely predicted by the user, usually experienced with a trial-and-error approach. Trials that are generally seen as errors have the great potential to foresee alternative ways to use the technology to reach new results, enlarging the ways to process the material and, consequently, the possible uses in real exploitations. Bearing in mind the case study, the first layers of the Physical Product Library represent the output of this phase, which means the biggest and simplest three-dimensional samples of that library section. They represent the synthesis of this tuning experimentation by showing the main combinations between process parameters, materials formulations, physical properties, and expressive-sensorial qualities. Also, in this case, the user directly handles the results of this practical activity, adding some experiential knowledge to what they previously experienced on materials.

Experiencing Products

The third step in fostering speculative tinkering is oriented toward speculative design and real implementations. The phase of Experiencing Products (Fig. 2, phase 3) aims not only to continue the previous tinkering and explorative paths but also to encourage possible experimentations, projects, and exploitations of the physical and experiential contents. At this point, the experimentation is mainly linked to digital technologies and tools by designing and developing possible applications and physical artifacts, representing the first trials of real implementations. New products, artifacts, or even some cutoffs or parts allow the designer to investigate the possible outcomes from a formal point of view, making tangible some crucial aspects to consider during the design process of new products. In detail, fields of application, technical features, possible geometries, and different aesthetics are analyzed by materializing them within plausible products. Showing some plausible examples, as well as some real products or work-in-progress concepts, should not be intended to limit the range of use and applications of the analyzed materials and technologies. Contrarily, it aims to further stimulate the development and design of different artifacts by materializing some ideas, which could then be considered as references for new projects. Furthermore, it aims to encourage the investigation of new possible features, geometries, and aesthetics to be achieved by exploiting the showcased materials and technologies. In this case, the final layers of the Physical Product Library resume the output of this final step, increasing the shape complexity and introducing some applications as a reference for future works and speculative approaches. The user can use them as a starting point for exploitations in real contexts through their design and professional activity.

Experiencing the Path

A possible fourth phase emerges as a potential experiential and speculative tool from the analysis of the case study, as shown in Fig. 3. As a matter of fact, the materials library of the case study helps in encouraging speculative approaches to sustainable materials and technologies by sharing the experiential knowledge to facilitate their use in real contexts. However, it also represents a way to showcase some results obtained using digital tools and skills, promoting their use. For this reason, the library may be used to foster the transfer of new digital skillsets and attitudes amongst designers and practitioners. According to the previous analysis, experiencing the path (Fig. 3, phase 4) for the materials library development allows the users to acquire these skills through a practical and experiential approach, which means taking part in the process of building the tool itself. From this perspective shifting, the tool acquires an active role in transferring new digital craftsmanship skills and is not just representing a passive knowledge transfer tool to be used in its final version. This approach paves the way for new possible uses of this tool, i.e., distributed replication, participation, and implementation, since experiencing the path adds a further level to experiential knowledge transfer. Moreover, first-person practical activity focused on the library helps in acquiring the skillset to pursue speculative tinkering on possible exploitations through hands-on activities, taking part in the process of envisioning new artifacts by directly participating in the fabrication path. Thinking about possible ways to replicate or create new versions of the library considered as a case study would be a possible way to foster this speculative hands-on approach amongst designers and practitioners.

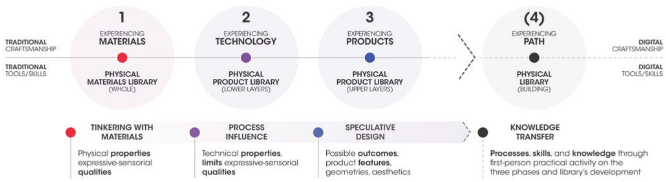

Figure 3. Contribution of experiencing the path in developing a materials library in spreading digital tools and skills for speculative tinkering.

Conclusion

This contribution reflected on the use of digital technologies in speculative approaches linked to new circular materials from waste, fostering new projects and real exploitations. The analysis was performed through a reflective practice approach to the design and development of the materials library of FiberEUse. Three different incremental phases in fostering speculative tinkering emerged from the analysis, linked to a specific part of the library, which means: (i) experiencing materials with traditional crafting tools to explore physical properties and expressive-sensorial qualities (*tinkering with materials*); (ii) experiencing technology with hybrid approaches to understand its potential and limits (*process influence*); and (iii) experiencing products with digital crafting tools to envision new applications through tangible examples (*speculative design*). A further step was then added as a possible fourth phase, which means (iv) experiencing the path by transferring digital crafting skillsets through first-person hands-on activity in participating in the development of the tool (*knowledge transfer*). These reflections should be furtherly enriched by considering additional case studies, circular materials, digital technologies, and users. However, materials libraries may assume an active role in fostering speculative tinkering through digital technologies such as 3D printing and in transferring new digital craftsmanship skills thanks to its potential use as participative learning and experiential tool to be replicated, modified, and implemented. Their meaning is, therefore, also in experiencing the path to obtain them, and not only in their final design, paving the way for a new way to interact with materials libraries, circular materials, and 3D printing. Further work should be done to assess the use of Materials Libraries in different contexts, i.e., in didactic activities, during the design process, or define how to evaluate the outputs from the speculative tinkering, for instance, the feasibility and technology readiness level of the envisioned applications and artifacts.

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