

A Framework for Capturing Creativity in Digital Fabrication

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Abstract: Digital fabrication laboratories (FabLabs) influence how we think, ideate, do, make, and create. To enable the full capacity of materialization of the most creative ideas in the FabLab, a fundamental understanding of the processes in the FabLab is required. To accomplish this, we propose a framework for dynamically and ubiquitously capturing human-human (team) interactions, human-tool/machine interactions, and human-design-object interactions in the complex scenarios that occur in the paradigm of making in FabLabs. The framework elaborates three methods. The first method produces categories of creative spaces about activities and users in the FabLab. The second method identifies interactions between users and tools, and between users. Last, the third method identifies in-depth cognitive and thinking types of makers in the FabLab. The proposed framework can improve creative results and experiences of all stakeholders in the making process in the FabLab, and provide easy customization of the FabLab training for different audiences.

Keywords: creativity, FabLab, spaces, interaction, thinking

1. Introduction

Digital Fabrication Laboratories (FabLabs) are spaces where creative production from art, science, and engineering perspectives takes place as users blend physical and digital technologies to explore ideas, learn skills, and create (Sheridan et al., 2014). The use of FabLabs is not well understood. Particularly, it is not understood how the contemporary thinking around co-design methods, service design models, and access to public data/big data relate to creative FabLab experiences. Often, the users of FabLabs fall into two general categories. One is that of a motivated maker, who spends a lot of his or her time making, experimenting, and trying new things, ideas, or approaches (Analytis et al., 2017). The other category consists of the uncertain creator for whom it is difficult to begin, and who often gives up after an initial challenge.

Suitable environments are required for boosting creativity. Appropriate FabLab technology encourages creating the 'most wildly expressive things' (Mandavilli, 2006). It is possible for FabLabs to enable creation of open source scientific hardware and research environment (Pearce, 2012). The previous work in the area so far indicates that creative spaces may trigger the best possible creative

performance (Thoring et al., 2012). The types of space typology—Space for Making, Space for Deep Work, and Space for Collaboration—are particularly relevant in the case of FabLabs (Thoring et al., 2016). General making spaces are investigated in a number of FabLabs in university environments (Barrett et al., 2015), identifying varieties in their locations, membership and access, and operational models (student run, dedicated staff run, and faculty run).

3D fabrication and prototyping provide an effective way to materialize creative ideas in objects and gadgets. FabLabs have the potential to become an interface to the city, a creative hotspot (Mostert-Van Der Sar et al., 2013; Troxler, 2016). In FabLabs, entrepreneurship and community make for creativity is a major perspective on making (Vossoughi & Bevan, 2014). Digital fabrication is an inspiring and creative way to use modern technologies and communication tools to support the potential development of innovation with a business impact (Anderson, 2012). Furthermore, making deeply builds on the development of the Internet of Things (IoT) (Schön et al., 2014). As an example of an impact on innovation and business, the FabSpace 2.0 project (2016) highlights the role of FabLabs in universities for their regions and their overall contribution to the performance of society.

Interactions in the processes of prototyping and making are crucial aspects of the phenomenon of digital fabrication. As an example of systematic data gathering of interactions, a dedicated microcontroller system (wearable) was used to capture the inter-personal interactions in an engineering design team in digital fabrication (Sjöman & Steinert, 2016).

In this article, we argue that it is possible to enable a wide typology of users to materialize their bravest ideas in the FabLab. For this, we need to have a profound understanding of the creative processes practised in the FabLab. This is because digital fabrication is breaking boundaries between disciplines and creating a new paradigm that influences how we think, ideate, and create. This occurs on multiple levels, from physical to behavioural and cognitive. To capture creativity in the FabLab, we propose a framework for dynamically and ubiquitously capturing human-to-human (outside teams, for instance, spontaneous collaboration of two strangers in the FabLab or when asking the instructor) and team (teamwork) interactions, human-tool/human-machine interactions, and human-design-object interactions in the complex scenarios that occur in the paradigm of making in FabLabs.

2. Background

Cognitive states (Bilda et al., 2008, Wiafe et al., 2011) and their identification are important for creative engagement with a system. Furthermore, from a cognitive perspective, creative production in FabLabs involves art, science, and engineering, blending of digital and physical technologies to explore, learn, and create new products (Martin, 2015). The constructionism learning in FabLabs has been discussed as learning by making (Schön et al., 2014). Furthermore, the importance of failure (Martin, 2015) in the FabLab context has been emphasized. Consequently, trials in the context of making are of significant importance. Pursuing many materialized prototypes during the earliest phases of the design process is regarded as very beneficial for learning (Neeley et al., 2013). Georgiev and Taura (2015) identify the role of cycles of ideation and materialization (through digital fabrication) in expanding the concept space in creative thinking.

Some cognitive processes related to creativity are analysed when the participants use generative software tools in digital fabrication (Lee et al., 2015). These are related to distinct processes and activities regarding the design. Furthermore, some of the cognitive characteristics have been compared before and after a digital fabrication course; and confidence has been reported as an important initial barrier that needs to be overcome (Analytis et al., 2017). More recent research analyses the cognitive states of students before and after a digital fabrication (project-based

machine construction and mechatronics) course, where an increase in student creative confidence and motivation has been observed (Slåttsveen et al., 2016).

Furthermore, a custom wearable was used to capture the interpersonal interactions in the product development process (Sjöman & Steinert, 2016), delving into the team interactions during digital fabrication. On a qualitative level, creativity is analysed by the interactions between the digital fabrication designers and the users of the custom-prototyped interactive fabrics (Treadaway & Kenning, 2015). Furthermore, the general creative potential of some of the processes in digital fabrication has been investigated (Sadar & Chyon, 2011). Previous studies point out that 3D fabrication facilitates easy materialization of objects that are otherwise difficult to produce; hence, it can expand the possibility of the production of creative shapes and products (Georgiev & Taura, 2015; Sass & Oxman, 2006). Sass and Oxman (2006) demonstrated the importance of tools and machines in creative production through digital prototyping in the case of architectural design.

Recent findings in design research and design cognition identify patterns in in-depth cognitive and thinking types, and their importance in the perspective of creativity (Nagai et al., 2010; Georgiev et al., 2011; Georgiev et al., 2012; Junaidy & Nagai, 2013). Tasks and expertise highlight significant differences in in-depth cognitive and thinking types, both quantitatively and qualitatively (Junaidy & Nagai, 2013).

On this theoretical basis, to enable the full capacity of materializing the most creative ideas in the FabLab, we *aim* to propose an analytical framework of the processes in the FabLab. To deepen our understanding of the creative processes practised in the FabLab, we build upon the following assumptions:

- Creativity in the FabLab context relates to the use of spaces, kinds of interactions, cognitive states of makers, and in-depth cognitive and thinking types.
- Certain kinds of interactions, use of spaces, cognitive states of makers, and in-depth cognitive and thinking types can enhance creativity. These can be used in planning, designing, and managing FabLabs so that the creative outcomes are maximized.

3. Framework and methods

Based on the above assumptions, we propose a framework that elaborates three methods to address the goals to capture and understand creativity in FabLabs.

3.1 First method: *Creative fabrication spaces*

The first method produces categories of creative spaces (Thoring et al., 2016) through segmentation, identification and classification of activities and users in the FabLab. Previous studies have identified different types of creative spaces (Thoring et al., 2016): for example, Space for Making, Space for Deep Work, and Space for Collaboration. While, overall, a FabLab is a 'Space for Making' or 'thinker space', our experience points to a much more complex utilization of the FabLab than being solely Space for Making. The FabLab almost equally appears to be a Space for Collaboration, both formally (in the context of education, courses, workshops or other types of leaning), and informally (in the context of self-motivated making, which requires to collaborating with and learning from others). The FabLab may also occasionally be a Space for Deep Work. All these types of spaces relate to creativity in digital fabrication.

Figure 1 illustrates the distinct FabLab where we will gather data to test the framework proposed here. There are several design spaces (focused on work, collaboration and making) and spaces where

tools and machines are used (3D printers, laser cutter, vinyl cutter, points for constructing electronic devices, soldering stations, computers, etc.).

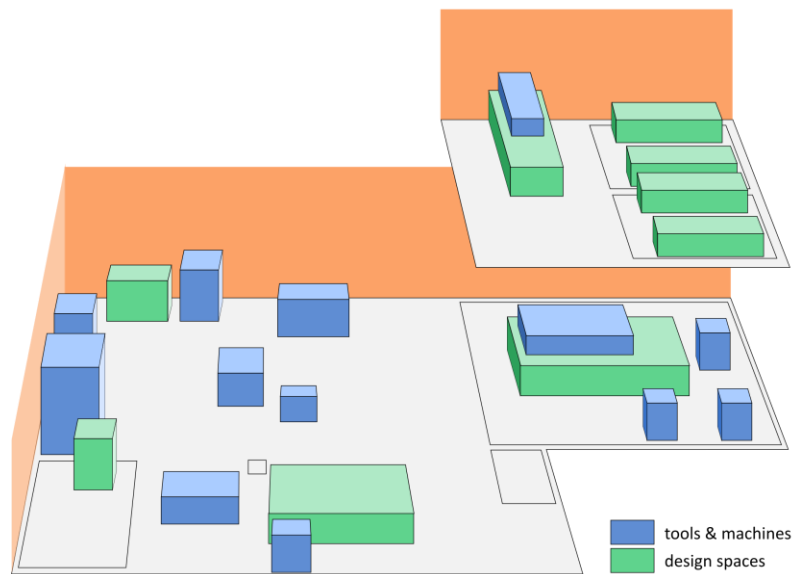


Figure 1. The FabLab Oulu layout and spaces

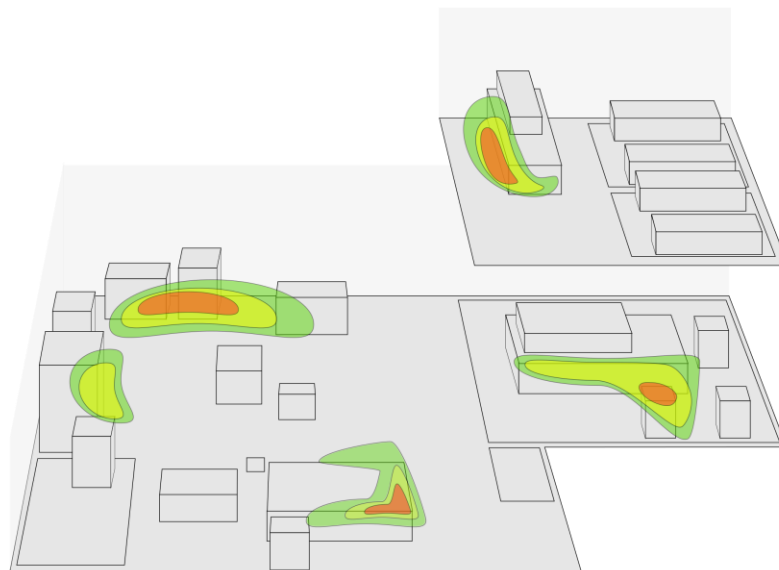


Figure 2. A heat map (based on subjective observations) of making a prototype

3.2 Second method: *Interactions in making*

It is important to capture data about the interactions in making because of their relationship to creativity and their complexity (Analytis et al., 2017; Papavlasopoulou et al., 2016). Such interactions occur between users and tools/machines, and between users, either individually or within teams (Sjöman et al., 2015). The existing options for data capture rely on personal observations or on a custom wearable (Sjöman & Steinert, 2016).

In the second method, we propose to dynamically, continuously, and ubiquitously capture data about the various making activities, using mobile context instrumentation. The method will identify the interactions between users and tools/machines, and between users per se, individually or within teams (using AWARE framework for smartphone sensing [Ferreira et al., 2015; 2017;

www.awareframework.com]) using smartphone sensing (various sensors present in every modern smartphone) and beacons. This method will have the advantage of not requiring the FabLab users to wear any additional devices, other than the smartphones that they already use. Such data will allow the identification of patterns, strong and weak points, contributions, and creative moments in various interactions in making.

To increase the precision of the gathered data, the use of long-term deployable beacons will allow richer data of interactions between users and tools/machines. Furthermore, such sensors can be used to quantify the infrastructure demand, wear and routines, and the overall appropriation of the FabLab. The proposed approach will use mobile devices and beacons/sensors-based system for dynamically capturing human-human (team) interactions, human-tool/machine interactions, and human-design-object interactions in the complex scenarios during creating (making) in the FabLab.

As an example of the kind of data that may be expected from the second method, Figure 2 provides an illustration (based on subjective human observations) of the making of a prototype in the FabLab. Different tools/machines and design/make-spaces (Figure 1) are used for this prototype.

3.3 Third method: *In-depth cognition and thinking*

The third method identifies in-depth cognitive and thinking types based on interviews with makers regarding the works they produce in FabLabs and their creative features (Georgiev et al., 2012; Junaidy & Nagai, 2013) or (user) interactions with the FabLab products (Gwilt et al., 2010).

Creativity has an inherent connection with the deep cognitive processes and thinking types of the designers, craftsmen, and makers. The analysis of these cognitive processes and thinking types reveals fundamental differences between the designers and the craftsmen (Junaidy & Nagai, 2013). Moreover, it points to creativity barriers, new opportunities to address the adoption of new technologies and techniques, knowledge and skill acquisition in relation to new technologies and techniques, and education of such. Hence, this method has the potential to put the findings based on the two previous methods in the context of human (designer, maker) thinking and cognition.

Furthermore, these cognitive processes can be indicative of the essence of the interactions and the experiences of works and products (Gwilt et al., 2010). For example, the identified in-depth associative concepts can be indicative of one cognitive and thinking type in the particular case of making of a prototype in the FabLab (Figure 3, presenting an example of a prototype of a custom lid for a water boiler). The in-depth associative concepts are identified based on the associative concept network built because of the makers' own prototype description.

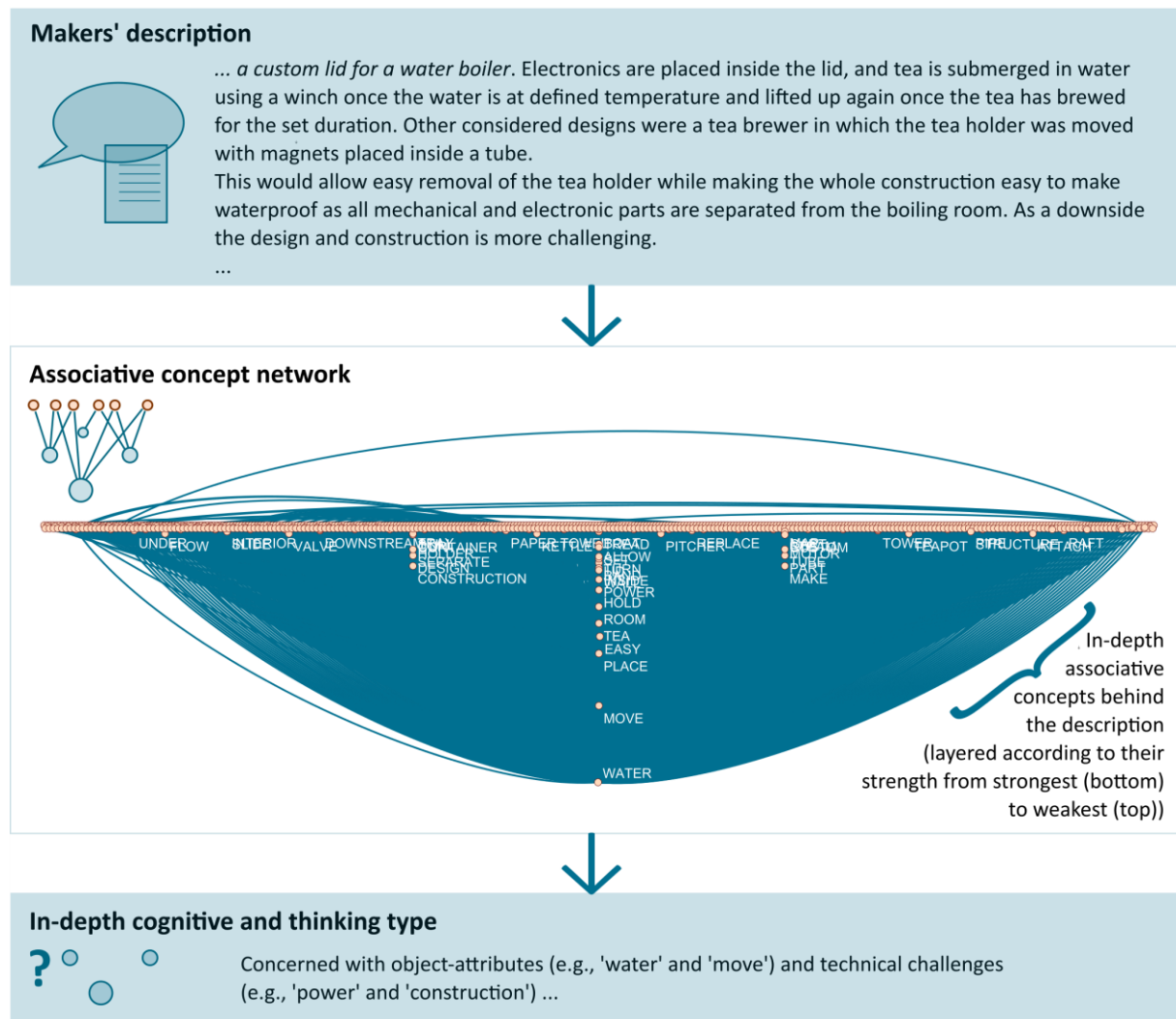


Figure 3. Example analysis of cognitive and thinking type related to FabLabs. The applied approach is based on Georgiev et al. (2012) and Junaidy & Nagai (2013).

4. Discussion

The proposed framework outlines how data can be collected to capture creativity in making in the FabLab. It elaborates on the variety of data to understand the creative processes in digital fabrication.

The intersection of the three proposed methods provides unique opportunity to analyse data, trace creativity and related phenomena from cognitive to technical levels, back and forth. For example, we expect to identify unique circumstances for the occurrence of creative ideas in fabrication. A metrics for creative ideas can not only be the creativity evaluation of ideas and prototypes (Georgiev et al, 2016), but also the users' self-reports on dimensions such as motivation, fun, etc. (Analytis, 2017). Extensive data capture allows getting back to individual moments or circumstances of creative events and gain deeper understanding of the phenomenon. Furthermore, inspirational and motivational events, spaces and interactions can provide a context to better understand creativity. For our future work, we are planning to provide methodologies to analyse the different data in an approach that identifies the three methods proposed here. In addition, the FabLab appropriation, use of tools and machines, and overall ergonomics can be improved (Anguelova, 2009).

The proposed framework can contribute to the following directions:

1. Improve creative results and experiences of all the stakeholders in the making process in FabLabs, in particular, by facilitating the use of existing making spaces and also facilitating various human-to-human and team interactions;
2. Improve the participatory aspect, providing for more effective involvement of the stakeholders in the design and making in FabLabs, especially, by facilitating the involvement of first-time users, distant stakeholders, non-university users, etc.;
3. FabLab appropriation, specifically:
 - Better performance and utilization of resources of FabLabs, especially by utilizing resources precisely when and where they are needed;
 - Identification of issues with processes and experiences in existing FabLabs;
4. The development of research-facilitated, fully augmented, and context-aware FabLabs;
5. Provide easy customization of FabLab training for different audiences (e.g., specialized workshops). Conducting FabLabs workshops that are better customized for different audiences (e.g., workshops designed for high-school students, or for users from different generations);
6. Improve the design of future FabLabs through, for example, better synchronicity of spaces, activities, interactions, and in-depth cognitive and thinking types that trigger the best possible creative performance;
7. Develop a “creativity studio” FabLab, which would bring together industry blues-sky design and research projects that would be undertaken by the staff and the students from the university to work together on speculative ideas in a “safe” and neutral environment.

As a limitation, the proposed framework cannot fully account for the processes related to digital fabrication, which may occur outside the FabLab. Specifically, the processes related to spaces and interactions that may occur outside the FabLab may not be fully understood.

FabLabs have considerable social impact, both locally and as a global social movement (Walter-Herrmann & Büching, 2014). This is also the way we will measure the success of the framework. The framework aims to achieve more meaningful and effective involvement of all the stakeholders in the making process in FabLabs. This leads to a tangible and measurable value (1) for the local community by increasing their use of the FabLab, including various co-creation activities; and (2) in terms of an innovation incubator for businesses, making FabLabs an easily accessible ground for start-ups and new product development. The latter is essential for the contemporary technological society. The comparison of the states on these two points before, during and after this project will be a measure of its success.

In addition to the impact of this research on the topic of creativity in design (a suggested direction for research as per Papavlasopoulou et al. [2016]), the societal impact of this research in the short term will be the FabLab’s tendency to outgrow its university scale. This means it will become a centre for creation and making involving a wide range of stakeholders with different backgrounds, ages, and experiences. In the long term, this research will enable us to have FabLabs as widespread and integral parts of our society, not requiring any special user knowledge and skills to use and innovate.

5. Conclusion

We proposed a framework for dynamically and ubiquitously capturing human interactions, human-tool/machine interactions, and human-design-object interactions in the complex scenarios that occur in the paradigm of making in the contemporary phenomena of FabLabs. We addressed this problem/opportunity by proposing an analytical framework. The framework elaborated on three methods: (1) the identification of categories of creative spaces about activities and users in the FabLab, (2) the identification of interactions between users and tools, and between users, and (3) the identification of in-depth cognitive and thinking types of the makers in the FabLab. Using this framework, it will be possible to capture and better understand creativity in the context of digital fabrication. The proposed framework can improve creative outputs and experiences in the making process in the FabLab, provide easy customization of FabLab training for different audiences, and improve the design of future FabLabs.

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