Learning Spaces for Engineering Education: An Exploratory Research About the Role of Lean Thinking

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Abstract. In the last decade, learning spaces have moved from the traditional classrooms and laboratories to sophisticated spaces that leverage on emerging technologies to facilitate and enhance active, social, and experiential learning. Engineering institutions around the globe are investing their resources in the creation of this spaces in order to provide students with a holistic training in line with the current demands in the job market. The present work identifies the main learning spaces implemented for engineering education and conducts and exploratory research about the role that Lean Thinking plays in their educational programs. The results suggest a clear distinction between Learning Factories and the group made of Fab Labs, Hackerspaces, and Makerspaces, which can be attributed to differences in governance and technical features. Learning Factories have successfully integrated Lean Thinking into their engineering curriculum, and while there is scarce literature concerning FLs, HSs, and MSs, there are elements in these spaces that can be considered lean enablers that could be exploited to integrate Lean Thinking into their research and educational activities.

Keywords: Learning space; learning factory; product development; lean thinking.

1 Introduction

The term “Learning space” refer to the physical setting where learning takes place, providing the context for the development of educational activities, the interaction of involved participants, and their use of available resources for the achievement of educational objectives. In the traditional sense, learning spaces include classrooms, libraries, laboratories, etc.; however, nowadays learning takes place in more diverse locations beyond these spaces. As more institutions are embracing experiential learning, an approach that recreates real-world situations and thinking, learning spaces are being reconceptualized, with an increasing number of emerging models designed to facilitate active, social, and experiential learning [1]. Furthermore, the use of technology as an enhancer of the experience taking place within a learning space has been identified as conducive to active learning and having a significant impact on student learning [2]. In the particular case of engineering faculty and institutions, a variety of learning spaces are being established, leveraging heavily on modern technology to recreate spaces that enable hands-on experiential learning specific to this discipline. While individual learning spaces of this type are widely covered in literature, there are few publications that conduct comprehensive analysis of the spaces themselves, especially those with a thematic focus in particular. Given that hands-on experience in a realistic environment has been identified as one of the most suitable ways to interiorize lean concepts [3], this paper attempts to explore these facilities and to uncover the role that Lean Thinking plays in their educational programs, whether as a key component of their educational curricula, a philosophy behind the design of the latter, or others.

2 Research Objective and Methodology

Given the context presented in the previous section, the current work attempts to answer the following questions:

- RQ1. What are the learning spaces implemented in an engineering educational context?
- RQ2. What is the role of Lean Thinking in engineering learning spaces, if any?

Accordingly, the methodology adopted for this study is a systematic literature review consisting of two phases: first, the identification and characterization of the learning spaces relevant for the study, followed by the analysis of said learning spaces in the context of Lean Thinking.

2.1 Learning Spaces Identification and Characterization

The database used for sourcing the literature is Scopus, which was selected due to its rich metadata and relevance in the fields of education and engineering. The literature relevant for the first phase was retrieved using the keywords "learning space" and "engineering", resulting in a total of 382 articles, out of which 91 were excluded on the basis of scope and retrievability. The articles' metadata was mined and examined in search for mentions of learning spaces. Out of the nine learning spaces initially identified, five were excluded on the basis of scope and formalization. Formalization -in the context of this study- refers to the existence of a definition and a set of characteristics associated to the learning space that are well documented in academic literature. The learning spaces that fit these criteria are: i) Learning or Teaching Factories (TFs), ii) Fab Labs (FLs), iii) Hackerspaces (HSs), and iv) Makerspaces (MSs).

2.2 Analysis of the role of Lean Thinking in engineering Learning Spaces

A second set of literature was retrieved using the keywords "lean" and "learning", "teaching", or "education" in conjunction with the keywords corresponding to each of the four learning spaces identified. These search strings were composed considering the different known conventions in spelling and variations in the ending of the terms used to refer to these learning spaces. From the resulting 87 articles: 85 correspond to TFs, 2 correspond to MSs, while there were no articles related to FLs or HSs. Due to the low number of publications related to the latter 3 learning spaces, an internet search with the same keywords was conducted using the Google search engine, which resulted in additional 15 scientific articles and 9 websites associated to MSs, FLs, and HSs. All these sources are analyzed qualitatively with the objective of (i) extracting key characteristics of the learning spaces, (ii) identifying instances in which lean practices, methodologies, or tools are referenced, and (iii) extracting insights from observed trends.

3 Learning Spaces in Engineering

As a result of the first phase of the analysis, there were identified four learning spaces that are commonly implemented with the purpose of facilitating activities associated to engineering education. The following paragraphs include a brief summary of their definition and history, followed by their characterization based on features relevant for the study.

TFs originate as an approach to develop tools to recreate problems found in real industrial environments, which are addressed in an academic setting and result in the acquisition of competences. In terms of the physical setting, TFs are replicas -scaled down or actual size- of multiple phases of the value chain with a high degree of realism, grounded on a didactical concept with emphasis on active learning. Although the historical development of TFs goes back to the 80s, they have gained more prominence in recent times as they can be considered the response of academic institutions to the challenges posed by the Fourth Industrial Revolution. In the last decade several TFs have emerged in Europe and gained recognition from academia as well as industry [4]. The International Association of Learning Factories (IALF), which currently counts with 17 members, is the main existing network. On the other hand, the concept of FLs was initially developed in the early 2000's by the Massachusetts Institute of Technology (MIT) as a medium to explore the impact of personal fabrication in locations without access to it. Nowadays, FLs take the form of low-cost workshops equipped with computer power and simple tools for prototyping, facilitating entrepreneurship, research, innovation, and education through the collaboration and exchange of ideas among participants [5]. The Fab Lab Network has approximately 1500 FLs indexed in 90 countries all over the world [6].

In contrast to TFs and FLs, whose origins are closely tied to engineering faculty and institutions, HSs and MSs have emerged in different circumstances, notably outside of the university system. HSs emerged in Germany during the mid-1990 as a social club-like open space for social gathering and project development among computer enthusiasts. The movement was formalized through the publication of a document containing a set of general guidelines for the creation and organization of hackerspaces. Currently, there's a registry of 796 listed hackerspaces all over the world that consider themselves to be part of the hackerspace movement [7]. With a similar origin, the emergence of MSs is intertwined to the 'maker' movement which appeared around 2012 [8]. The movement brings together the DIY spirit and the sharing culture associated to the web and digital tools, initially just for children and later becoming more widespread. This is materialized in MSs with the inclusion of several pieces of equipment for prototyping,

primarily 3D printers. As the cost of the technology associated decreased, MSs began to spread to more locations. However, there is no indication of the existence of an organized network at an international level.

Based on the information extracted from literature, there were identified eight features through which the identified learning spaces can be characterized. These features (Table 1) allow for a multi-dimensional understanding of these spaces as they describe the existence of an organized network and/or governance, as well as their environment, purpose, and technical features associated to products and processes. These features are defined as below:

Table 1. Characterization of the learning spaces included in the analysis.

Feature	Learning Factory	Fab Lab	Hackerspace	Makerspace
Main network	Int'l Assoc. of Learning Factories	Int'l Fab Lab Association The Fab Foundation	Hackerspaces.org	-
Governance	High	Medium	Low	Medium
Environment	Academic Non-academic	Academic	Non-academic	Academic Non-academic
Purpose	Education Research Training	Collaboration Education Entrepreneurship Innovation Research	Collaboration Education Entrepreneurship Innovation	Collaboration Education Entrepreneurship Innovation
Entry Barrier	High	Medium/Low	Medium/Low	Medium/Low
Product Lifecycle	Full life cycle	Product Development	Product Development	Product Development
Processes	Authentic Simulated	Authentic	Authentic	Authentic
Products	Selected for TF	Unlimited	Unlimited	Unlimited

- Main network. Existence of an organized and collaborative structure to which individual learning spaces can subscribe.
- Governance. Degree to which an underlying system controls the network and its operations.
- Environment. Setting in which the learning space is established.
- Purpose. Main purposes behind the establishment of the learning space.
- Entry barrier. Degree to which certain factors such as initial investment, required expertise or experience can prevent newcomers from establishing a learning space.
- Product life cycle. Phases of the life cycle reproduced at the learning space.
- Processes. Nature of the processes reproduced at the learning space.
- Products. Type of product that can be produced, manufactured, or assembled at the learning space.

Concerning the presence and/or role of Lean Thinking within these four learning spaces, two main trends were observed: i) Lean Thinking addressed as a learning topic, or ii) Lean Thinking implemented as an educational methodology. These trends are summarized into two categories called “Education for Lean” and “Lean for Education”.

1. Education for Lean. Several examples of TFs showcase production lines dedicated to the teaching of the use and implementation of lean management tools and practices [9] [10] [11]. Lean management is often addressed with a holistic approach and has been one of the main topics in the educational and research agenda of learning factories in the last 10 years [12]. Furthermore, recently TFs have started to address the topic of Lean in conjunction with Industry 4.0 in terms of the competences required from the workforce [13]. A common approach observed in several TFs is the implementation of lean practices in a production line followed by the demonstration of the performance enhancements brought by Industry 4.0 [14].
2. Lean for Education. TFs and MSs make use of Lean concepts to create learning process methodologies such as problem-pull, theory-push, and reflection-first [15] or the implementation of the Lean Launchpad methodology for the development of the engineering curriculum [16].

4 Discussion

The analysis shows a clear difference between the presence and role of Lean Thinking between TFs and the group of learning spaces made of FLs, HSs and MS. This difference can be attributed to two factors linked to the features of these spaces: the level of governance and the technical features.

4.1 Level of Governance

The results show that there are more than a thousand FLs, HSs and MSs all over the world, and that the structure of the associated networks suggest a low level governance. While there are no exact figures about the number of MSs, literature suggests estimates of hundreds of such facilities that are organized in small regional clusters. In the case of FLs and HS, there is no centralized governance model that exerts control over the specific purposes, processes, techniques, methodologies, etc. implemented by each learning space node in the network. Furthermore, there are lists of technical equipment that is required for FLs or recommended for MSs in order for facilities to call themselves as such, but there are no further requirements or expectations in terms of their operations and activities. Nonetheless, TFs show a different type of network and governance. While the IALF counts with less than 20 TFs as members, literature suggests that currently there are around 100 TFs operating all over the world. While the IALF does not set the research and educational goals for TFs, considering the low number of nodes within the network and the existence of an established cluster of TFs at its core, it can be observed from literature that the research activities of the TFs in the main network influence the activities of those within, in the form of internal collaborations, and those outside in the form of external collaborations. This difference in levels of governance is crucial to understand the degree to which the learning spaces included in the analysis are able to unlock and exploit the collaborative potential associated to organized networks.

TFs are learning spaces that address Lean Thinking as a core component of their research and educational agenda, making use of their production lines to showcase the implementation of lean tools and practices. The outcome of their activities is actively shared among the network community through an exchange of best practices, methodologies, potential research lines, etc. that collectively advances forward the body of research surrounding the topic and enhances the quality of the educational content delivered as well as the effectiveness of the learning experience. In contrast, the activities conducted at the large majority of FLs, HSs, and MSs are highly decentralized, with every individual space operating within its own confines or, at most, cooperating with a few other spaces. Furthermore, the educational activities imparted at these learning spaces often include introductory lessons about equipment use and safety measures, giving learners a high degree of autonomy to develop their own projects, hence the emphasis on innovation and entrepreneurship. While both formal and informal learning take place in these spaces, this configuration does not facilitate a smooth knowledge exchange and development such as the one taking place for TFs. Therefore, the lack of literature discussing in depth the implementation of Lean Thinking in these spaces might not necessarily be indicative of it absence but, instead, the absence of an organizational structure that enables its documentation and dissemination.

4.2 Technical Features

Concerning the technical features, the learning spaces included in the analysis show a clear divide between the recreated product lifecycle, with TFs focusing mostly on production, while FLs, HSs, and MSs are oriented towards product development. The TFs identified in the literature showcase a production line -simulated or authentic- built to manufacture or assemble a product in mind; therefore, the Lean Thinking curriculum includes the utilization of various known methods of the lean toolbox such as 5S, VSM, JIT, Kanban, supermarket, among others for the improvement of production processes. On the other hand, the facilities of FLs, HSs, and MSs are furnished with various equipment ranging from small 3D printers to large industrial machining centers such as precision measurement and laser cutting machines used for rapid prototyping. In some cases, these spaces operate in cooperation with incubators that nurture the development of startups. While there is abundant literature about the implementation of Lean Thinking in production -even outside the scope of this work- those addressing stages preceding production are less common. There are known methods and tools used in lean product development such as set-based engineering and rapid learning cycles; however, this research found no implementation of such methods at FLs, HSs, or MSs. This absence could be attributed to the higher emphasis placed on production or also to the low governance of these spaces, although it could also be indicative of the lack of an structured and effective learning approach.

5 Conclusions and Future Works

The present work conducted an exploratory research about the role played by Lean Thinking in TFs, FLs, HSs, and MSs. The research shows that Lean Thinking has been successfully integrated into the engineering curriculum by a number of higher educational institutions through the implementation of TFs. TFs address Lean Thinking as a core component of their research and educational agenda, making use of their production lines to showcase the implementation of lean tools and practices. On the other hand, while there is scarce literature addressing Lean Thinking in FLs, HSs, and MSs, there are elements in these spaces that can be considered as lean enablers that could potentially be exploited in order to integrate lean methods and practices into their research and educational activities. For instance, the Lean Startup methodology could be adopted as a structural foundation for their activities such as rapid prototyping and entrepreneurship development. Therefore, while TFs offer an optimal setting for the teaching of Lean Manufacturing, FLs, HSs, and MSs have the potential to be used as settings for the teaching of Lean Product Development and the Lean Startup Methodology.

This exploratory research identified and characterized four main learning spaces implemented for engineering education. The results obtained from the analysis might be limited by the choice of a single scientific search engine -complemented by the use of an internet search engine- and the inclusion of works published in English language. Future studies to expand on this work, therefore, could include the obtention of a database that includes publications not indexed in Scopus and a wider grey literature such as theses or magazines in order to identify a larger sample of learning spaces, especially to account for the activities conducted by FLs, HSs, and MSs. Additionally, future research could attempt to study more in depth the reasons behind the emphasis placed by some learning spaces such as TFs on the production stages, and the pedagogic approaches for the teaching of Product Development within a wider scope of learning spaces. In the particular case of learning spaces for engineering education, to understand how to leverage on their technology, practices, environment, or any other feature to facilitate the teaching of Lean Product Development.

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