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Innovative Framework to manage New Product Development (NPD) Integrating Additive Manufacturing (AM) and Agile Management

Júlia Fornaziero de Almeida[a]*, Daniel Capaldo Amaral[a], Reginaldo Teixeira Coelho[a]

[a]*Department of Production Engineering, São Carlos School of Engineering, University of São Paulo, Av. Trabalhador São-Carlense, 400 – Parque Arnold Schimidt, São Carlos, 13566-590, Brazil*

* Corresponding author. *E-mail address:* julia.forna.al@hotmail.com; julia.f.almeida@usp.com

Abstract

The global competition requires from industries New Product Developments (NPD) with innovation, speed and flexibility, which has to be tightly connected with new manufacturing technologies, in order to achieve success and constant growth. Additive Manufacturing (AM) is an emerging technology from Industry 4.0 capable to address such challenges. It provides better and functional product development, promptly allowing running tests and reducing time to market, promoting agility, as a whole. Parallel evolution is in course regarding the theory of Agile Project Management (APM) applied to NPD, especially when conducting development of innovative products and technologies. However, to achieve the whole benefits with such new approaches towards the NPD process, it is necessary to study and understand how to combine AM and APM for improve NPD. The present research proposes an innovative framework to manage NPD with AM, incorporating APM envisioning innovative products, customer involvement and successfully obtaining a final product faster than conventional routes. The proposal is based on a rigorous Systematic Literature Review (SLR) method, which identified the most appropriate practices to be combined to promote a NPD with agility and flexibility when using AM. All concepts and practices were analyzed and systematically organized, generating the proposed framework. The result can be a reference model to companies conjointly adopt AM and APM.

Keywords: New Product Development; Additive Manufacturing; Agile Management; Functional Prototypes; Framework.

1. Introduction

One of the main driving forces of global-economy growth today is correlated with new product development (NPD), which requires innovative ideas, demands for new technologies and is at the core of success in most large manufacturing industries nowadays. Companies need a steady development of new and innovative products in order to keep their competitiveness in today global market, with all concepts brought about with Industry 4.0 (I4.0). NPD is an expensive and time-consuming process, usually performed with marginally involvement of customers. Such scenario can be changed incorporating Additive Manufacturing (AM) and Agile Project Management (APM) in a rather advanced concept applied to NPD.

AM is one of the nine pillars of I4.0 [1, 2] and has been widely exploited by industries. AM has a great potential to reduce the time required to produce prototypes, besides allowing the production of customized parts in low batches reducing production costs.

During the NPD process, prototypes can be produced by AM and tested to validate some of its features and visualize

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some aspects besides those in the virtual computer added design (CAD). That association can reduce time to market, errors in production, and promote collaboration and dynamism to the product development team [3, 4]. Additionally, AM can provide functional prototypes, which can be effectively used in normal service [5]. Although the process of NPD has also a high potential for AM applications, Fontana et al. [4] has identified a lack of studies to promote AM for NPD and studies combining AM and agile product management (APM) for new products [6].

APM was developed to conduct projects with high level of uncertainty in an inventive environment, where the activities are not developed in a straight forward way, but with a series of iterations, constantly improving the original idea along the way [7].

The present work proposes an innovative framework combining, AM process and APM, aiming at improvements for NPD management creating new possibilities of customer interactions during the product development and keeping a Backlog to register the whole process. A systematic literature review (SLR) was performed to lay down the foundations for the proposed framework.

2. New Product Development (NPD) Process

Product development comprehends an extensive set of activities through which a product specification and its production processes are defined. It is crucial, since new products are constantly demanded to stay competitive and still suitable for customer demands, at global level [8]. Such development process relies on management practices [8] and it can be improved delivering the product faster, with better qualities and according to customer satisfaction.

Amaral and Rozenfeld [9] integrate the best practices for NPD in a unified and comprehensive vision, based on an initial proposal of Florén et al. [10] and Oh, Lee, and Yang [11]. Despite of the success of that model, new technologies and tendencies are requiring agility, changing the way products are developed. Conforto et al. [12] and Cooper [13] found that tendency by means of theoretical studies and, then, proposed new models for product development incorporating new suggestions [14]. Edwards et al. [15] applied those models for small and median enterprises (SMEs), and, more recently, new publications, such as Conforto and Amaral [16] and Lichtenthaler [17] used them incorporating technological innovation, as well. Therefore, NPD is a field always moving towards improvements incorporating new ideas and concepts, as with the present proposal.

3. Additive Manufacturing (AM)

AM is “a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies” [18]. It is a revolutionizing and disruptive way to manufacture any 3D complex parts directly from a CAD software and also capable of creating new business [19]. AM technology can be classified into seven groups: Binder jetting; Directed energy deposition (DED); Material extrusion; Material jetting; Powder-bed fusion (PBF); Sheet lamination; and Vat photopolymerization [20]. Many industries are heavily investing in AM for metals [21], being the PBF and DED the most explored technologies [22, 23].

Some advantages of AM can be: reduction of wastes and number of manual operations; mass customization, responding quickly to new business opportunities; production on site, facilitating logistics management, presenting flexibility and potential drop in production costs, significantly reducing time-to-market [24]. It can also be used for manufacturing many types of prototypes during the development process, allowing the test and final definition of product performance. Design decisions, such as proportion, ergonomic, functions, as well as, patterns and models can be readily and easily decided using functional prototypes produced by AM [3].

4. Agile Project Management (APM)

The APM approach emerged as a complement to traditional project management, emerging from the need to update and improve the project management process, making it flexible and iterative. It also aims at obtaining the best performance and results, with less efforts, when working with innovations, adding value to the product in the view of customers [7]. The main difference between APM and traditional approaches are: a self-management team and a broad vision of the whole process. It includes iterations with customer involvement during the product development process [7]. To be efficient, agile teams must apply the simplest and leanest practices during the development of the project.

To build a record of all experiences, the concept of Backlog is proposed, which might serve as a consulting source referring to the whole developed work [25]. According to Leffingwell [25], the Backlog is the only definitive source of information for the team. It includes all experiences and stories, which are managed and logged according to the needs of the team during product development. The Backlog is a “to-do” list, containing a set of stories experienced in order to launch a specific product [25].

A new understanding of NPD is needed and the use of agile management will be demanded for AM applications, according to Jiang et al. [26]. However, it was not found any research on how to integrate AM and APM. For example, with the benefits of AM the time to market physical products can be reduced using functional prototypes. Nevertheless, it is necessary to orient the product design teams on how to incorporate customer validation cycles, using prototypes and customer involvement. The iterative practices, from APM theory, could be used to bring together all feedbacks from customers. Therefore, a way to associate APM and AM processes, applying them to NPD, would be to further understand those two concepts and propose a framework to help management with NPD.

Based on emerging needs coming with I4.0, this study proposes an innovative framework to manage NPD. The framework addresses NPD using AM and incorporating APM concepts. The idea of a Backlog is also involved to keep record of the whole process with customer involvement. The whole proposal is based on a rigorous Systematic Literature Review (SLR) method used to identify the most appropriate practices to be combined promoting agility and flexibility when using AM. All concepts and practices were analyzed and systematically organized, generating the proposed framework.

5. Systematic Literature Review (SLR)

A SLR was performed to obtain the best ideas correlating NPD, AM and APM. A SLR allows researchers to find, in a systematic way, published material to support a proposed idea. Basically, a SLR consists of selecting published works covering the main databases and following the sequential three steps: Input, Processing and Output [27]. To perform the search, the roadmap for SLR proposed by Conforto et al. [27] was followed with the assistance of the a free systematic review software, called StArt™, developed by *Laboratório de Pesquisa em Engenharia de Software* (LaPES) from *Universidade Federal de São Carlos* (UFSCar). Such software helps to organize a large set of publications extracted from any database.

Basically, the SLR software searches for links between a selected set of strings, which are submitted to the database (Scopus). The data from Scopus is exported to BIBTEXT format and transferred to StArt™ tool. Then, the papers were submitted to 3 filters applied by the authors: F1, select papers based on title, abstract and keywords, F2, selects based on introduction and conclusions and F3, selects for reading the full paper.

Considering the complexity of finding relationships including NPD, AM and APM, it was decided to perform 4 consecutive SLR searches integrating all subjects, i.e., AM, Agile, Backlog, Prototypes, Rapid Tooling and Functional Prototypes.

After each SLR, the papers were studied and new research strings were identified to guide the next SLR. Fig. 1 shows a schematic of the whole SLR performed.

6. Results and Discussion

From the 1st SLR, 3 papers were studied [3, 4, 6], 3 after the 2nd SLR [28, 29, 30], 3 after the 3rd SLR [31, 32, 33], and 2 after the 4th SLR [34, 35]. The study of those publications provided the backbone to structure the proposed framework.

6.1. 1st SLR: Additive Manufacturing AND Agile

Schuh et al. [3] analyzed 7 individual applications for AM in I4.0, evaluating the maturity and potential application for each one. The use of AM for manufacturing prototypes represents a high level of maturity and reveals a potential application for the technology. Therefore, the investment and deployment of AM is recommended. Applying AM to manufacture prototypes are mature enough to be adopted by the industry presenting high potential applications.

Barbosa and Saisse [36] explore the use of AM for production of spare parts employing agile management principles. It is evidenced by the author that AM has the potential to reduce inventory and to manufacture parts on demand. The combination of AM with agile management helps designers to speed up manufacturing and reduce development time in an iterative way.

The research performed by Fontana et al. [4] identified seven elemental domains within a value chain, were AM could bring benefits for companies and their customers, such as: prototyping; enhanced designs; incremental product launch; customized products; improved delivery; tooling production and process concentration. The authors highlighted three major implications of AM in NPD, according to interviewees: transformation of team dynamics, from a plan-drive set-up to a more agile-driven approach; the reduction of uncertainty, flaws and errors in the final production process, due the possibility to test the prototypes and improve them, as well as the feeling of speeding up the project development.

6.2. 2nd SLR: Agile AND Backlog

The 2nd SLR found studies dealing with the best practices to develop the Backlog, which helps to manage NPD in a simple and faster way. The study made by Sedano et al. [30] states that the Backlog is “an informal model of work to be done (and not a requirement specification)”. The same work identified 13 practices, being the most important for NPD is the dual track. It means splitting the work for groups continuously working in parallel, “like train tracks” [30]. Track 1 involves product designers and Track 2 engineers. Track 1 fills up the product Backlog (creates the stories), and Track 2 empties it (implement the stories) [30].

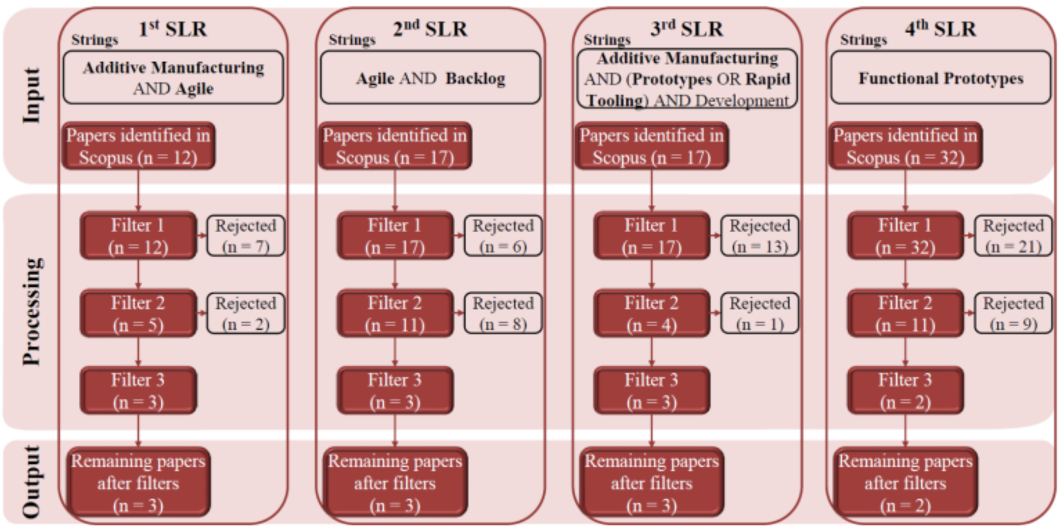

Fig. 1. Schematic followed by the SLR.

The Backlog can express and record all thoughts, helping to create a broader picture to work with, and also guide engineers towards ordering tasks to be performed [30]. Once the Backlog is set, it is constantly modified during the development of the product. Alsalemi and Yeoh [28], for example, identify 11 reasons to modify the Backlog: defect fixing missing; missing requirements; functionality enhancement; product strategy; design improvement; scope reduction; redundant functionality; obsolete functionality; erroneous requirements; resolving conflicts; and clarifying requirements.

Depending on the project, the size of the Backlog can be managed informally (e.g. "stickies" on the wall) for small projects or with a tool to manage a Backlog for long-time projects. The structure of the Backlog needs to integrate all details, allowing the users to see the whole project up to the details they are specifically interested in [29].

6.3. 3rd SLR: Additive Manufacturing AND Prototypes OR Rapid Tooling AND Development

Studying the 3 papers, it was possible to see that with the advances in AM technologies, manufacturing of functional parts using a wide range of materials, such metals and ceramics, expands its applications in industries [31]. The use of AM for prototypes to NPD can save time and costs to produce, as expected. Time required to design and validate the product is reduced and most features can be improved [31]. Studies, such as those performed by Collins et al. [32] and Nambi and Herbert [33] shows rapid prototypes successfully applied.

6.4. 4th SLR: Functional Prototypes

In usual NPD process, the customer is involved only in the first stage of development and at the end to receive the product. Ideally, customer must be involved at every stage of the process. Such involvement is often neglected because the data usually is in the form of highly technical documents, most of them difficult to understand. The use of functional prototypes, however, can mitigate such problem and promote more involvement. That kind of prototype exhibits a high level of realism with all product characteristics, so the customer can visualize and even test the prototype, given feedbacks to improve the product during development [35].

According to Campbell et al. [35] receiving feedbacks during development increases the chances of success. The authors proposed a method to promote the customer involvement in NPD using functional prototypes. After a first product design specification, a functional prototype is presented to the customer. With feedbacks, the product is upgraded and new prototype constructed for further customer evaluation. Such cycle repeats itself to achieve customer approval and subsequent manufacture and delivery to the market [35]. The prototypes will change from one phase to another until become a fully functional representation of the final product [35]. Booysen et al. [34] shows, in a case study, how functional prototypes can promote design iterations involving the customer into the NPD process.

7. Proposed Framework to manage NPD integrating AM and Agile Concepts

Barbosa and Saisse [36], from the 1st SLR identified applications of agile concepts introducing AM. This would allow improving the speed of NPD, reducing uncertainties and reducing costs, as in the 3rd SLR. Schuh et al. [3] also finds that AM technologies are mature enough to be used for prototypes and reliable for NPD. In contrast, Fontana et al. [4] finds necessary to modify the dynamics in the NPD team, and no work has been found that indicates how to implement such modification.

The SLR on Backlog provided a pathway. The Backlog is the team reference source incorporating customer involvement through prototypes. Therefore, a way to establish a new agile team dynamics would be the integration of Backlog and AM for prototypes, creating a cycle of design-built-test involving customers.

Following these considerations, practices and procedures found by the SLR searches, the framework shown Fig. 2 is proposed. It is based on the reference model for NPD [9], encompasses the Backlog, the iteration pattern presented by Leffingwell [25] and practices identified in the literature, such as, the dual track [30].

The framework contains 3 main stages: Pre-development, Development and Post-development [9]. Each stage contains specifically defined activities combined with new concepts of AM and APM.

7.1. Pre-Development Stage

This stage must lay down the direction, vision of the whole development process, integrating the idea of all customer

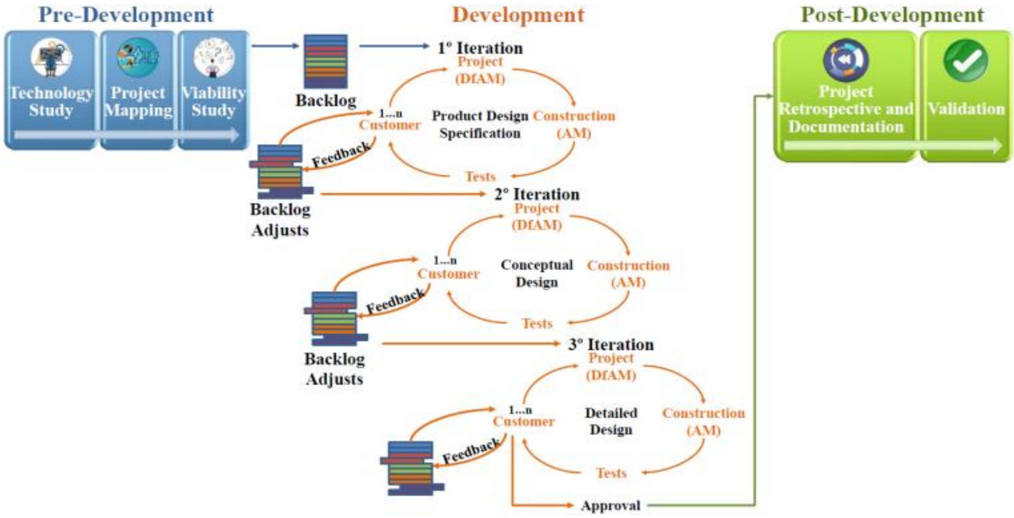

Fig. 2. Proposed framework to manage NPD integrating AM and APM.

involved with the NPD using AM. The stage must systematically map opportunities and restriction, to create the Backlog for the whole product development process [8]. The activities in this stage are performed by Track 1 [30]. The techniques of Market Research [37], user involvement [38], business modeling (Business Canvas, etc.) and innovation would be useful to generate the project vision.

The Technology Study assess which knowledge is needed to develop the product, incorporating environmental and ecological aspects too. It can help designers to see what possibilities are offered by AM. Some activities, such as attending workshops and congresses, as well as benchmarking, can provide knowledge to a successful application. These studies would result in new items for the Backlog and the vision will improve.

A Project Mapping will map the process and may create a first sketch, allowing an overview and a first economic viability study.

A Viability Study must analyze and support the choice of AM technology. According to Bland and Conner [39] several aspects must be accounted for, such as, product complexity. Traditional process could take too long or be technologically unviable to produce complex parts. The customization level and production volume (number of parts) must be accounted too. The next step is to perform a cost analysis of the process including all costs and development of the first CAD model. Tracks 1 and 2 [30] should work together at this stage to evaluate the viability of the project. If approved, the product is structured and the Backlog created.

7.2. Development Stage

At this stage, a functional prototype can be fabricated using AM and iterations with the customer starts to improve product details. Track 2 assumes this part of development by fulfilling the tasks of the Backlog. This part of the framework includes 3 phases developed in an iterative way (see Fig. 2). According to Campbell et al. [35], they are: Product Design Specification; Conceptual Design; and Detailed Design.

Within each phase, there are 4 steps (Fig. 2): Design for AM (DfAM), Construction, Tests and Customer. Design the prototype using DfAM concepts with a CAD model. Then, the part is constructed using AM and tested. A functional prototype is obtained with the real product characteristics. This prototype is then sent to the customer to evaluate and, if necessary, test in real applications.

During that process, customer feedbacks are collected and Backlog filled [28]. Backlog updates mark the end of each iteration. New prototypes are built incorporating Backlog activities until the final product is obtained. Iteration cycles are repeated at least twice, as suggested by Campbell et al. [35].

7.3. Post-Development Stage

In the last stage, the project is documented and the product validated. At the Project Retrospective and Documentation both Tracks creates together a document reviewing all decisions made and all lessons learned. This kind of documentation will share all knowledge in an explicit way certainly improving future product developments. That characterizes a “knowledge-creating” company, whose business is continually innovated [40]. The Validation is the last step in this stage and represents the end of the NPD process, obtaining the desired product with all requirements.

All the framework activities must flow seamlessly, and the team in charge must be fully engaged. Only in such way the NPD can be successfully achieved with results faster than any traditional route, using AM and APM.

8. Conclusion

The present work proposes an innovative framework to manage the NPD using AM and APM. A thoroughly SLR was performed and identified the backbone to support the proposed framework. The proposed framework contains three stages: Pre-development, Development and Post-development. All activities to be performed inside each stage are described to guide a team throughout the whole process. The framework also incorporates the concept of dual tracks. Track 1 studies and designs the product and Track 2 develops and builds the product. There must be iterations with customers, in which functional prototypes are built during the Development stage. Iterations promote costumer involvement, allowing the specification refinement through the feedback provided by the customer. The concept of Backlog is also introduced to keep records of all activities and iterations. With the combination of all those aspects and new concepts, it is expected a significant increase in the chances of product success in a faster way.

The proposed framework presents an innovative structure. It specifically intends to assist managers and researchers to development new products with AM technologies using agile approaches in metal working industries. It may be capable of delivering results faster to the market and closer to customer needs. In the near future, the framework will be applied in an industry manufacturing farming equipment. The feedbacks will be used to improve the framework and find out its limitations.

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