Lean product development and agile project management in the construction industry

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Abstract

Purpose – In recent years, innovative methodologies of product development such as lean product development (LPD) and agile project management (APM) have emerged. Even though previous research studies focused on these subjects, only few of them were focused on traditional industries, as civil construction. The purpose of this paper is to cover a part of this gap by estimating the potential of the application of these two new approaches (LPD and APM) in the construction industry, more specifically on the design stage.
Design/methodology/approach – For this, a case study has been conducted in order to understand if some of LPD and APM tools and practices had already been used, and also to evaluate the potential application of these new methodologies. Three Brazilian companies have been evaluated, all of them were exclusive executors of the design stage and presented distinct characteristics (size, structure, business model, etc.).
Findings – The results show that there is currently little adherence to LPD and APM practices within the companies studied. In terms of potential application of these new methodologies, the study has identified evidence regarding technical similarities between the reported cases and others mentioned in literature. However, the interviewees' reception of these concepts was mostly pessimistic, showing considerable resistance to changes in the current process.
Originality/value – According to the analysis, the study identified that the main challenge/hampering to the implementation of these tools in the cases studied herein are the functional organizational structures, the customer–supplier relationships and the internal cultural resistance to change.

Keywords Construction industry, Design management, Agile project management, Lean product development

Paper type Case study

Introduction

The organizations are constantly under pressure to increase agility and efficiency in product development. Facing this scenario, researchers and professionals started to reinvent the current methods, arguing that existing methodologies were not always aligned with new challenges (Serrador & Pinto, 2015). In this context, several techniques, methodologies and alternative philosophies appeared, two of the most famous are lean product development (LPD) and agile project management (APM) (Salgado & Dekkers, 2018; Serrador & Pinto, 2015).

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These methodologies originally came from companies connected to Information and Communication Technology and the automotive industry (Salgado & Dekkers, 2018). Despite new features regarding the subject, is it possible to question if these new methods of product development could be applied in traditional industries, such as civil construction, especially during its design stage.

Several studies analyzed the applications of both methodologies (LPD and APM) in different industries and segments, such as automotive, software development, and even in traditional industries of mass production (Serrador & Pinto, 2015). However, few of these analyses were specifically focused on the construction industry (El. Reifi & Emmitt, 2013; Owen, Koskela, Henrich, & Codinhoto, 2006). Furthermore, these studies were held in different countries and may carry the singularities of these markets.

The aim of this research is to study the potential application of the LPD and APM approaches in the product development of the construction industry. The potential application of LPD and APM concepts was investigated not only in the technical dimension but also in the social dimension of the studied phenomenon. The technical dimension is discussed in the research based on the similarity presented by some situations found in the companies investigated, comparing them with situations and cases in literature already solved with the proposed approach. The social dimension is approached in the identification of the context in which similar problems are found, promoting interviews with managers in order to investigate the current problem solving strategies, degree of knowledge, the agents' perception on the alternative approach and interaction with internal (other employees) and external agents (customers and suppliers).

Therefore, this paper focuses on the design stage of the construction project, because it is the most similar one to product development process (Owen *et al.*, 2006). The results will enable the establishment of a clearer scenario of some Brazilian companies, and will aim to identify the main factors that influence the potential application of LPD and APM tools and techniques in the current design processes in the civil construction industry.

Bibliographic review

Lean product development (LPD)

The lean concept emerged in manufacture as a multidimensional approach that comprised a variety of management practices, such as just in time, quality systems, production cell, etc. (Shah & Ward, 2003). Although lean is a wide concept, it is based on five principles: value, value stream, flow, pull and perfection (Womack & Jones, 1997).

After the success of lean's application in the manufacture stage, companies started to realize that the new productive obstacle became the development of new products (Marodin, Frank, Tortorella, & Netland, 2018). At that moment, there were many attempts to apply the same lean principles to these development stages, the result was the LPD (Salgado & Dekkers, 2018).

In the same way lean concept reached a huge range of practices, LPD also became vague at times, with many practices and principles associated with it (Wang, Conboy, & Cawley, 2012). Thus, many previous studies spent considerable effort in trying to consolidate a list for the LPD description. The Lermen, Echeyeste, Peralta, Sonego, & Marcon (2018) study compiled a list of more than 40 practices and tools that literature associates to LPD. Dal Forno and Forcellini (2012) pointed out, after a bibliometric analysis over the theme, 15 practices and principles also associated to LPD, while Salgado and Dekkers (2018) consolidated a list with more than 18 LPD principles, after a systematic review of literature. In face of several options, mainly for simplification, LPD principles will be considered herein as:

- Value stream mapping: mapping of the main interactions (internal and external) involved inside a process, seeking to separate value-adding activities, required non-value-adding activities, and non-value-adding activities (the latter must be fully

eliminated) (Hines & Rich, 1997). This principle, in which the goal is the elimination of waste, is in the lean's foundation, according to the original model proposed by Womack and Jones (1997).

- Set-based concurrent engineering (SBCE): it is a concept originated from manufacture that was highlighted in literature mainly after the publication of Ward, Liker, Cristiano, and Sobek's (1995) article, in which the model of Toyota's SBCE (Salgado & Dekkers, 2018) was presented. SBCE consists of the intentional effect of defining, discussing and exploring a series of possible sub-optimal solutions, instead of trying to modify and adapt one single solution (Ward, Liker, Cristiano, and Sobek, 1995). It is in this vision that multiple tests are encouraged, through creation and development of various prototypes (Ward, Oosterwal, & Sobek, 2018). It is vital that these alternative solutions converge and be tested with the final product, seeking to minimize errors in the production stage (Schäfer & Sorensen, 2010). Still, as focal point of this technique, there is a head engineer (called *shusa*, inspired by Toyota's head engineers who are responsible for the whole project including during its use), who is responsible for the general technical validations and correct allocation of resources and people within the project (Ward *et al.*, 1995). Finally, to ensure a better use at this stage, it is important that records of lessons learned are checked and updated. These records are essential to reuse the knowledge already developed in other projects, besides limiting the creativity within practical periods (Takeuchi & Nonaka, 2009; Ward *et al.*, 1995).
- Visual management: it is the concept of using visual tools to facilitate the team's communication on topics such as project scope, visible problems, quality, time and cost indicators (Pinheiro & Toledo, 2016). These visual tools have many goals, such as representing data and assumptions (always updated), communicating the limits for the creativity of those involved, facilitating the development of relationships among several variables, etc. Visual management is a powerful technique that tends to rationalize resources by reusing knowledge and preventing errors. In addition, an efficient visual management can speed up the development process through optimizations, elimination of "dead ends," decrease of iterations and effective communication between departments (Ward *et al.*, 2018).
- Voice of the customer: the customer involvement, especially during the product development stage, is a key factor to assure the design quality (Kpamma, Adjei-Kumi, Ayarkwa, & Adinyira, 2018). This contribution becomes more valuable in the early stages of development, when it is possible to influence variables such as cost and lead time effectively (Cristiano, Liker, & White, 2000).

It is important to point out that this study did not seek a universal and absolute image of the main LPD practices. Its objective was only to investigate and present important foundations provided by literature, comparing them with the reality of the companies studied herein.

Agile project management (APM)

Another applicable approach to the development of new products is the APM. Agile methodologies are mostly based on the Manifesto for Agile Software Development (Beck *et al.*, 2001) and underpin the belief that initial plans are not effective and that an evolutionary iterative process is more efficient (Dybå & Dingsøyr, 2008). APM differs from traditional projects and products management (known as waterfall model) by emphasizing continuous design, flexible scope, living with uncertainty, and the constant customer interaction, as well as modifications in the project team's structure (Serrador & Pinto, 2015).

APM emerged in the software industry (MacCormack, Verganti, & Iansiti, 2001), however, its application might be extended to other industries in need of more flexible methodologies (Conforto, Salum, Amaral, Da Silva, & De Almeida, 2014). Serrador and Pinto (2015) empirically proved that APM application has significant influence on project success, concerning efficiency, stakeholder's satisfaction, and the perception on the performance of the project in general. Nevertheless, the same study shows that this correlation appeared only in innovative industries. In more traditional sectors (construction, manufacturing and retail), it was not possible to find the same statistical correlation.

Similarly, LPD, APM is also a wide concept, with several associated practices (Wang *et al.*, 2012). Below, we selected some APM principles found in literature on the subject:

- Flexible and constant planning: the struggle to keep the original course of a plan is perceived since the 1950s (Serrador & Pinto, 2015), especially in projects with uncertain goals, open scope, several alternative solutions and high stakeholder involvement (Carvalho & Rabechini, 2011). From this dynamic context, planning loses its rigidity and must be constantly reviewed as the project evolves (Shenhar & Dvir, 2007). APM proposes to face this challenge through constant redesign focused on short-term and periodical reviews. This way, the plan becomes more mature as the objectives are defined (Schwaber, 2004).
- Iterative development: while the traditional project management is based on clear scope definitions, APM develops the scope definition through iterative development (Fernandez & Fernandez, 2008). In general, these iterations occur through continuous and partial deliveries/validation (Schwaber, 2004) and also enable a cycle of continuous growth and customer feedback (Dybå, Dingsøyr & Moe, 2014).
- Self-directed teams: self-directed teams are responsible for managing and monitoring their own process and tasks to be executed (Dybå *et al.*, 2014). These groups need to work as independent cells, which demands that the members are multidisciplinary. In order to maximize results, these teams should be physically located in the same place (Chen, Damanpour & Reilly, 2010).

It is important to point out that this study did not seek a universal and absolute image of the main APM practices. Its objective was only to investigate and present important foundations provided by literature, comparing them with the reality of the companies studied herein.

Product development in construction: the design stage

Civil construction is one of the most traditional sectors of the economy, mostly due to its longevity, universality and management models focused on predictability and risk reduction. Also, its operations are highly project oriented (Cooke-Davies & Arzymanow, 2003), which are mostly complex and involve several stakeholders (Toor & Ogunlana, 2010). However, this sector rarely applies new technologies or develops innovative products, being most common the development of traditional and typical deliverables (Shenhar & Dvir, 2007).

Usually, a construction project is divided in three main stages: design, construction and operation (Arditi & Gunaydin, 1997). However, it is possible to find more subdivisions on the design stage, as proposed by the Royal Institute of British Architects (2013). The design stage is divided as: strategic definition, preparation and briefing, concept design, developed design and technical design.

Design is a complex stage accomplished by several agents, who are often in more than one organization or department (Tjell & Bosch-Sijtsema, 2015). It is at this stage that several actors (multifunctional teams composed of architects and engineers from different areas) are pushed to discuss and propose technical solutions for design and to describe

the future enterprise to be defined (Chun & Cho, 2018). Due to this initial purpose, which defines the scope of future and more expensive stages (construction and operation), the design phase becomes one of the most important and impacting steps for the development of a construction project (Arditi & Gunaydin, 1997). The impact of this stage is not only due to the final costs of the project as a whole, but also to its final quality (Emmitt, 2006).

However, even with all the relevance, it is common to find problems and waste during the design stage. One of the greatest difficulties is that all this range of multidisciplinary professionals involved in the process as a whole has a limited capacity for rational decision making (Chun & Cho, 2018). This occurs for several reasons, from traditional conflicts between executors and designers (based on negative and strong stereotypes) (Loosemore & Tan, 2000) to several hidden agendas and power games involving many agents (Lohne, Svalestuen, Knotten, Drevland & Lædre, 2017).

Another common drawback is the poor communication and mismanagement of wants and needs of clients and customers during this stage (El. Reifi, Emmitt & Ruikar, 2014). Not only costumers but also the designers have difficulty in designing, communicating and agreeing to the desired and needed specifications within a new venture (Chun & Cho, 2018). It is quite common for the client to have many hopes and expectations in the beginning of the construction project. This, combined with frequent haste to initiate the project, leads to several changes in scope and rework during the entire project duration (El. Reifi & Emmitt, 2013). Moreover, only accomplishing the expected specifications does not guarantee clients' satisfaction, which have a desire for the final project to exceed their expectations. These hopes can be hard to achieve since some of them might be implicit or were poorly communicated during the design stage (Wood, Wang, Abdul-Rahman, & Abdul-Nasir, 2016).

Furthermore, another difficulty mentioned is the mismanagement of the design stage. This downside might be connected to the common mistake of project managers in not considering the differentiation between design stage and construction, which leads to the replication of the same traditional methods for both stages (Knotten, Svalestuen, Hansen & Lædre, 2015). This is inefficient since design stage has differential characteristics, mostly because the problems from design stage cannot be simply defined, and by that, do not provide one single simple solution (Lawson, 2006). During design (especially in the initial stage of this phase) the processes are creative, iterative and innovative. This characteristic adds complexity to the management activities, since it almost makes it impossible to sequentially plan them, for not knowing exactly what the necessary tasks are and much less what is the sequential relation between them (Knotten *et al.*, 2015). This singularity moves the design away from the hard paradigm (connected to severity, clear goals and efficiency), which is a lot more applicable in the construction stage (and consequently embedded in the mindset of the project's participants), and brings it closer to the soft paradigm, which favors knowledge, participation and facilitates the analysis of projects (Pollack, 2007). This paradigm differentiation must be reflected in the project management system applied (Pollack, 2007) since a more comprehensive and suitable methodology to the reality of the projects is one of the key factors for the success of its execution (Joslin & Müller, 2015).

However, despite the perspective presented, some studies have already shown a tendency of the design management toward the soft paradigm. Owen *et al.* (2006) showed that the design stage has a great receptivity to the principles of APM due to its characteristics of uncertainty and need for collaboration. El. Reifi and Emmitt (2013) also demonstrated, in a survey of British designers, that 15 percent of the interviewers stated using lean approaches, such as initial agreement with all stakeholders, value mapping, progressive description and employee training in lean concepts.

Methodology

As the analysis of this phenomenon contains a strong influence of its context (participants, stakeholders, clients, etc.), many times it is hard (almost impossible) to separate the phenomenon from the context. Therefore, this paper opted to conduct a case study, as suggested by Yin (2014). Multiple case studies are used to avoid finding singularities instead of real representatives of the majority of the organizations (Miguel & Sousa, 2018).

In order to choose the cases, we chose some examples that displayed certain characteristics, in order to increase the representativeness of the selected sample (Eisenhardt, 1989; Miguel & Sousa, 2018). Consequently, three companies from the field of civil engineering projects were selected, with the following characteristics.

Case 1 (C1): small family business (under 20 employees), not located in an important economic center, and specialized in structural design of reinforced concrete (a specific stage of the design process). This is a subcontracting company and develops only the structural design, not being involved in the rest of the design process. Its clients are always other companies (often freelancer architects and small contractors) and its projects are less complex (residential houses and small apartments).

Case 2 (C2): multinational public company, medium-sized (more than 200 employees in Brazil), located in the City of São Paulo and operates in the design of urban infrastructure. Most of its clients are government offices (concessionaires, city halls and state government) and all stages and design specializations (structural, hydraulic, geotechnical, etc.) are made by its own employees, allocated in specialized departments. These specialized departments were, until a few years ago, independent companies, recently merged. Its projects present high complexity characteristics, both technical and political (high involvement of internal and external stakeholders, direct impact on society, etc.).

Case 3 (C3): national private company, medium-sized (around 60 employees), located in the City of São Paulo. It is involved with the development of great infrastructure projects and its clients are, mostly, private companies. It is responsible for all stages and design specialties. However, the company does not execute any of those disciplines. All of these specialties are subcontracted to specialized designers, which execute the design elaboration. Thus, the studied company only conducts the management of the subcontractors (deadlines, costs, contracts, etc.), technical validation of deliveries and compatibility of final products. Due to this operation typology, the teams are basically formed by highly specialized experts (for the designs validation) and project managers. Its projects also present high complexity characteristics, both technical and political (high involvement of internal and external stakeholders, direct impact on society, etc.).

The cases were selected by heterogeneity parameters, such as size, source, location, final product, type of customer, implementation methodology (in-house or outsourced). This selection was purposeful, because with a diffuse sample it is expected to find opposite results, and possibly, identify propositions for cause-effect relationships (Miguel & Sousa, 2018).

In order to standardize the data collection, semi-structured interviews were conducted with employees directly involved with design management. In all three cases more than one interview was held in order to achieve data triangulation, assuring a higher reliability (Yin, 2014). Thus, two people were interviewed in C1 (the owner and one of the engineers), four people in C2 (a manager and three coordinators) and four people in C3 (a manager and three coordinators). The interviews were analyzed based on narrative patterns among the interviewees.

The themes of the interviews were approached in the following order:

(1) Understanding of the actual process for product development during the design stage. In this stage, we tackled a predefined series of questions, selected with the intention of understanding the current processes of the companies studied. This initial comprehension sought to identify the problem in each organization and its

similarity with the main elements for solution proposed by LPD and APM. These topics related to the problems and their resulting practices are presented in Table I.

(2) After the full presentation of the current process (in other words, when all the questions from Board 1 were answered), interviewees were asked about their current knowledge over the LPD and APM topics and the main practices of these methodologies.

(3) Next, after the interviewees finished answering and presenting their previous knowledge about these methodologies, the features of LPD and APM were briefly shown. This stage enabled a basic leveling of knowledge that enabled a better use of the following questions in the script.

(4) After the interviewees absorbed the definitions of these practices, we asked if any of these concepts would be applicable in the organizational context they were inserted to. Moreover, we asked the interviewees to list the expected challenges involved in the implementation of these new practices.

Besides the conduction of interviews, observations of the execution processes were collected, seeking examples of the studied subjects (both from APM and LPD). These observations were also important as a source of complementary data to the interviews, in order to increase the strength of the conclusions (Yin, 2014).

Potential limitations of this approach were some possible methodological bias and the sample size. In terms of methodological bias, it is possible that the interviewees were not completely honest in their statements, avoiding extreme answers or transmitting a negative company image (Sinkovics, Penz & Ghauri, 2008). In order to minimize this limitation, the observations collected were important to check the affirmations made during the interviews, as suggested by Yin (2014). Considering the sample size (three cases), it is slightly below the amount of four to ten cases suggested by Eisenhardt (1989), which indicates a potential limiting factor of the generalization in the conclusions reached. However, a smaller sample enabled a deeper analysis, achieving a better understanding of the organizational context and development processes of each case (Miguel & Sousa, 2018).

Results

After the interviews, the collected answers and observations were aggregated around the elaborated questions on Table I and analyzed seeking to find patterns (Yin, 2014). The summary of this consolidation can be found in Table AI.

Questions	LPD/APD associate practices
How are the activities of the design stage planned and controlled?	Value stream mapping; visual management; voice of customer; flexible and constant planning
How are definitions and technical decisions made during the design process?	Value stream mapping; SBCE; visual management; iteration development
How is the client involved during the process?	Voice of the customer
How does the development process flow between the teams and the employees? (Focus on authorities and responsibilities)	Self-directed teams
How does the progress of the projects is reported to the in-house team and to the clients?	Visual management
Was the current process reviewed in the past? Is there a plan for any change in the future?	Value stream mapping

Table I. Questions for the interviews and its correspondent associate practices of LPD and APM

After data consolidation, it is possible to identify that C1 presented itself in a distinctive level comparing to other cases. The development process in C1 was rather rudimentary, lightly structured and overly simple. This probably occurs because of the context of the organization and the different markets if what should contribute to a more modest management, especially if compared to C2 and C3. In C2, we found a highly functional structure inside its sub-departments, which may be a result of the recent merger of this very company. This merger process ended up being carried in a sudden way and failed to create a spirit of unit inside the organization. This led to a visible fragmentation, many times giving the impression that it is not a unified company, but a series of companies coalesced in a forced manner. C3 showed a softer structure, a lot due to its dynamic operation focused on subcontracts and costumer pressure (such customers are, in general, large private companies).

The adhesion of each one of the cases to the elements of analysis is summarized in Table AII. In this board, it is possible to find a summary of what should be found in an adhering situation (according to literature) and what was seen in the interviews and in the observation field. In this way, it is possible to conclude that the adherence of the studied cases, in both LPD and APM, is usually very low. However, the technical context found in the study did not present any barriers for the implementation of both APM and LPD.

In fact, regarding the potential application of LPD elements, there was a technical similarity among the studied situation, however, there was a low social adhesion in the cases studied. Value stream mapping was subtly identified in C3, in which the development process was recently adjusted in order to include the clients and also the future executors. None of the interviewees had any kind of process mapping formalized, much less affirmed to get into a habit of rethinking the current development process, even though there is no obstacle to implement it. The barriers to its application, according to the interviewees, occur usually because the productive days end up being often filled with day-to-day questions and with the preparation of meetings with clients. Besides, production is almost always "pushed" between departments/subcontractors with no proactivity, causing frequent wastage and waiting time in all three cases.

As for the voice of the customer, C1 has not demonstrated any type of interaction with the customer, who only receives the final project. In this case, as it is about a technical deliverable (structural design), it is common for clients to evaluate the quality of the design solely during its execution. It is only at this stage that problems are perceived, and the correction costs end up being enormous. C2 showed a constant interaction with client's/costumer's technical staff through frequent and lengthy validation meetings, which indicates a costly and time-consuming process. This, according to the interviewees, happens because their clients are, in general, government agencies, and their "work pace is different." Yet, the client sees these meetings as a necessity and as a good sign of quality management. It is important to point out that project executors do not participate in these meetings, and the design is only validated by the agencies' designers. While in C3, despite the client's technical staff validation, it was possible to observe that there was a unique involvement of future executors. Even though they do not participate in all validation meetings, the executors were involved at the end of the final version of the project in order to evaluate it in terms of feasibility and technical validation. That, according to the interviewees, occurred due to the client's request. Knowing that the executors were, in general, subcontracted companies that performed the validation process this way, the contractors became co-responsible (technically and legally) for the design. This leans on reducing contractual disputes during the construction stage, according to the interviewees.

Slight traces of SBCE were found only in C3 because the subcontractors always report to the subject specialist, who needs to approve all the solutions. This refers (in a way) to the specialist seen as the *shusa* (title received by the head engineer in the LPD practice). However, the similarities are still very limited because the process continues to move at its

own traditional pace from this moment on. No type of visual management was found in any of the studied cases; communication was made mainly verbally or by unstructured e-mails. It is important to highlight that the differences or technical limitations that would suppress SBCE application were not found, mainly because C3 showed an embryonic application that can be enhanced. As for visual management, the observations found are not so different from the reality of other companies that applied this practice. Thus, no technical hampering was found to suppress its application.

Regarding the application of APM practices, it was found little adherence. Activity planning, when implemented (C1 did not show any kind of planning), is still made and controlled through traditional methodologies, with its schedules defined in the beginning of the project and controlled with defined frequency. Changes in these schedules are not welcome either by members or subcontractors (in the case of C3) and there is little flexibility to modifications. Constant delays, reported by all cases, might happen due to this excessive rigidity.

In terms of product development, it is accomplished through big deliveries, specifically made at the end of predetermined stages defined in the contract, rarely containing intermediate validations. All technical decisions made must be sized and designed, sometimes even quantified, before being submitted to a necessary validation. This, aside from showing little adherence to APM's iteration development, also shows the lack of LPD's value stream mapping.

In terms of self-directed teams, C1 is the one that showed a higher adherence. In this example, the responsible engineer has total autonomy to make decisions, consulting with the owner only about more complex questions. This does not seem to occur due to an agile mindset, but due to its organizational context, as a result of the lack of more available resources. C2 showed a similar behavior, with every team having total autonomy within their own expertise. Even so, according to the collected observations in the interviews, this characteristic occurs more in function of the strong hierarchical segmentation found in this company than due to a mindset oriented to agility. In case C3, as a result of outsourcing characteristics, subcontractors show little autonomy.

The problems faced after the deliveries were similar in the three cases. Especially in C2 and C3, in which the project execution is usually made by other companies (usually medium/large-sized) there are many contractual disputes motivated by alleged project errors. None of the interviewees considered that these disputes happened due to low quality of the delivered product, affirming that these conflicts occur due to the bad faith of the contractor who seeks to maximize the value of the contract through additional claims.

In addition to the low adherence in the cases found, it was possible to realize that neither LPD nor APM were minimally known to the interviewees. Despite not knowing about LPD, many of them had had previous contact with lean manufacturing applied to construction (also known as lean construction). As for the APM, only C2 and C3 interviewees affirmed that they had previous contact with it through lectures on the subject; however, they did not possess considerable knowledge about the theme. Yet, some affirmed that it was presented to them as if APM practices were applicable only to project management in other fields, such as software development.

After a brief explanation of the foundations of LPD and APM, the perception about the potential application of these tools diverged. In C1, interviewees affirmed that such techniques might be applicable, however, it is very unlikely that current processes will change, because "it is working fine just the way it is." Besides that, the interviewees considered that the company was too small for any change to become significant. In C2, the reception was pretty cold, the interviewees presumed that the applicability would be improbable, because it would bump into a cultural problem both internally and with clients (government agencies). Furthermore, the functional organization structure and the rigidity

of public procurement precluded the execution of these LPD/APM practices. On the other hand, C3 was more receptive; however, the interviewees seemed worried since it would require great efforts for implementation. According to them, the main challenges would be to change employee's culture, especially regarding the senior staff, and the current subcontracting structure would reduce the impact of change in external partners.

Discussion of results

After encounter data analysis, we realized that the potential application of new approaches demonstrated technical similarity with cases in other companies registered in literature, however, the social dimension showed very little adherence of the companies studied to the principles of LPD and APM. These findings are even worse than those of El. Reifi and Emmitt (2013), who looked at UK designers and found reduced but more significant adherence. This raises the possibility of having a certain connection between the company's nationality/market of operation and its maturity concerning LPD and APM concepts.

One of the variables that delivered one of the biggest impacts was the extremely functional organizational structure found in C2. This characteristic showed a huge impact on how the company's strict behavior might be the main reason why C2 showed itself so little supportive to new practices. These findings are in agreement with previous studies, which suggest that project-oriented structures facilitate the application of LPD (Ward *et al.*, 1995) and APM (Conforto *et al.*, 2014).

A contributing factor (within the social dimension) was the company's relationship with its customers and suppliers. In both C2 and C3, we realized that there is a great difficulty concerning the implementation of any non-traditional management measure if there is no conductive environment to receive these changes outside the organization. This factor shows that APM and LPD implementation is hampered when they are not in self-sufficient "islands," being necessary a transformation in the entire value chain involved.

Regarding the influence of the company's size in the studied phenomenon, different behaviors were found within the evaluated cases, with no noticeable type of pattern. The case that stood out in this point was C1, which presented quite different characteristics, due to its simple management system, which might even be considered rudimentary. This simplicity is probably a result of the company's small size.

Another reason that may contribute for the low adherence of LPD and APM in the companies studied is little knowledge of the interviewees on these themes. None of the interviewed had heard about LPD, despite being familiar with lean manufacturing applied to civil construction. This supports Pinheiro and Toledo (2016), which affirmed that LPD does not receive as much attention as lean manufacturing. Regarding the APM, some interviewees showed they had a basic knowledge over the subject through lectures. Despite that, the information given to them is that APM is an exclusive methodology for software development and that it was not applicable to civil construction. This raises the concern that some APM promoters might have an erroneous vision of the methodologies that are being spread to the public. Past studies showed that, although APM is more applicable and shows more results in non-traditional industries such as in information technology (Serrador & Pinto, 2015), its execution is completely possible within more traditional industries (Conforto *et al.*, 2014).

Last but not least, when questioned about the potential application of LPD and APM in their organization context, all the interviewees pointed out strong cultural barriers as the biggest obstacle for implementation. These obstacles are in several levels, both internal (in-house teams) and external to the organization (customers/suppliers). They configure themselves as a huge resistance to change their ecosystem. This is in accordance with the study by Owen *et al.* (2006), which affirmed that in the construction sector, cultural

transformation should be the first step toward a change in management paradigms. This cultural conversion is needed before the implementation of new methodologies in management of construction projects.

Findings and suggestions for future research

In the current market, increasingly demanding faster and integrated solutions, concepts like LPD and APM could gain strength, since they pledge for a dynamic and robust project development. This study aimed to investigate the potential application of its technical and social dimensions in one of the most traditional industries of the world: civil construction, more specifically in the design stage. The literature review around the subject indicated that these concepts would be applicable at this stage. Therefore, in order to study this phenomenon, a multiple case study of three Brazilian companies in the sector was carried out. From this research, we concluded that, at the moment, the cases studied show little adherence to LPD and APM concepts within their organizational context. When technical aspects of this low adherence were analyzed, we did not find technical reasons that would hamper the adoption of LPD and APM. On the other hand, the social dimension (obstacles concerning organizational culture and social relation established in the current organizational structures) stands out as the biggest barrier to LPD and APM's non-adoption.

It was found that the context of the technical challenges faced by the studied companies did not differ from similar ones solved with the help of LPD and APM. Even though the companies studied herein present significant differences between product typology, organization's size, business models and end customers, only a few examples of practices connected to LPD and APM were found. In addition, none of the interviewees affirmed having a satisfactory knowledge of LPD and APM. This demonstrates that any example of application found would be more of an empiric attempt than a conscious application of LPD and APM.

Therefore, the elements that influence negatively in the application or adoption of these methodologies were identified in the social dimension as being the companies' organizational structure, its relationship with suppliers/clients, and the culture and mindset of those involved.

In terms of organization structure, it was possible to observe that strongly functional and hierarchical organizations hamper the application of softer ways of product development, due to highly hierarchical social interactions and rigid and vertical decision making.

Regarding suppliers and customers impact, we realized that the applicability of LPD and APM becomes much more difficult when only one link in supply chain is involved in this evolution, while the rest retains their traditional methods. The companies studied tend to shape the needs of their client's and the products of the suppliers, and any modification in this stream would need not only an adjustment of the organization, but also of the entire value chain. Therefore, the greater the inertia of these external participants, the greater the difficulty seems to appear in the potential application of these concepts.

Finally, the cultural factor was the most cited of all, concerning hampering and obstacles in deployment of new practices and methodologies in construction. This resistance to change occurs both in internal environment of an organization and in external ecosystem (mostly suppliers and customers). This cultural point might be reinforced by the country in which the companies where studied, because the findings exposed herein showed less adherence than the ones found in similar research studies carried out in the UK (El. Reifi & Emmitt, 2013).

Although its aim was the systematic analysis of the phenomenon, utilizing techniques already established for data collection and analysis, this study is naturally subjected to limitations. First, there are imposed restrictions by the qualitative nature of the study in question. This kind of study, as it was said previously, will exemplify, increase and even create new theories about the subject, but will not have strength enough to test any

existent theory (Yin, 2014; Miguel & Sousa, 2018). Yet, as cited previously, the size of the studied sample makes it difficult to generalize the findings, according to Eisenhardt (1989) metrics.

Accordingly, there is still room for related future research studies. Qualitative research studies with other companies could broaden the empirical evidence of the propositions herein submitted, regarding to social and technical dimensions, or in the identification of additional factors that influence the adoption of LPD and APM in the design stage of civil construction. Quantitative research studies based on surveys could deepen the factors herein identified, exploring its occurrence on probability samples.

On the other hand, the literature collects success cases regarding the application of LPM and APM in other industries. Its adoption was considered significant for the survival and development of several companies (Conforto *et al*., 2014; Serrador & Pinto, 2015). Therefore, being able to identify the effective adoption of these practices in the design stage of civil construction, or even, produce such cases through action-research strategies. This would aim to quantify the application's impact of these concepts, both in projects results and the cost-benefit of the developed products (e.g. shortening of development time, greater efficiency during construction stage, etc.). This way, it is possible to pursue the quantification of the LPD and APM rate of return, which is significant factor aiming to break the obstacles here demonstrated. Together with these reinforcements suggested in literature about the subject, it will be possible to have a better understanding of this phenomenon, and, more importantly, raise the interest of more professionals and companies from this industry to gather more information to try out the application of these methods in their productive chains.

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Question	Case 1	Case 2	Case 3
How the activities of the design stage are planned and controlled?	Short meeting between the owner and the responsible engineer. Delays are common	Meeting between teams leaders of each area. A WBS and a detailed schedule are developed. The schedule is controlled every 15 days. Delays are common	Meeting involving in-house and subcontracted designers. A WBS and a simple schedule are developed. The schedule is controlled every 15 days. Delays are common
How definitions and technical decisions are made during design process?	Engineer defines everything by himself, with the owner intervening only in complex cases. Clients are not involved because "they are not technically familiarized with the subject"	Each has total autonomy to make technical decisions about its specialty. Errors in this definition process are source of constant and common reworks	Subcontracted designers submit their technical decisions for approval of the specialty expert. There is no subcontracted integration. Erroneous decisions are only realized at the end and reworks are constantly needed
How is the client involved during the process?	The client is not involved. Only receives the final design	Constant and long validation meetings with the client's designers to approve every decision point. The process is reported to be long and slow paced	Clients biweekly validate the progress. Future executors (contractors) are also invited to evaluate the design at the end
How does development process flow between the teams and the employees? (Focus on authorities and responsibilities)	Responsible engineer handles the whole development process, with the help of interns	It is a functional organization structure. Areas have full authority under its specialty. Integration between areas is always made through formal hierarchy	Subcontracteds rarely speak among themselves directly. All the communications are made through the project manager (reported to be a slow and bureaucratic process)
How the progress of the projects is reported to the in-house team and for the clients?	With clients: e-mails/calls (not in a structured way) Internal: verbally	With clients: technical meetings and monthly boards with mangers from both sides Internal: periodic meetings involving department leaders only	With clients: technical meetings and semi-monthly boards with managers from both sides Clients: verbally (little integration reported)
Was the current process reviewed in the past? Is there a plan for any change in the future?	It always worked this way and there are no plans for change	The process was defined after the merge process. Political barriers prevent revisions	Due to constant reworks in the past, the client was more involved. The intend to further improve the process, although it will be no radical change
There are problems with your products after your deliver it?	Some problems in the execution phase. Clients sometimes complain of high costs due to allegedly over-design.	Executors often ask for contract amendments due to design's errors. The	Executors often ask for contract amendments due to design's errors. The

(*continued*)

Table AI.
Summary of collected answers

Table AI.

Question	Case 1	Case 2	Case 3
	However, these complaints are "unsupported"	company claims it occurs only due to bad faith of the contractor	company claims it occurs only due to bad faith of the contractor
Are you familiar with the concepts of lean product development?	Has never heard of	Has never heard of LPD, however, has heard about lean construction	Has never heard of LPD, however, has heard about lean construction
Are you familiar with the concepts of agile project management?	Has never heard of	Has heard about it in lectures, however, the knowledge is reported as "shallow"	Has heard about it in lectures, however, the knowledge is almost null
Are these methodologies applicable to your reality?	Possibly, however, the implementation seems improbable	Improbable	Very applicable, however, difficulty in implementation would be significant
Which are the main challenges (or roadblocks) for the implementation of the methodologies, considering your companies context?	Cultural. "The current way is working well"	Cultural, functional organization structure, clients' responsiveness, contractual structure (defined costs, deadlines and specifications)	Cultural, contractual structure with the subcontracted designers and the impossibility of imposing methodologies in the suppliers

Appendix 2

Element	Adherent situation	Case 1	Case 2	Case 3
Value stream mapping	Processes are mapped and known. There is focus on activities which add value to the client. Pulled production	No process is mapped/optimized; Pushed production	No process is mapped/optimized; Pushed production	Recent revisions, although nothing was formalized. Pushed Production
		No Adherence	No Adherence	Low Adherence
SBCE	Discussion of sub-optimal solutions, prototyping and use of lessons learned	Technical designs are fully developed before being delivered	Technical designs are developed independently by each specialty. There is little compatibility between the specialties	Technical designs are elaborated independently by each subcontracted designer and submitted only to in-house specialty expert approval. Erroneous decisions are realized only at the end an reworks are common
		No Adherence	No Adherence	Low Adherence
Visual management	Communication flow with the team is optimized. Visible information about project's scope, issues, quality indicators and costs	Non-structured communications (verbally or e-mail)	Non-structured communications (verbally or e-mail)	Non-structured communications (verbally or e-mail)
		No Adherence	No Adherence	No Adherence
Voice of the customer	Constant involvement of the client	Client is not involved on the development process	Periodic meetings with the client's designers	Periodic meetings with client's designers and specific meeting with future designer's executors (contractors)
		No Adherence	Low Adherence	Low/Average Adherence
Flexible and constant planning	Constant planning, focused on short-term goals, and periodically revised. Plan gets more mature as the project's objectives are becoming more defined	Planning is virtually nonexistent	Detailed schedules which are updated biweekly	Simple schedules which are updated biweekly
		No Adherence	No Adherence	No Adherence
Iterative development	Iterative development through deliveries, validated in a constant and periodic way	Full deliveries of finished products	Full deliveries of finished products	Full deliveries of finished products
		No Adherence	No Adherence	No Adherence
SELF-DIRECTED TEAMS	Independent cells, multidisciplinary and with physical proximity	Responsible engineer and his team are in the same room and have great autonomy	Each area has autonomy over its specialty. Team members share the same building floor, but each area stays in a different one	Subcontracted designers have very little autonomy. Project managers and technical experts impose their will on the subcontracted
		Average Adherence	Low Adherence	No Adherence

Table AII. Summary of the adhesion of each one of the cases to the elements of analysis from LPD and APM

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