Chapter 2
Lean Product Development and Design Management

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2.1. Introduction

For over 30 years, researchers and practitioners from diverse fields of knowledge aimed to improve the efficiency and effectiveness of the New Product Development process (NPD), addressing complex design and production issues. At the end of the 90's Kagioglou et al. (1998) stated that the manufacturing industry was under transformation due to increased globalised competition, which reflected on a need for companies to search for fast responses to changing customers' requirements. The ability of companies to respond to those requirements relies on communication with customers and the capacity to translate their requirements into finished products and services, which is the main concern of NPD. This has also been the main focus of lean design and construction initiatives and remain as current today as it was more than 25 years ago.

Lean construction has focused on reducing waste in construction projects, and diverse initiatives have been successfully implemented in the industry to manage production, e.g. the Last Planner System of production planning and control (see Chapter 3 by Ballard). Lean design addresses design as a production process, in which information is transformed, value added to it continually informed by clients, as opposed to the transformation of physical materials. The importance of design has been highlighted in lean as the main means to generate value to clients. However, the adoption of lean thinking is still modest in design. Attempts to implement lean design highlighted the need to integrate design and production, emphasising the adoption of lean thinking from briefing and conceptual design throughout the whole development process (Emmitt, Sander and Kirk-christoffersen, 2004).

The complexity in identifying and managing requirements, the multiple and sometimes competing requirements for efficiency, sustainability and cost, handovers between professionals and organisations, the inherently temporal nature of construction teams and the continuously evolving technological agenda make the undertaking of projects increasingly challenging. As such, recent developments have promoted improvements in various aspects of the process, often bringing about significant saving and increases in quality. This book presents many of these within the context of lean construction.

This chapter starts by briefly discussing NPD in other sectors with a main focus in manufacturing. It then discusses how developments in manufacturing have influenced lean design and construction. Following, the chapter presents issues around design management. An overview of Lean product development and design management research by the International Group for Lean Construction (IGLC) is presented to identify the progress made over time, as well as highlighting the evolution of the subject area in that period outside IGLC. Within this overview, subsections present brief descriptions of the main topics related to lean design, some of which are discussed in subsequent chapters in detail. Finally, areas for future research are identified.

2.2. New Product Development Process

Cooper (1994, p.3) defines the new product development process as: " a formal blue print, road map, template or thought process for driving a new product project from the idea stage through to market launch and beyond". According to Ulrich and Eppinger (2000), product development is the process through which a product is conceived, designed and launched in the market, and includes feedback from both production and product use. New Product development begins with the perception of a market opportunity and typically involves the capture and management of customer requirements, concept development, product design, market launch and collection and dissemination of feedback data (Cooper et al., 1998; Yazdani and Holmes, 1999). Hence, it includes both product and production process design activities. This concept makes explicit the importance of design, but also the interfaces between design and production, through the links between information and physical production (Tzortzopoulos, 2004).

A number of process models describing stages, activities and stakeholders were proposed aiming to support the management of the NPD (Kagioglou et al., 2000; Wang et al., 2011). Examples of influential models include: Clark and Fujimoto (1989) focusing on execution, manufacturing and ramp-up; Cooper (2001), who proposed the stage-gate management approach, which has been largely influential and applied in industry (Kagioglou et al., 1998); and Rozenfeld et al. (2006) describing process, and including after-launch activities, follow-up and plans for product discontinuity. The purpose of those process models is to be a reference or a generic template of the process, providing a set of tools and techniques to support the development of different activities, including the use of Information Technology (Tzortzopoulos, 2004). These models also aimed to ensure that the definition of the NPD is customer and market oriented (Kagioglou et al., 1998; Wang et al., 2011).

Kagioglou et al. (1998) argues that there is no single solution to NPD, thus companies should adopt different combinations of available tools and approaches according to their particular market context, product and process complexity, duration of projects and other factors. When considering the available approaches, companies should find a balance in the combination of the success drivers pursued, as each approach offers advantages and disadvantages that must be considered (Kagioglou et al., 1998). The same authors also state that the drivers for success relate to flexibility and speed, control and focus, which provide guidelines to the new product development process.

In manufacturing, there has also been research looking at lean product development specifically, in an attempt to both identify Toyota's NPD strategies (as the leading NPD company at the time), and define strategies to improve NPD through lean approaches. As discussed in Allen Ward's study of the Toyota Production System, lean product development addresses the following issues (Ward and Sobek II, 2014):

- Reduction of long development cycle times;

- Reducing the high costs of development;
- The need for more innovative solutions;
- Reduction of production costs;
- Redevelopment cycles.

Lean NPD was defined by Wang et al. (2011) as "*the application of Lean principles to the product development process to eliminate waste*", considering adaptations to materials and information flows, which supports the development of the company's value stream pulled by customers' orders. Morgan and Liker (2006) state that waste in product development can be regarded as the issues that negatively affect the overall performance of the process, affecting product cost, quality, development time and production capability.

Griffin, Langerak and Eling (2019) further state that there is a need for the establishment of an overarching theory of NPD as a focal research topic to fully understand its benefits. A similar lack of a holistic view of NPD occurs in construction. NPD process models and elements of the lean NPD have influenced research in design and construction. Some of the main influences are described as follows.

2.2.1. Product Development process models in design and construction

In the late 1990's, developments from manufacturing inspired construction researchers to develop process models adapted to the characteristics of the industry (Kagioglou et al., 1998; Ballard and Koskela, 1998; Kagioglou et al., 2000; Tzortzopoulos, 2004). Ballard and Koskela (1998) stated that the main lesson to be learned concerns value generation, specially the identification and capture of customers' requirements and their translation into product specifications (Ballard and Koskela, 1998).

Tzortzopoulos (2004) defines the product development process in the built environment as "*…the set of activities needed for the conception and design of a built product, from the identification of a market opportunity to its delivery to the client*." As such, it includes the design front-end, design development, design related activities that occur during production (and the interfaces between design and production processes), as well as post occupancy evaluations.

Process models present phases, each of which provide deliverables, increasing progressively the level of design detail through a series of creative activities (Ballard and Koskela, 1998). Process models must portray relevant information e.g.: (i) the content of main activities; (ii) precedence relationship between activities; (iii) main inputs, outputs and how information flows along the process; (iv) the roles, interests and responsibilities of the stakeholders (Tzortzopoulos and Formoso, 1999; Kagioglou et al., 2000).

The process protocol proposed by Kagioglou et al. (2000) is one example of such models. It defines project phases focusing particularly on the early stages, defined as the fuzzy front-end. Kagioglou et al. (2000) based the development of the process protocol around six key principles: (i) holistic project view, encompassing design, construction and demolition of projects and embracing customers, business and technical perspectives of construction; (ii) consistent process, and adoption of a standard approach for performance measurement and control reducing the ambiguity and uncertainty in the design process, assisting continuous improvement; (iii) progressive design fixity, an approach based on hard and soft gates for design enables the approval of evolving solutions throughout the process; (iv) co-ordination, managing activity zones; (v) stakeholder involvement and team work, especially at early stages of design, by promoting a collaborative environment, communication at the right time and supporting decision-making; and (vi) feedback offering lessons learnt through a legacy archive.

The RIBA plan of works is the most widely used process model in the UK. **Error! Reference source not found.** illustrates a generic model for construction projects, adapted from the RIBA plan of works (2013), outlining the scope of design management within this process.

[FIGURE 2.1 HERE]

Although process models have been widely discussed, there are limitations in practice in the adoption of such models, specifically at more detailed activity levels, and hence limited empirical data about their success. Some of the issues include:

- Tailoring a generic process model to the specific situation – at the company level, but also at the project level, which involves diverse company's processes;
- Having enough detail for medium and short term management;
- Process models generally do not provide inputs to how communication and collaboration is organised and how decisions are made.

As the structure of the industry is fragmented, there is no ownership of such models or a collective agreement, and there is no knowledge maturity to adopt such models consistently across all parties in the sector. The RIBA plan of works comes closer to being more widely adopted – also making it harder to change and adapt in incorporating current thinking and embedding current innovation practices.

2.3. Design Management in the context of Lean

Design management is an element of the product development process focused on organising the design team and understanding its nature, stages and activities, aiming to support communication, coordination and improve the integration of information flows. According to the Design Management Institute (DMI), design management includes the processes, decisions and strategies that enable the creation and innovation of product and services that provide organisational success and improve quality of life (DMI, 2019). Furthermore, it aims to provide practices and methods to design, including decision making, controlling processes, maintaining costs within the expected and ensuring profitability (Cooper, Junginger and Lockwood, 2011). Accordingly, DMI (2019) states that design management fosters the collaboration and synergy between design and business perspectives, aiming to improve the effectiveness of the process.

As such, "*design management endeavours to establish managerial practices focused on improving the design process, thus creating opportunities for the development of high-quality innovative products through effective processes*" (Tzortzopoulos and Cooper, 2007, p. 18). This definition highlights the emphasis on the process, linked to the basic ideas of lean construction.

In lean, design has been examined as a production process (Ballard and Koskela, 1998). Hence, following Koskela's Transformation, Flow and Value theory (TFV), three perspectives are considered: (i) transformation, i.e. the conversion of product requirements into the design of a product; (ii) flow, i.e. the flow of information across design activities and stakeholders; and (iii) value generation, i.e. design consists of the process of adding value through the fulfilment of customers' requirements. Some early developments include Huovila, Koskela and Lautanala (1997), who developed a conceptual framework for design management considering TFV, and Tzortzopoulos and Formoso (1999), who discussed the application of the TFV principles through the development of a design process model.

Understanding design as a flow of information can lead to reducing waste by minimising non-value adding activities, and the potential to increase efficiency (Ballard and Koskela, 1998). This enables the reduction of time, for example: (i) waiting for available information; (ii) inspection of design solutions; (iii) rework, i.e. reviewing the design solutions according to the requirements (Ballard and Koskela, 1998). The same authors state that viewing design as a flow supports the identification and coordination of interdependencies and integration between design and construction.

The design process is also the means to fulfil costumer requirements, which involves capturing clients' requirements, translating them into design solutions, and producing goods as specified in the design, generating value (Tzortzopoulos, 2004). The value generation process of fulfilling customers' needs occurs in cycles of information capture and conversion to deliver a product or service (Koskela, 2000).

Lean construction research has proposed the use of diverse approaches to support product development and design, in recognition of its essential role in providing value to customers. The following section highlights some of the main issues in design as discussed in the lean literature. These have been the levers for a number of lean design developments, which are briefly presented on the section after that.

2.3.1. Design management problems

Design problems have been described as ill-defined, or wicked problems. Wicked problems have particular characteristics, e.g. there is no definitive definition of a solution to a problem - understanding the problem and building its solution occurs in cycles of comprehension and formulation of the solution (Buchanan, 1992; Whelton and Ballard, 2002). Hence, the information captured to understand the problem is dependent on the possible solutions. As there is no definitive solution, problem solving is framed by time and resource limitations. As such, structured processes and group management skills are needed to support the problem identification and the development of the best solution possible to satisfy multiple perspectives, design criteria and project needs (Buchanan, 1992; Coyne, 2005). Furthermore, the definition of problems results from the combination of the complexity of the project context variables and stakeholders value sets.

The nature of design problems influences the management of the process. The lean literature has highlighted design management issues, which can lead to poor design quality, and have a strong impact on the effectiveness of the production stage. These issues are summarised on Table 2.1, and briefly discussed as follows.

[TABLE 2.1 HERE]

Design managers tend to focus on managing projects, tasks, resources and contracts (Howell, Windahl and Seidel, 2010) and less on managing people, production processes, environment and technology (Koskela et al., 2002; Pikas et al., 2015). This has led to disjointed management and contradicting methods; management of deliverables focused on producing models and drawings, while needs, requirements and alternatives are poorly specified or studied; misalignment between design flows, between others (Pikas, Koskela and Seppänen 2017). These are issues which have proved difficult to tackle over time.

According to Kagioglou et al. (2000) the lack of coordination, high variability and poor communication in construction projects are partially caused by fragmentation. For instance, the briefing process is performed by a team which is different from the one involved in production, who should deliver a project according to predefined design criteria (Ballard and Koskela, 1998). Tauriainen et al. (2016) add that within the current unstructured design management practices, where different teams adopt different design practices and lack standards for collaboration, the chances for error and conflict increase.

Multiple issues have been discussed around managing requirements and generating value. During design, there are multiple trade-offs between conflicting requirements, and divergent design criteria which needs to be considered from different perspectives (Ballard and Koskela, 1998). However, such trade-offs commonly happen based on inadequate information within a context of elevated budget and schedule pressure.

The lean literature also highlights a number of issues around the design process itself. One important issue is the relationship between design errors and waste. It is known that complexity causes design iteration which can be value-adding or wasteful. Waste as defined by Womack and Jones (1996) is “any activity, which absorbs resources but creates no value”. It is also known that waste in design arises from delays, waiting, design errors, over processing and negative iteration (Ballard, 2000). Such waste can have major impacts by undermining efforts to complete construction on time. Therefore, elimination of waste in both design and construction requires an emphasis on controlling and eliminating errors in design, as errors are main contributors of waste and value loss.

An important design management issue is the lack of effective planning and control to reduce the influence of complexity and uncertainty, and to ensure that the information flow is adequate and consistent to support design decision making. According to Ballard and Koskela (1998), early design stages are especially hard to evaluate and control due to the lack of clear deliverables hindering the estimation of the amount work done and remaining. Moreover, there should be formal ways to control information flows, and the use of soft and hard gates have been described to support this (Emmitt, Sander and Kirk-christoffersen, 2004).

However, many managers and designers believe that the design process is not suitable for planning due to its creative and iterative nature and the excessively detailed design plan would hinder creativity (Khan, 2016). According to the same author, design planning and control still is one neglected area in construction resulting in a chaotic environment and the large use of improvisation to solve design issues. Furthermore, many problems in design can be a consequence of the lack of consideration of interrelationship and precedence relations between design activities. Particularly, many activities are reciprocally interdependent, which adds complexity to design development and variability in the workflow.

Finally, the use of technology to support design has been at the forefront of many initiatives, and Building Information Modelling / Management (BIM) has been posed as a means through which information flows can be better managed, increasing productivity, efficiency and quality (Arayici et al., 2011; Eastman et al., 2011; Dave et al., 2013) – see Chapter 4 by Dave and Sacks for a detailed discussion around lean and BIM.

BIM provides great potential for improvement, but at the same time creates challenges related to its implementation. According to Arayici et al. (2011), such challenges include: (i) overcoming resistance to change; (ii) adapting exiting design workflows and training staff; (iii) collaboration and integration among different design teams and clear understanding among stakeholders; (iv) developing new managers' capabilities for BIM to improve the definition, schedule and evaluation of design activities; (v) improving the information flow to avoid disruption. Hence, one of the greater issues in BIM implementation relates to the need for changing the design process, working within predefined and agreed structures to produce and share information. Ballard and Koskela (1998) highlighted the need for a solid understanding of engineering and construction to be embedded in any specific applications to support design and production, which applies for BIM.

The following section presents the more prominent lean design approaches, which were developed aiming to resolve some of the issues described above. The section starts by presenting an analysis of research efforts reported throughout the past lean construction conferences, describing the main areas of work, and offering references for further details on each area.

2.4. Overview of product development and design management research at the IGLC – International Group for Lean Construction

This section aims to provide a broad overview of lean product development and design management developments over time, as discussed in papers published in the Annual Proceedings of the Conference International Group of Lean Construction (IGLC). An analysis of the 306 papers published from 1997 to 2018 was developed to provide a broad overview, as well as insights about future research needs in the area.

Firstly, the analysis aimed to portray how the topic evolved over time in a quantitative form. **Error! Reference source not found.** illustrates that the number of design management related papers has increased over time in the conference. In general, from 1997 until 2018, the relative frequency of papers related to design in relation to other areas represents an average of 17.62% of the conference papers, which is relatively low considering the importance of the field. However, it is noteworthy that recently the proportion design management papers in relation to the total has increased, reaching a peak in 2016 with 33% (39/120) of the publications.

[FIGURE 2.2. HERE]

Figure 2.3 presents an analysis of the purpose of the LPD and Design Management research, which was categorised into: (i) theoretical, and (ii) empirical. The first category includes papers focused on theory and predominantly based on the literature. Systematic literature reviews, literature review papers to develop a new solution to a problem and the analysis secondary data from previous studies were classified as theoretical. Empirical papers are those focussed on applying or adapting solutions in a specific context, e.g.: (i) the prescription of a solution to a practical problem; (ii) implementation of lean product development models, approaches, tools and techniques; (iii) assessments of the application of lean and its approaches, methods, tools and techniques; (iv) use of IT or BIM tools in design; among others.

[FIGURE 2.3 HERE]

The analysis shows that the focus of the research has been mainly empirical, rather than theoretical, as shown in Figure 2.3. Interestingly, early on, from 1996 to 2000, the topic was mostly addressed from a theoretical perspective. The analysis illustrated in **Error! Reference source not found.** indicates that the proportion of empirical and theoretical papers has oscillated over the years, and theoretical research represent around a third of all design related publications. The predominance of empirical papers portrays a peculiar characteristic, as there is a wide range of solution developments, adaptations and implementations. Furthermore, many solutions are mentioned once or there are partial implementations of tools, reflecting some fragmentation of the body of design management knowledge by the IGLC community. Additionally, this highlights that theory is not evolving at the same rate as practical implementations, and there are limited successful examples, and hence poor support to new lean design implementations.

Noteworthy is the fact that most papers adopt a qualitative method, many employing case studies. However, from 2010 the applications of Design Science Research (DSR), a prescriptive research approach, started to emerge. Furthermore, many of the solutions proposed in the papers are shortly implemented or tested, in a qualitative way, which contributes to the fragmentation of knowledge in the area. In summary, there is a need for exploring new theory developments to support the proposition of these solutions and deeper exploration and building upon existing ones continuously to obtain major benefits on NPD and design management.

The topics discussed and frequency of papers on lean new product development and design management has increased in the last 10 years in IGLC, as shown in **Error! Reference source not found.**. Early papers discussed the three views of design (TFV) as presented earlier in this chapter. Many of these discuss the adaptation of lean construction principles from manufacturing to design in the construction industry.

[FIGURE 2.4 HERE]

From 2013 to 2016 the volume of NPD process models and approaches as well as the design management tools and techniques increased, possibly due to the transformations in the industry regarding BIM. There have been four or more BIM related papers each year in the last 5 years presented at the conference, with further technology papers not directly related to design. This reinforces the relevance of recent technological developments in construction.

Other areas have been brought to light in the conference, such as value, design issues and waste and mass customisation and industrialisation. The least frequently discussed topics analysed were collaboration and early involvement of stakeholders (17), constructability and design construction interface (8), and design theory (6) respectively. Those less discussed development areas may offer fruitful opportunities of further research.

Many topics have been discussed under the umbrella of lean new product development and design management. Considering this, a timeline presenting when some influential developments first appeared in IGLC is shown in Figure 2.5.

[FIGURE 2.5 HERE]

Table 2.2 presents a categorisation of lean product development and design management themes, examples of which are briefly discussed as follows.

[TABLE 2.2 HERE]

2.1.4. Design Theory

Koskela has promoted the view that design theorising started in Antiquity, with the method of analysis (from geometry) and rhetoric as the first models of design by analogy. It is proposed that these two models still provide a superior understanding on design.

The method of analysis has been discussed as the proto-theory of design. Koskela et al. (2014) discussed how the method of geometrical analysis, proposed by Aristotle, provides a theoretical underpinning for design, which has been forgotten over time. The authors highlighted that this compels researchers to see the evolution of design under a new light – and although scholars of design have endeavoured to discover the core theory, progress has been painfully slow and results fragmented. Koskela et al. (2014) further argue that this missing of the core theory has arguably contributed to the maintenance of disciplinary fragmentation around design, calling for a unified design science.

Koskela et al. (2014) also highlighted important terminological problems. A starting point to understand the nature of design has been the analysis-synthesis-evaluation model, with initial proposals developed around 1960's, then influential models e.g. Markus and Arch (1973), which have been refined into many different variants, including Pahl and Beitz (2013) model.

However, there have been discussions around the concept of analysis and synthesis. According to Koskela et al. (2014), the two types of analysis include finding (a solution) and proving (an assertion, say, on the validity of a proposed solution). The authors further argue that the main difference of these is that in the former, one endeavours to create a chain of inferences from the problem towards a solution, whereas in the latter a solution is first guessed and then analysed for its validity. In the design literature, analogous approaches have been called problem-oriented and solution-oriented strategies, and it is recognised that completing a design requires the application of both (Wynn and Clarkson, 2005; Emmitt and Ruikar, 2013).

From the existing models, some state that analysis precedes synthesis (Asimow, 1962), some that synthesis precedes analysis (Hall, 1962); such models have tried to accommodate and clarify both types, with varying success (it is important to note that in these models the meanings of analysis and synthesis have drastically drifted from the original sense of these terms, as used in Greek geometry) (Koskela et al., 2014).

These descriptive models have a common feature in the assumption of selections and decisions between different ideas, or sub-solutions, being made in satisfactory manner; however, the models are silent on how the decisions are or should be made.

The terms analysis and synthesis have maintained a longstanding prestige in design, and as the understanding of their original meaning has been corrupted, new meanings have been given to them in different knowledge domains. This has led to a fundamental confusion of the role and meaning of analysis and synthesis in design. The current popular understanding in the design literature of analysis as a rational stage and synthesis as a creative stage is in direct contradiction with the ancient understanding.

Another important issue are rich connections between rhetoric and design, which have been analysed in prior research (Buchanan, 1985; Buchanan, 2001; Ballard and Koskela, 2013; Koskela, 2015). It is known that rhetoric originated from the need of citizens in ancient Greece to make speeches in a court of law. Understandably, the discipline of rhetoric was then built up around the unit of a speech.

Koskela (2015) contends that legal proceedings, as they have evolved from Antiquity, embrace important and effective principles for the collaborative – and simultaneously competitive - pursuit of a common goal. Hence, these principles can also be useful in the context of collaborative design. Koskela (2015) presented the seven principles as: (i) hear both parties; (ii) reasoned judgment; (iii) right to appeal; (iv) use of both logical and rhetorical arguments and reasoning; (v) standardised proceedings and documents; (vi) public nature of proceedings; as well as (vii) dedicated and structured space. The main idea is that, up to now in design theorising, the angle of competition of ideas has either mostly been abstracted away or only some specific topic has been examined; however, theoretical and practical gains have been modest. Consequently, the question on how this competition should be arranged has been left disregarded, and provides fertile grounds for new research.

Furthermore, design theorising has covered several narrower topics (partly based on Kroes, 2002), such as creativity in design thinking, design education, design effort, conceptual design as a process, design progress, communication of design knowledge, managing design information, the role of computers in design, design as a cognitive activity, decision making in design, design intent/rationale, collaborative design, and team cognition. For a further discussion on lean theory, please refer to Chapter 1 by Koskela.

2.1.2. Value

Value generation has been discussed as a main goal for lean construction and a focus for design management. The concept of value is complex and ambiguous, and as such its development has been informed by theories from different domains.

Value generation is considered by identifying design criteria and customer needs to be used as input to the process (Ballard and Koskela, 1998; Tzortzopoulos and Formoso, 1999). Furthermore, the consideration of customers' requirements involves gathering information about demand and feedback from surveys, post occupancy evaluation and facilities management (Emmit, Sander and Chirstoffersen, 2004). Value can be improved through a combination of better requirements management, collaborative interactions, communication (knowledge sharing), and supporting creativity through adequate management of design activities (Dave et al., 2013).

The value gained at early design through the efficient capture and management of requirements and intent can be significant, which is one of the core tenets of lean. Buildings are built to serve a purpose, and the construction industry should to focus on that purpose, as illustrated in Figure 2.6.

[FIGURE 2.6 HERE]

Creating value should be more important than minimising design costs, as the impact of any investment in design is likely to be greatly outweigh by having a building which supports its users' needs and hence supports business profitability. Hence, a shift of focus from the delivery of products to the generation of value and benefits to clients is needed. The main concern is no longer the capital asset on its own right, but linking clients' business strategy to projects, maximising revenue generation and managing the delivery of benefits in relation to different stakeholder groups (Winter et al., 2006).

The traditional approaches to 'value' have been focused on defining a set of requirements in the project brief, and designing and delivering a building through a generally linear process. There is not much emphasis on evaluating and refining the design early against requirements through an iterative process (Ballard and Koskela, 1998). However, requirements evolve over time as ideas are tested and alternatives evaluated, but this notion is not sufficiently considered or supported by traditional processes or tools. 'Value' is more typically associated with value engineering, which is generally more aligned to construction cost reduction.

In this context, generating value implies understanding client's purposes and helping them to fulfil those purposes with minimum resources (e.g. costs, time). Integrated lean and BIM concepts can help in this, as it enables the industry to better focus on life cycle values (Dave et al., 2013).

At the IGLC conferences, reflexions about the concept of Value itself emerged in 2009 with Salvatierra-Garrido, Pasquire and Thorpe's paper, and discussions on how value perception is established in a hierarchical manner for customers, which was also highlighted by Lima et al., (2009). From 2011, some research focused on adapting the means-end chain theory to understand how project attributes and consequences in use can lead to the achievement of goals and values desired by customers (Bonatto, Miron and Formoso, 2011; Brito and Formoso, 2014; Hentschke et al., 2014; Nascimento and Miron, 2017). Overall, research around value as a concept, and how to better support its achievement in design is still needed. Further detailed discussions around value generation can be found in Chapter 6, by Tillmann and Miron.

2.4.3. New Product Development approaches

This broad title is used here to present some developments on the conceptualisation, adaptation or implementation of overarching product development approaches, such as: concurrent engineering (CE); target value delivery (TVD); integrated project delivery (IPD) and benefits realisation. Each of these approaches is very briefly described, and references made to sources for further information.

2.4.3.1.Concurrent Engineering - CE

One of the first new product development approaches to be discussed in IGLC was CE, in the early 2000s. CE involves the simultaneous consideration of multiple requirements from diverse stakeholders (Kamara, 2003). It introduced the concept of overlapping activities, where two or more activities should be performed simultaneously. Kagioglou et al. (1998) and Ballard and Koskela (1998) state that its combination with cross-functional integration and teamwork could bring benefits to construction projects. The concept has influenced much research in construction, and brought to light the need to integrate the multidisciplinary project team into a unified development process, enabling downstream aspects of design and construction and non-value adding activities (waste) to be considered throughout design (Love and Gunasekaran, 1997). Some of the more recent ideas around overlapping design and construction are discussed in Chapter 15 by Biotto and Kagioglou.

2.4.3.2. Target Value Delivery - TVD

Target Value Delivery (TVD) is the practice of steering design to targets, using costs as a driver to design, and not as a consequence of it, constraining the design and building of a facility to a maximum cost (Ballard, 2008). Collaboration is an essential element of the approach, which originates in the area of value engineering. Glenn Ballard is the main proponent of TVD, and details can be found in Chapter 8.

According to Zimina, Ballard and Pasquire (2012) Target Value Design is an adaptation of target costing to construction, that is an effective management technique for achieving cost predictability, focusing on attaining market defined price and accomplishing financial returns.

The approach is mentioned here as its implementation impinges changes in the way design is developed. A main change is that both cost and value are considered as drivers to design development; hence there is a push for designing to targets, instead of calculating the cost of a complete design (Zimina, Ballard and Pasquire, 2012). Such approach needs to be supported by the use of BIM e.g. enabling the fast production of design alternatives, and fast cost estimation of alternatives. Successful examples of TVD implementation have been reported, where the approach is used in conjunction with IPD, briefly discussed as follows.

2.4.3.3. Integrated Project Delivery - IPD

The American Institute of Architects (AIA) defines Integrated Project Delivery (IPD) as: *"a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimise efficiency through all phases of design, fabrication and construction".*

IPD focus on collaboration, waste minimisation and integration of key stakeholders. It enables key features of lean, such as early contractor involvement, integrated design and the whole life cycle approach. IPD leverages early contributions of knowledge and expertise through use of new technologies, allowing all team members to better realise their best potential while expanding the value they provide throughout the project life cycle. It is important to note that the collaborative structures inherent to an IPD legal agreement break down barriers and enable benefits to be achieved (Fischer et al., 2014). IPD is discussed in detail in Chapter 9 by Alvez and Lichtig.

2.4.3.4.Benefits Realisation

Benefits realisation emerged in the information systems sector during the 1990's. It was motivated by the low success of technology implementation on generating the expected business benefits of investments, related to the organisations' strategic aims (Ward and Daniel, 2006). The same authors explain that the focus on benefits also brought a different perspective to business justification, complementing the traditional justification based only on monetary gains.

In the UK, the Office of Government Commerce (OGC), a governmental agency that provides policy standards and guidance on good practices of project management, recommends that projects should clarify the benefits they intent to achieve in their business case, track them during implementation and evaluate their realisation after delivery (OGC, 2007).

A benefits realisation model, BeReal, was developed based on the ideas of benefits management suggested by the OGC and others (Sapountzis et al., 2010). The model was developed focusing on the development of healthcare infrastructure. The BeReal model includes a series of workshops for the definition of the expected benefits of projects, and a full description of such benefits with the definition of how and when their realisation will be measured (Sapountzis et al., 2010). Then, a design process in which key stakeholders evaluate the options against benefit criteria follows. Finally, an assessment phase is carried out, in which benefits are reviewed based on interviews, questionnaires, post occupancy evaluation and other techniques. Hence, the BeReal model is based on the understanding of value as the achievement of a purpose, giving emphasis to the advantages that can be generated over the lifecycle of a project, which is the reason for its implementation and justification for the investment.

In the IGLC, benefits realisation has been addressed suggesting the active management of expected intent throughout project delivery, starting from capabilities to the realisation of expected benefits (Tillmann, Tzortzopoulos and Formoso, 2010; Rooke et al., 2010; Tillmann et al., 2012; Kagioglou and Tzortzopoulos, 2016). Chapter 6 by Tillmann and Miron briefly discusses the concept further.

2.4.3.5.Building Information Management - BIM

BIM has become a ubiquitous term across the industry and there is widely documented research on the theme. A host of benefits from the adoption of BIM in design have been highlighted, including e.g.: reduced design development life cycle; effective capture and flow down of intent; reduced rework; increased iteration for value improvement; improved predictability of investment and life cycle costs; enhanced ability to engage with stakeholders (Kiviniemi, 2005).

The links between lean and BIM have attracted much interest since 2011 with e.g. the UK government BIM strategy requirement that all suitable government construction projects use BIM by 2016. It has been recognised that BIM contributes directly to lean goals, enabling lean processes. Furthermore, lean processes can also facilitate the adoption of BIM, hence there are diverse positive synergies between the two (Sacks et al., 2010 Tauriainen, et al., 2016).

Dave et al. (2013) have highlighted some characteristics of a lean and BIM project, specifically for the design stage, as those that include: (a) collaborative development of design and detailing; (b) co-location of the design team; (c) involvement of downstream stakeholders in design; (d) using last planner in design; (e) detailing BIM models for construction use.

In the IGLC conferences, BIM papers first appeared in 2010. Following, many papers integrated the implementation of BIM with other product development approaches and tools as a way to support design have been presented. Some discuss how to solve specific design problems through the use of BIM based tools and management, such as clash detection, design coordination, information management, construction and demolition waste management. Chapter 4, by Dave and Sacks, presents a detailed discussion around lean and BIM.

2.4.4. Design management tools and techniques

Design management in lean construction realise its principles through the application of tools and techniques to support a specific design activity or part of the product development process, promoting lean principles such as collaboration, efficiency, and reduction of waste. This section briefly presents some of the existing tools, i.e. Choosing by advantages (CBA); Set Based Design (SBD); Last Planner System (LPS) applied to design, and Design Structure Matrix (DSM).

2.4.4.1. Choosing by Advantages -CBA

Suhr (1999) defined Choosing by Advantages as a decision making system in which the significance of the advantages guide design decisions. Parrish and Tommelein (2009) describe CBA as "*a system that considers advantages of alternatives and makes comparisons based on these advantages*."

CBA includes decision making methods, from very simple to extremely complex (Suhr, 1999). The overarching idea is that by using sound methods, practitioners can make better decisions that will guide their actions, and produce improved outcomes. The main CBA principles as presented by Suhr (1999) are shown in Table 2.3.

[TABLE 2.3 HERE]

CBA includes the phases: (i) stage-setting, an innovation stage; (ii) the decision making; and (iii) implementation. The first appearance of choosing by advantages in the IGLC was in 2009 with Parrish and Tommelein (2009)'s paper. For detailed information on CBA, see Chapter 10 by Arroyo.

2.4.4.2. Set-based Design

The concept of set-based design involves a simple idea – that designers need to consider sets of alternative design solutions from the start of the process, instead of developing one alternative in detail. Hence, designers consider sets of possible solutions and gradually narrow the set of possibilities to converge on a final solution. Such narrow down happens based on additional information from design development, testing, the customer etc. A wide net from the start, and gradual elimination of weaker solutions, makes finding the better solution more likely (Sobek II et al., 1999), as designers reason about, develop and communicate sets of solutions in parallel and relatively independently. According to Ward et al (1995) Toyota's engineers and managers seek to delay decisions until the last responsible moment, so the approach is viewed as a funnelling process.

In lean construction, Parrish et al. (2008) sates that this approach seeks to maintain the design space as open as possible for as long as possible. The final solution is defined based on discussions about design alternatives and their trade-offs considering different stakeholders' perception of value (Parrish et al., 2008). Ballard (2008) summarises set-based design, arguing that: "*the basic idea is to apply all relevant criteria in producing, evaluating and choosing from design alternatives from the beginning of design, rather than introducing new criteria as new stakeholders come onto the team*".

According to Ballard and Koskela (1998), set-based design integrates the perspectives of conversion, flow and value. Parrish et al. (2008) discuss that set-based design promotes communication, avoids rework and supports the development of solutions focused on value within target cost boundaries. As a method, set-based design requires a shift in design management thinking, as it allows more of the design effort to proceed concurrently and defers detailed specifications until trade-offs are more fully understood. As such, it keeps design options flexible for as long as possible during the process (Ward and Sobek II, 2014).

Finally, it should be mentioned that although facing some cultural barriers and organisational issues, the implementations of set-based design in building projects has presented very sparse but good results, as well as promising opportunities for improvements (Ballard, 2008).

2.4.4.3. Last Planner System (LPS) applied to design

There have been attempts at implementing the last planner system of production planning and control to design, with initial attempts reported on the IGLC conference as early as 1997 by Koskela, Ballard and Tanhuanpãã (1997).

According to Fosse and Ballard (2016), the last planner can support key aspects of planning and control during the design process. It is argued that it can improve the transparency of the design process through scheduling and provide metrics to control progress (PPC – percent plan complete) and establish benchmarking opportunities across projects. Benefits pointed out in the literature also include improvements on collaboration and commitment, by supporting and promoting the understanding of the role of other designers in the process. According to Khan (2016), although LPS improves construction planning and control reliability combining collaboration and coordination, a limited number of studies to date have successfully applied LPS in the design process.

There have been reported benefits in implementing for instance weekly work plans in design, however the implementation of medium term planning in design has proven challenging. This is mainly because of the high variability in the process, in which one piece of new information may change the priority of design activities quite dramatically. The literature also states that the implementation of LPS combined with BIM could significantly improve design workflow (Khan, 2016), but this is currently an area for further research.

2.4.4.4. Design Structure Matrix

Design Structure Matrix is a method for information flow representation, where tasks are organised according to their expected chronological order in rows and columns as a matrix (Koskela, Ballard and Tanhuanpää, 1997). A precedence matrix is developed to show design dependencies, where the information flow between activities can be visualised.

Hence, the tool can be used to represent and manage design flows (Ballard and Koskela, 1998). The marks on the diagonal of the matrix represents that a task provides input for an earlier task, which represents the loops on the design process (Ballard and Koskela, 1998). Khan (2016) states that DSM can improve design planning by considering the precedence between tasks. Furthermore, Hassan (1996) proposes that DSM can be regarded as a technique to optimise the order of design tasks, identify design loops and plan design based on the needed iterations.

Koskela, Ballard and Tanhuanpala (1997) describe an experiment in which the optimal sequence of design tasks is analysed by means of the Design Structure Matrix: a schedule is prepared on the basis of the ordered tasks, and the execution of tasks is controlled through the last planner system. The authors state that resulting design process was more disciplined in comparison to a process managed in a conventional style. However, there are difficulties in implementing the

DSM in design, as the information needed to produce the matrix needs to be produced at a detailed level, which is very difficult to predict in advance in design. There are clear opportunities to further investigate its application to support design planning in construction.

2.4.5. Mass Customisation and industrialisation

Mass Customisation (MC) is a strategy that aims to offer products that fulfil customers' requirements, potentially adding value, through flexible process and structure, with costs and delivery time similar to mass production (Hart, 1995; Jiao, Ma and Tseng, 2003; Fogliatto, da Silveira and Borenstein, 2012). The main challenges in the application of MC are capturing customers' requirements (Barlow and Ozaki, 2003; Tillmann and Formoso, 2008; Martinez, Tommelein and Alvear, 2017) and keeping the balance between offering variety and maintaining affordability (Martinez, Tommelein and Alvear, 2017) without affecting the efficiency of the production process (Nahmens and Bindroo, 2011). Several MC practices have been associated to lean construction concepts, e.g. reducing lead time, increasing value by systematically capturing customer requirements, and increasing output flexibility.

At the IGLC, initial discussions about mass customisation and industrialisation began with concepts of MC and open building, by Barlow (1998) and Cuperus (2001) respectively. Research shifted to identify connections between related topics such as modularisation, open building and prefabrication around the year 2005. These papers are also concerned with design and production process of industrialised and prefabricated systems, and how to improve productivity reducing on site activities and approximating construction to manufacturing and its benefits. In 2006 balance between standardisation and value generation for customers in the papers of Höök (2006) and Bjornfot and Sarden (2006). The discussions about mass customisation were re-established in 2008 by Tillmann and Formoso, and little research was published in the area until more recently. In 2017, the concept of platform design started to be discussed. The area provides fertile grounds for further research, which could also address issues around construction productivity.

2.4.6. Collaboration and early involvement of stakeholders

Collaboration is an essential concept across lean construction, and a diversity of research efforts have identified benefits steaming from its adoption and related practices, proposing that collaboration could help solve many of the deeply rooted problems of design. The term collaboration has been used widely, carrying a variety of meanings. As a consequence of the lack of conceptual clarity, the concept of collaboration remains amorphous (Poirier, Forgues and Staub-French, 2016).

Attempts at understanding collaboration have resulted in normative definitions and checklists of antecedents and criteria for successful collaboration (D'Amour et al., 2005). However, researchers have argued that normative definitions fail to account for the evolutionary and dynamic nature of collaborative interactions, because they tend to consider collaboration as an endpoint, rather than an evolving feature of the activity (Poirier, Forgues and Staub-French, 2016; Gomes and Tzortzopoulos, 2018).

Nonetheless, procedures for collaborative working are needed to support designers concurrently working on the same project. In this context, the following issues need to be considered:

- how to ensure that all stakeholders have up-to-date information;
- how to make sure that several people are not editing the same information at the same time;
- how to notify about ongoing work and changes.

Also, other issues have to be addressed when coordinating multidisciplinary design, including (Dave et al., 2013):

- what information is needed by designers for critical decision making, and when is it needed?
- there are many temporary changes in trying to find solutions, so when is it adequate to exchange information?
- is there a need to 'freeze' design solutions so that other disciplines can start design?

A value stream (process) mapping exercise can help understand these issues including identifying critical design handover points, the level of detail required from each discipline at handovers, and general scheduling of the design process. Hence, effective information management through collaboration is a prerequisite for process improvement. Collaboration in early project stages is discussed in Chapter 20 by Gomes and Tzortzopoulos.

2.4.7. Design issues and waste

Regarding the concept of waste in design, as discussed earlier in this chapter, design errors are waste. Activities which are developed but not taken forward, could be classed as wasteful. However, in practice, it is very challenging to identify which design activities may lead to waste, and which interactions are needed to generate value – e.g. the development of design alternatives is needed to enable teams and clients to better understand what is possible within the project constraints- and, indeed, the concept of waste in design is still poorly understood (Mryyian and Tzortzopoulos, 2013). Further discussions around design management issues have been presented earlier in this chapter.

2.5. Future Research

Improving the design process is still seen as a bottleneck for the improvement of the construction industry. Although there have been attempts to adapt lean construction principles and develop lean design tools over the last two and a half decades, the impact of lean thinking is still much stronger in the production process (Svalestuen, Lædre and Lohne, 2014).

Long ago, Ballard and Koskela (1998) proposed a research agenda for design management pointing out: (i) need to understand design management as a facilitator to value generation and waste reduction, including the relationship among stakeholders, and (ii) a need for the identification of tools and techniques to integrate product and process design and to plan and control early design stages. Complementarily, Tzortzopoulos and Formoso (1999) indicated that research in design management should consolidate the value generation view of design, further investigating cycle times, waiting activities and variability, aiming to reduce waste without compromising creativity. The above issues are still relevant today. Some potential topics for further research in lean product development and design management include:

- Further consideration of the concepts of analysis and synthesis and how clarifying these can support better practices in design management - this missing of the core theory has arguably contributed to the maintenance of disciplinary fragmentation around design, calling for a unified design science;
- Rhetoric and how its principles could be adapted to design and used to support design management;
- Theorising on collective action has developed slowly and has remained fragmented – existing concepts like common ground, shared understanding, boundary objects present a multitude of fertile ideas that can be investigated further in support of collaboration; also, there is a need to better understand how theories link to practices like e.g. the big room;
- How to support creativity in design; how a better understanding of creative processes could support better design outputs;
- How simplicity concepts could be used to help manage design (e.g. Maeda, 2006);
- Communication and action - while systematic processes provide structure, the communication practices by which action occurs requires further attention. To understand how communication and action can be improved, it is vital to achieve an understanding of stakeholder decision framing (Whelton and Ballard, 2002);
- NPD urges for new holistic approaches which cope with the current needs for innovation, speed and adding value for customers, this means that existing practices and solutions should be adapted to support companies in the competitive environment of start-ups, open innovation and so on (Griffin, Langerak and Eling, 2019) in manufacture as well as in construction;
- The need for a systemic view also is reflected in design management, which according to Uusitalo et al. (2017) could be improved by the combination of different lean design management methods, tools and techniques;
- Research around value as a concept, and how to better support its achievement in design are still needed;
- Value generation/early design/optioneering – links to client value; links to benefits; links to BIM through fast development of alternatives;
- BIM and LPS implementation in design – how they complement each other at detailed activity levels and; how complexity theory could help in building resilience in design management;
- Other technological developments e.g. robotics, 3D printing – and how they affect design. There has been nearly no consideration of such technological developments by the IGLC community, and these provide somehow untapped rich grounds for research
- Artificial Intelligence – its developments in IT and there are fertile opportunities to further investigate its use for example in supporting project planning or in the evaluation of the design of existing buildings. For example, a rules-based and case-

based optimisation of design and production planning with automatic order processing and progress checking could eliminate the need for planners! AI based location based tools could also eliminate crew clashing on building spaces and crews standing whilst other work gets completed;

- Improved levels of automation in design – code checking, standardised products, platforms, mass customisation;
- Platform Design and Mass Customisation - The area provides fertile grounds for further research, such as exploring the balance of flexibility-productivity trade-offs and further connections with lean construction concepts as ways to improve productivity, value generation and potential of practices to be adapted to new contexts;
- Better understanding the concept of waste in design can provide insights into effective tools for managing the process and its intricated information flows.

The relentless pursuit of better NPD and Design management processes is never ending. Developments on the above will certainly help bring about significant improvements. Furthermore, the interface between academia, industry and professional institutions needs to become more agile, responsive and welcoming of new innovations (both process and technological). The need for holistic seeing-the-whole understandings has never been more relevant. As the boundaries between disciplines, project phases and actors become more permeable there will be a need to embrace an approach where processes influence and are influenced by human and technological agency in an iterative and evolving manner whilst focusing on delivering project and wider space and social benefits addressing societies grand challenges.

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