

THEORY OF PRODUCTION IN CONSTRUCTION INDUSTRY: AN ANALYSIS OF THE LITERATURE

TEORIA DA PRODUÇÃO NA INDÚSTRIA DA CONSTRUÇÃO: UMA ANÁLISE DA LITERATURA

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Abstract

In the absence of an explicit and specific theory, the management of production processes in construction is essentially based on a Taylorist view, based on the economic theory of production. Thus, given the particularities of construction, the plans developed are often unreal, with recurring delays and unforeseen circumstances during production. Thus, because of the importance and the latent need to develop a specific theory, this article uses a systematic literature review (SLR) to comprehend what has been developed and discuss the topic. The main objective is to answer the following research questions: 1) What is being proposed to develop a production theory applied to construction? 2) What is the approach used in the publications? 3) What can be proposed for the body of knowledge in question to fill gaps? Based on the results of the SLR, it was verified that the development of such a theory appears to be very incipient and not formalized in the publications, with inconclusive results and weak multidisciplinary cooperation. Furthermore, there are indications that authors associated with Lean Thinking may be leading research on production theory in construction since most of the publications have results that were conceptually based on Lean Construction principles. It is understood that the content of this article is relevant because it outlines the current stage of development of the theory and indicates possible paths to achievements.

Keywords: Construction management. Construction theory. Production theory. Lean Construction.

Abstract

Na ausência de uma teoria explícita e específica, a gestão dos processos de produção na construção se baseia essencialmente em uma visão taylorista, com base na teoria econômica da produção. Assim, dadas as particularidades da construção, os planos desenvolvidos são muitas vezes irrealistas, com atrasos recorrentes e imprevistos durante a produção. Assim, pela importância e necessidade latente de desenvolver uma teoria específica, este artigo utiliza uma revisão sistemática da literatura (RSL) para compreender o que foi desenvolvido e discutir o tema. O objetivo principal é responder às seguintes questões de pesquisa: 1) O que se propõe para desenvolver uma teoria da produção aplicada à construção? 2) Qual a abordagem utilizada nas publicações? 3) O que pode ser proposto para o corpo de conhecimento em questão para preencher lacunas? Com base nos resultados do SLR, verificou-se que o desenvolvimento de tal teoria parece ser muito incipiente e não formalizado nas publicações, com resultados inconclusivos e fraca cooperação multidisciplinar. Além disso, há indícios de que autores associados ao Pensamento Enxuto podem estar liderando pesquisas sobre a teoria da produção na construção, uma vez que a maioria das publicações apresenta resultados que foram conceitualmente baseados nos princípios da Construção Enxuta. Entende-se que o conteúdo deste artigo é relevante porque delinea o atual estágio de desenvolvimento da teoria e indica caminhos possíveis para realizações.

Keywords: Gestão da construção. Teoria da construção. Teoria da produção. Lean Construction.

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Introduction

Management of production processes in the Construction Industry (CI) are planned and managed by deterministic and outdated methods that focus, almost exclusively, by conversion processes, neglecting other aspects such as flow and value, which are as important to be managed as the transformations (HENRICH et al., 2006). As Lean Construction principles have pointed out, so-called flow and value creation activities are systematically ignored or inefficiently planned and managed, resulting in unrealistic planning and construction work with recurring delays and unforeseen events. As Frederick Taylor (TAYLOR, 1991) has already stated, the root cause of issues related to wasted labor effort is non-scientific management, so managers are often more focused on the final results and not enough on the work processes.

For example, it is recurrent that CI's management and control practices ignore or oversimplify events that can occasionally affect the productive system. For instance, for certain tasks, productivity rates, rather than their variability, are constant over time, and flows are explicitly disregarded. Thus, considering the CI, some authors, such as Allen (2008), Lu, Croome-Clements and Viljanen. (2010), Koskela (1999a), Koskela (2000), Koskela (1999b), Howell and Koskela (2000), Koskela and Vrijhoef (2001), Koskela (2004) and Bertelsen et al. (2007), call attention to the need to apply an adequate and explicit scientific theory for the construction, considering the typical attributes of this sector. These authors justify this need by the fact that traditional management practices are becoming increasingly inadequate, given the continuous growth of the complexity of enterprises and the need for cost reduction.

In this context, it is observed a latent need, for academics and construction, as an economic sector, to develop a specific theory of management of the building site. Therefore, this article is dedicated to developing a systematic literature review (SLR) on theories associated with production management in construction to investigate aspects, such as the theoretical approach adopted in studies, the research methods applied, and the advances obtained. As a secondary objective, possible contributions are presented that may fill gaps in the body of knowledge in question when properly analyzed. Hence, articles published in the last twenty years in indexed journals were surveyed, analyzed, and classified, as described in the methodology's details.

It is understood that the results of this article are important, because they provide an overview of the current research scenario concerning the theme in question, in addition to addressing a topic little explored in the academic world. It is understood that this should bring expressive and impactful results in the CI, according to the possibility of developing new research to construct the theory under discussion. Besides, the development of this theory may represent a paradigm breaking in the area of management and economics of construction, from new possibilities of application of other concepts and techniques that, eventually, may become more useful and accurate in the face of a formalized and scientific understanding of the construction physics.

Problematics

In construction industry

To better situate the issue in the CI context, it is appropriate to present a brief understanding of the causes of the characteristics of production management in the CI. The traditional management and control practices in construction projects were inherited, or made possible, from the manufacturing management techniques

developed at the beginning of the 20th century. According to Koskela (2011), such techniques are closely connected to the production processes in three aspects:

- The science itself, of organization and management (general), was developed as an extension of industrial management and production (with the accumulated knowledge, mainly, of the industrial revolutions and Fordism);
- Such techniques were based on the premise of the use of organizational and, essentially, normative engineering and good practices;
- The management science was studied and developed by engineers or managers of production systems operations, i.e., people involved in the phenomenon in question, being Taylor and Fayol classic examples.

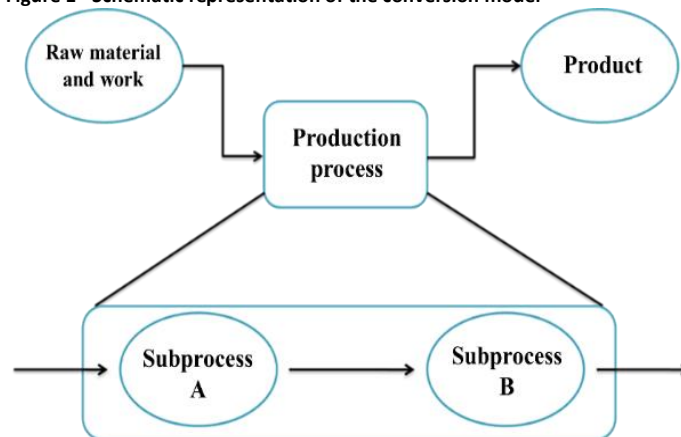
From the 1960s on, management science starts to adopt a different path from the one walked until then, a fact that undoubtedly also influenced the management practices at CI (KOSKELA, 2011). Changes strongly influenced by reports by Gordon and Howell (1959) and Pierson (1959) resided in the fact that in the science behind the management and organization of production processes became, essentially, guided by the social sciences, economics, and quantitative modeling of processes, which favored the development of research and methods in the field of Operational Research. Here, it is important to question whether this approach was adequate for production engineering. It is necessary not only the knowledge about the behavior of isolated subsystems but also about how things should be made/designed and their interrelationships to achieve objectives and functions (SIMON, 1997).

Thus, according to Buffa (1980), many types of research and, consequently, knowledge were developed regarding the modeling of production subsystems such as stocks, production schedules, quality control, etc., to the detriment of deeper and more proficient learning regarding the cause and effect relations between such subsystems. Starkey and Madan (2001), Tranfield (2002), Bennis and O'Toole (2005), Augier and March (2007) and Koskela (2011) show that this approach, over the years, has produced mostly unreliable and essentially irrelevant research to provide a basis that justifies the decision making in the context of the cause and effect relations mentioned.

In this case, the issue is that the behavior of production systems started to be understood from empirical generalizations, developed by researchers external to the phenomenon (production), in contrast to the classical administration. Corroborating to statements of Behrman and Levin (1984) apud Koskela (2011) and Bennis and O'Toole (2005), who highlight the incompatibility between the problems faced in real systems and the methods that are commonly proposed, much in part due to such generalizations, which are inaccurate facing the phenomenon under study. This incompatibility becomes especially critical and deficient in CI.

According to Lu et al. (2010), specifically in construction, both the design of the buildings and the operations management on the construction site have been supported by various models. For these authors, the evolution of the models used has been guided, essentially, abstraction, and simplification of events. According to Goldbarg and Luna (2005), the existence of models (such as those of planning and control) aims to seek a structured view of reality, having to be able to identify the variables and the fundamental elements of the real system, with the function of transporting them to a representation capable of being manipulated by devices or solution methods for a final result. In this sense, as a heritage of the Economic Theory of Production, it is a fact that the models developed for the production management in construction are strongly guided by the so-called conversion model, as illustrated in Figure 1.

Figure 1 - Schematic representation of the conversion model



Source: the authors.

The conversion model foresees the control and management, essentially, of the transformation processes (those that add value), neglecting activities that are consequences of these processes (conceptually: flow activities). Koskela (1992) shows that, in terms of management and control, one of this model's main flaws is that it does not explicitly consider the flows arising from processing activities. The construction management is focused on the control and gains of productive and economic efficiency, to the detriment of processes' effectiveness. Moreover, in convergence with the context previously presented, this model over-simplifies the cause and effect relationships between the various variables of a construction site.

In this sense, too much simplification of the details can increase the error margins of the possible results provided by these models. This simplification can be justified by the absence or inadequacy of a specific and explicit theory, which allows the modeling or application of techniques with more precise (or exact) results for this purpose. Thus, aiming at corrective approaches and, more than that, strategies that break paradigms and are relevant in practice, several authors pertinent to the theme suggest that one of the main contributions would be the attribution, development or adaptation of a specific theory associated with the phenomenon of production (in construction).

As mentioned earlier, the context in which management science is embedded and consequences for academia and practice also influence and reflect in the CI. Thus, the eventual theories related to production management in construction can be identified as deficient or even non-existent in the sector, which becomes something impactful when one seeks to understand, specifically, this fact in CI (HOWELL; KOSKELA, 2000; KOSKELA, 1999b, 2000; KOSKELA; HOWELL, 2002a, 2002b). In this sense, these authors defend the need for innovation in production management practices which, in turn, should be guided by theories (to be built), which could contribute to improving the accuracy and commitment of production management methods, in addition to the methodological renewal in the scientific field.

In the construction of the theory

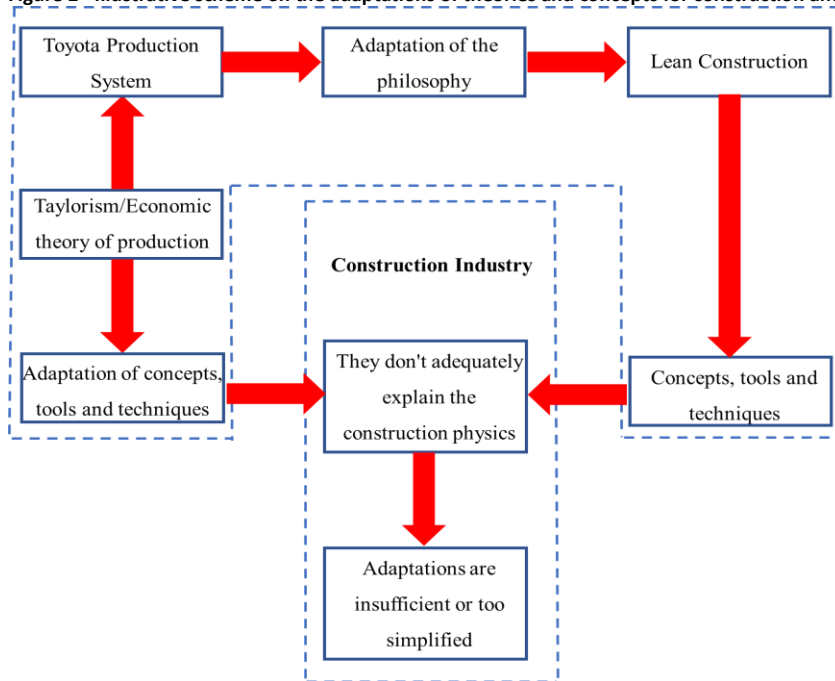
For Balbinotto Neto (2010), "Theories involve models and models involve variables. A model is a formalization of a theory. The models are descriptions of the relationships between two or more variables". According to dictionaries, a theory can be understood as a set of rules or laws, based on knowledge, which explains facts observed in certain systems, forming fundamental principles. According to Glaser and Strauss (2009), a theory can be understood as a lens through which various situations can be analyzed and understood, in addition to allowing a scientifically grounded argument in decision-

making. Rook et al. (2012) state that theory represents reality by identifying certain phenomena and abstracting others.

Popper (2004), in a more precise statement, shows that: “A scientific theory is a mathematical model that describes and codifies the observations we make. Thus, a good theory should describe a wide range of phenomena based on some simple postulates, but it should also be able to make clear predictions that can be tested”. It is noted that a scientific theory can be structured in four main aspects, namely: the development of the mathematical model, the description of phenomena, quantitative prediction, and confirmation of theoretical results in practice.

Thus, according to Popper (2004), in a simplified analysis, a theory should be based on postulates, whose unfoldings should be tested. The lower the susceptibility or possibility of these postulates being falsifiable, the more reliable the theory will be. It is understood that in the area of production management in construction, such postulates are non-existent or too deficient because when there is some specific definition, these are essentially based on adaptations of philosophies or theories derived from manufacturing (mostly). Therefore, there is a lack of formalized axioms in the specific scope of production management in CI, which allow the construction of an explicit theory for such industry sector, as outlined in Figure 2.

Figure 2 - Illustrative scheme on the adaptations of theories and concepts for construction and their impacts on management



Source: the authors.

The scheme of Figure 2 emphasizes that the various adaptations imply deficiencies in the description of production behavior in construction. Consequently, the concepts, techniques, and tools used to assist the professional become insufficient or present too simplified results, generating uncertainties and inaccuracy in construction management.

Research method

According to Gough, Oliver, and Thomas (2012), the SLR consists of checking on a central theme regarding what is known, how it is known, and how such information may vary among the different publications. Besides, it provides an overview of what has not yet

been investigated or understood in such studies. For Levy and Ellis (2006), the result of developing an SLR must constitute a state of the art and bring a new body of knowledge. According to Biolchini et al. (2007), the SLR can be understood as a method to map papers published in a target research theme, resulting in a summary of existing published knowledge. Thus, as far as its importance is concerned, Gough, Oliver, and Thomas (2012) highlight that the SLR results may provide possible paths for new studies relevant to the body of knowledge.

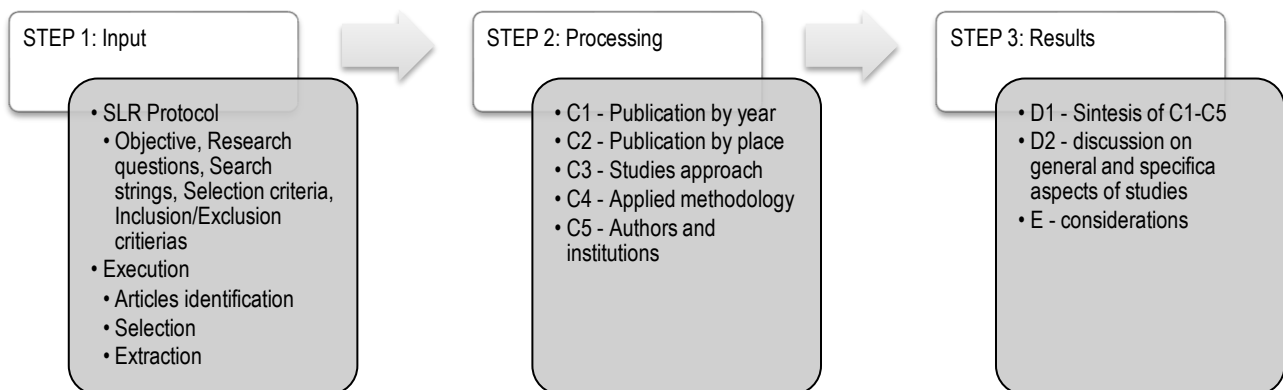
According to Conforto, Amaral, and Silva (2011) and Gough, Oliver, and Thomas (2012), SLR development includes procedures considered indispensable for this. For these authors, such procedures involve providing terms that allow the identification and description of publications, the processing of collected data with a critical focus, the synthesis of the identified context, and characterization of the possible paths to be initiated or complemented.

There are computational tools available to support SLR. StArt (State of the Art Trough Systematic Review) is an example. The StArt was developed by the Software Engineering Research Laboratory of the Federal University of São Carlos (LaPES-UFSCar). The StArt is free software whose version used was the 3.3 Beta 03.

It should be noted that StArt works from three processes that will generate the results of the SLR. The software's first process is called "Planning," in which the researcher defines the research protocol. The second process is defined as "Execution," in which the researcher identifies, selects, and extracts the articles' information. Finally, the third process is called "Summarization." The software, from the results of the second process, produces graphs about the accepted and rejected publications, besides assigning a score for the papers according to the input data in the first process.

The procedure adopted in the research methodology follows, in a general overview, the structure suggested by Conforto, Amaral, and Silva (2011). In this structure, the authors suggest that SLR should be divided into three main stages: input, processing, and output. Regarding the input stage, these authors show that SLR must present the data that will enable its development, such as the research problem and objectives, the search strings, and the articles' inclusion and exclusion criteria. Regarding the processing stage, the authors suggest starting collecting articles by conducting searches in the databases. Finally, concerning the output stage, Conforto, Amaral, and Silva (2011) show that SLR must present a summary of the results, with the possible conclusions and advances, in addition to possible theoretical models on the subject under study that may be developed with SLR. Next, these stages, also schematized in Figure 3, are better detailed.

Figure 3 - Steps and sub-steps of the methodology adopted



Source: the authors.

Protocol

The first activity of the SLR was the definition of the research protocol within the StArt Planning process. In this activity, it is possible to define which are the SLR objectives, research questions, search strings, selection and inclusion/exclusion criteria, publication language and databases used. The definition of the parameters of the research protocol is described in Table 1.

Table 1 - Parameters used in the SLR and their definitions

Protocol Parameters	Definition
Objective	Establish the state of the art on production management theories in construction, from the knowledge of the theoretical approach adopted in publications, the methods of study and the advances in terms of results that address the need for development/use of the theory of production management in construction in the last 20 years.
Research questions	1) What is being proposed for the development of a production theory applied to construction? 2) What is the approach used in the publications? 3) What can be proposed for the body of knowledge in question to fill gaps?
Keywords and strings	(construction theory AND production theory) OR (management science AND construction theory)
Selection criteria	- Periodicals classified in Engineering 1 by Qualis Capes; - Year of publication: 2000 until 2019; - Type of publication: only articles from indexed journals and congresses; - Language: English and Portuguese; - Databases: Engineering Village, Science Direct, Emerald and Scopus.
Inclusion/exclusion criteria for selected articles	Inclusion: the publication deals with the theory of production management in construction; Exclusion: it does not deal with management theory in construction; it is not in the area of civil construction; it is not in the selected languages; Procedure: title reading; abstract and keywords.

Source: the authors.

Execution

The databases were searched using combinations of strings for the defined time interval, as identified in Table 1. Thus, in each database, the **selection** criteria defined in Table 1 were applied. The search resulted in 152 articles in the Engineering Village, 40 articles in Science Direct, 50 articles in Scopus, and 1 article in Emerald. Also, 15 articles were added manually, related to congress articles of the authors' knowledge and important for the theme. This selection totalized 258 publications. The selected publications were recorded in ".bibtext" format to be imported into the StArt system.

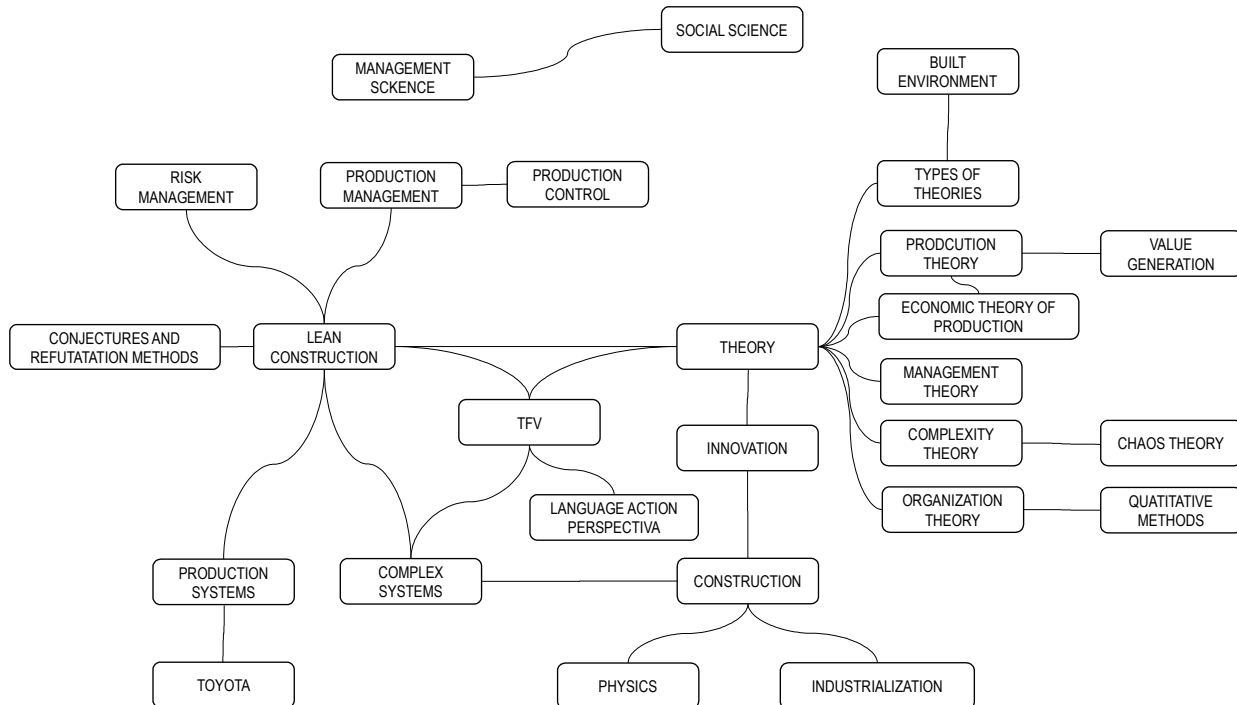
Once imported in StArt, the second step of the execution was to apply exclusion and inclusion criteria over the identified studies. Thus, according to Table 1, this screening procedure involved reading the studies' titles, abstracts, and keywords. As a result, of the 258 identified publications, only 51 (20%) were accepted, with 194 (75%) rejected and 13 (5%) identified by the software as duplicates. Concerning the rejected articles, the vast majority addressed the use of theories for very specific construction issues, such as supply chain management, contract management, value chain management, and case studies in management. Thus, these articles did not contain results or discussions regarding theories focused on production management in general construction. The other publications that were accepted met the parameters of the protocol.

The first activity of the extraction stage was to obtain the complete articles of the 51 selected. Since StArt does not link imported references with the databases, databases were accessed again to archive the publications. Once these publications were duly archived, the second extraction activity was initiated, which involved the complete reading of articles. It is important to remember that, in this activity, the main focus was the search for information so that the objectives described in Table 1 could be reached, answering the defined research questions. The results of this activity are presented below.

Results

The organization of the results of this SLR was based on the one used by Costa, Logsdon and Fabricio (2017) with some relevant modifications to the content of this study. As the first result, in Appendix A, the 51 articles selected in the described methodology are presented. For each article, the research method, the main concepts and the discussion developed or ideas used by the authors were associated. In the following subsections, the general content of the articles and the relationships between the identified themes are analyzed (Figure 4).

Figure 4- Possible relationships between the identified topics for construction theory



Source: the authors.

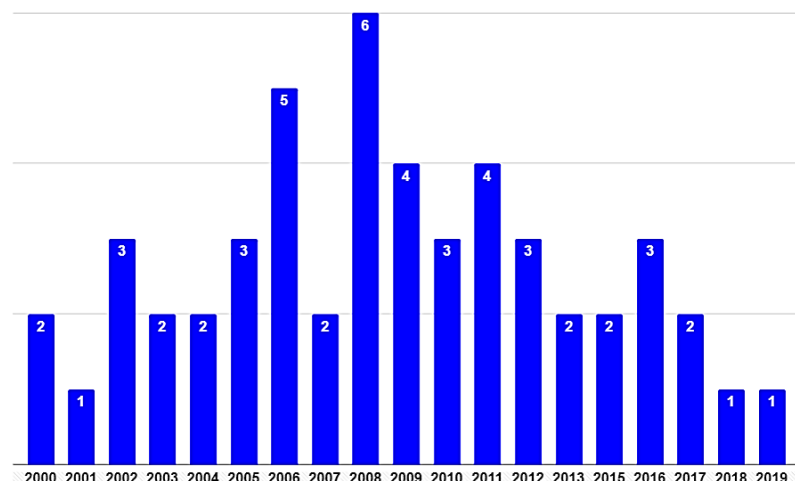
Year of publication

Figure 5 presents the number of articles per year within the defined period. In these 20 years, at least one article has been published per year, emphasizing the largest quantity in the year of 2008. It can be said that the theme (production theory in construction), therefore, is relevant, being on the agenda in the discussions, despite the low number of publications.

As illustrated in the graph in Figure 5, the years with the highest concentration of publications range from 2008 to 2012, with the first year of this range being identified with the highest record of publications. In all years of the research interval defined in the SLR, some publications address the theme. It was not possible to draw justification for such distribution, except for the one that can be defined by the authors' motivation and their respective research groups.

However, more than simply addressing the year of publications, it is necessary to highlight their quantity. According to the results, in 19 years of study, only 51 articles could be selected (an average of 2.7 articles per year, according to the strings used). It can be said that this represents an exceedingly small amount given the importance of the theme and its potential impact on construction, despite being a recurring theme.

Figure 5 - Chart with the distribution of publications by year



Source: the authors.

Dissemination vehicle

An interesting fact is that of the 51 articles accepted, 67% were published in congresses (Table 2). The others, 19 articles, were published in 7 different journals and, in one of these articles, the place of publication could not be identified. It is worth noting that that only 1 article was not in English, being published in Portuguese.

Table 2 - Distribution of the number of articles among journals and congresses

Journals	Quantity
Building Research & Information	6
Construction Management and Economics	4
Lean Construction Journal	2
Buildings	2
Journal of Engineering and Applied Sciences	1
Management Decision	1
Architectural Engineering and Design Management	1
Representativity	33%
Congresses	Quantity
IGLC	29
Encontro Nacional de Tecnologia do Ambiente Construído (ENTAC)	1
Berkeley-Stanford Construction Engineering and Management Workshop	1
PMI Research Conference	1
First International Conference on Built Environment Complexity	1
Not identified	1
Representativity	67%

Source: the authors.

The main publication journal is the Building Research & Information, which has an Impact Factor of 3.887. Besides, according to the Brazilian classification structured by CAPES, from 2013 to 2016, in Engineering I, this journal was classified as A1, which reflects the quality of the published studies and their impact on the related areas of knowledge. The second journal with the most publications (4 out of 18) was Construction Management and Economics, which has an Impact Factor of 2.45 and is classified as B2 by CAPES from 2010 to 2012. Regarding the articles published in congresses, 29 of them were published in the International Group for Lean Construction (IGLC) in different years.

As shown in Table 3, most articles (67%) were published in congresses. Among these articles, 85% were published in IGLC. Scientific dissemination at congresses is relevant because, to a certain extent, it shows a trend among authors whose research interest

involves Lean Construction. They are participative regarding the development or discussion of a construction management theory.

Another interesting analysis from Table 3 is related to publications in journals. In this sense, there is a significant decrease in publications. Almost 60% of the published articles are concentrated in two journals of relevance to management and construction economics. This difference in publications between congresses and journals can be explained by the fact that the agenda in question is relatively recent and, faced with this, there is a relative immaturity of publications and a lack of more concrete and impactful results, which end up being difficult factors for publications in journals.

Approach of the studies

Concerning this third category, we wanted to identify whether the focus of the studies:

- was directed towards the development or demonstration of concepts capable of structuring a theory; or if
- was essentially based on discussions based on theories and concepts, without proposing or demonstrating any possible solution as part of this theory.

Only 25% of the studies proposed potential parts of the theory of production in construction or could be critically analyzed. The remaining 75% present conceptual discussions, nevertheless also important for the contest.

Some key concepts are recurrent and should be highlighted: Lean Construction, Transformation-Flow-Value (TFV), and Complex Systems. Organizational theory is a less recurrent concept Table 3 presents the representativeness of the main concepts or theories addressed in the articles. It is interesting to note that most of the publications have results that were conceptually based on Lean Construction principles since such articles mention this philosophy explicitly (most of them) or implicitly. This may be an indication that researchers associated with lean thinking may be leading research on production theory in construction.

Table 3 - Percentage of the main concepts or theories addressed in the selected articles

Concept approached	Percentage of articles
Lean Construction	72.5%
TFV	31.4%
Complexity theory; complex systems	13.7%
Organizational theory and economic theory of production	11.7%

Source: the authors.

The results related to the publications' approach show that the research and corresponding results are still quite embryonic. The results of the 13 articles that present something beyond a discussion can be considered the low impact, considering that they are products that still cannot be considered as conclusive when analyzed as possible parts of the theory in question. This statement is coherent, considering that, there are not yet the molds on which this theory can be built, since, for this, the articles are quite vague, dealing essentially with philosophies and management tools that do not necessarily provide the necessary prerequisites for the development of this theory.

We observed that the concepts and theories that were addressed are essentially summarized in attempts to understand construction considering Lean Construction principles. The studies generate discussions, analyses, and models (quite simplistic) based on the generation of value, management of flows (with the mention of the TFV concept), and the economic theory of production. It can even be said that the analyses and discussions are even repetitive. It is often stated that the development of the theory in question should contemplate the concept of TFV, but without presenting something

concrete that can be affirmed as a postulate of this theory. Moreover, there is no deepening in the use of other concepts and theories that, in a certain way, could complement the mentioned approach and provide other ways of understanding and new resources.

Methodology used

The analysis of the scientific method was restricted to studies that presented a new proposition. We discarded discussion studies essentially based on bibliographic reviews and strongly based on the authors' opinions/personal criticism. Thus, among 13 articles with new propositions, the research method used was essentially based on a literature review with a development strongly based on the authors' empirical observations without a better-structured research method that would enable the continuity of research and the formulation of postulates. In only 2 of the 13 articles, exploratory studies or case studies were conducted to test or verify the statements or models described/proposed throughout the articles.

Analyses essentially based on bibliographic reviews, the strong empirical bias of most of the selected articles, and the non-existent formulation of axioms in studies that precisely address the construction of a theory, seem to demonstrate a hesitation the part of researchers. Perhaps this hesitation may be due to the low quantity of publications (and advances) and little concrete information on the subject.

More than that, the characteristics of the methodologies suggest a discontinuity of the articles' discussions and results, in the sense that analysis is constantly resumed without being conclusive and without a proposition to allow the advance of discussions and results.

Authors and research institutions

The fifth category concerns authorship. It is understood that this category is relevant to identify the main researchers and research institutions on the subject and the countries of origin of these institutions. 73% of the studies were authored by only four researchers: Lauri Koskela, Sven Bertelsen, Gregory Howell, and Glenn Ballard. The remaining 27% are distributed among 62 authors, who are responsible for the publication of 1 to 2 articles.

Among the authors of relevance stands out Lauri Koskela, with authorship in 47% of the publications (24 articles) in the study sample, as principal researcher or co-author. In the last 20 years, Lauri Koskela published articles being affiliated to 3 different institutions, being them: VTT - Technical Research Centre of Finland (Finland) with seven articles; University of Salford (England) with 16 articles; University of Huddersfield (England) with 1 article. Other institutions recurrent in the articles, such as the Lean Construction Institute (USA) and the University of Berkeley (USA), are also identified as affiliations of other authors.

It should be noted that only two Brazilian institutions participated in producing articles of the studied sample, being the Federal University of Paraná (UFPR) and the Federal University of Rio Grande do Sul (UFRGS). The production related to these institutions are in total 5 articles, corresponding to 10% of the amount.

Faced with a topic of recognized importance and the need for developments, the number of researchers who are notably dedicated to this topic is critical. According to the results, in more than 70% of the publications, only four authors are recurrent. Among these, Koskela stands out with in-depth discussions, providing an overview of the importance of research on the subject and, in a way, the first steps to be taken.

Therefore, there is a lack of greater incentive for research in management and construction economics within institutions. In the case of Brazil, given the importance of construction as an industry and its participation in the country's economy, it is fair to have greater support for Brazilian researchers. This incentive will certainly contribute to greater economic, innovative, profitable and reliable construction.

Regarding the general aspect of the articles

It is understood that if the purpose of the research is to build or provide input to a theory, then this should be done formally and not just by presenting philosophical discussions. In the first instance, such discussions are necessary but become irrelevant when recurrent, and especially when they do not substantiate, result, or are not formalized as parts of the theory. Also, there is a concern to observe events before or during the formulation of a hypothesis in some articles. This concern points to the structuring of inductive research when, given the current stage of development of the theory on the agenda (incipient), it is understood that a deductive method is more useful.

According to the understanding of Popper (2004) described in the introduction, the development of a theory should, in the first place, encompass the identification and description of phenomena, based on some simple axioms. It is understood that this involves understanding the physics behind the construction processes. Thus, knowing that construction involves a limited and known number of processes facing its production system, the boundary conditions can and should be established. Culminating in single or joint solutions from establishing a well-defined value problem solution would come through compatible techniques or tools. However, once again, there is a need to establish postulates that allow establishing such conditions. However, this is not what the selected articles indicate.

Given the SLR results and the discussions in this article, the panorama that the selected articles show is a line of research, as said, still quite embryonic and with very few conclusive results. Perhaps the most conclusive information is the coherence of the analyses that affirm that the production in construction should be managed from the TFV triad, which, of course, corroborates the principles of Lean Construction and, especially, with what Koskela (1999b, 2000) proposes. The TFV triad can be considered as one of the initial steps, but still very vague for developing a theory, given the challenge and the need to establish postulates.

Besides, several articles mention Lean Construction as a "theory" to be adopted and able to help resolve various problems, and this is understood, by some, as something conclusive concerning the theory on the agenda. Based on Karl Popper's ideas, this article does not interpret Lean Construction as a theory, but rather as a process management philosophy that includes several tools. Obviously, given the undoubted benefits and potentialities of this philosophy, it must be considered in constructing the theory under discussion. This consideration has been done, with reservations, because several authors approach the vision of the TFV in their studies.

Furthermore, most of the related articles are restricted to conceptual or philosophical discussions that are recurrent without presenting anything conclusive or, at least, generating some progress in the topic under discussion. Also, most authors are limited to analysis only within the scope of Lean Construction, which impoverishes discussions and advances in theory construction. It is understood, from Table 1, that the major contributions proposed by the main authors of the theme are in the understanding that the management should not be restricted to the Taylorist vision and to the Economic Theory of Production. As several authors listed support, first of all, the construction

should be understood as part of a system composed, basically, of transformations, flows, and generation of value which, with all certainty, the philosophy of Lean Construction and its tools can positively aggregate to the construction of the theory. However, few propose the analysis of the work's production under the aspect of complex systems, within which the non-linear dynamics can provide important contributions.

Research questions

Finally, the research questions described in Table 1 of the methodology are answered below.

What is being proposed for the development of a theory of production applied to construction?

According to the data analyzed and the comments already made, it can be said that very little is being done or proposed. Perhaps, the greatest contributions proposed are in the understanding that the management of the construction projects should not be held hostage only to the Taylorist vision and the economic theory of production. As several authors maintain, first of all, construction should be understood as part of a system composed, basically, of transformations, flows, and generation of value, which, with all certainty, the philosophy behind Lean Construction and its tools can aggregate. Few propose the analysis of the construction site under the aspect of complexity and dynamism.

Thus, it is reaffirmed that the few proposals considered as advances are not being structured with the formalities foreseen in the construction of a theory. Such a task is challenging and laborious, but it should not prevent possible advances and proposals from being formalized as part of the construction theory. In addition, this formalization would make it possible to systematize refutability tests, which is an important step in the construction of a consistent theory.

What is the approach used in the publications?

Most of the selected articles are restricted to recurrent discussions without presenting anything conclusive or, at least, generating some progress in the topic under discussion. More than 70% of the articles are restricted to analysis within the scope of Lean Construction, which impoverishes discussions and advances in constructing the theory.

What can be proposed for the body of knowledge in question to fill the gaps?

As a philosophy, Lean Construction and its techniques and tools can complement each other by adding particular construction management attributes to formalized theories, such as complexity theory.

Nevertheless, there is a latent need for scientific formalization of what comes to be the understanding of production behavior in construction and its consequences. This understanding should be done solely based on facts, without biased analysis toward one research stream. It is suggested that this be done through deductive research for discussions and subsequent tests of falsifiability.

Considerations

The main objective was to describe the state of the art on developments and discussions of an explicit production management theory for the construction industry. It was proposed an SLR to support the analysis of research methodologies, publication results,

among other parameters. It was possible to establish, in general, the current stage of development of a production management theory for the construction industry, as well as the discussions on the agenda among researchers.

Here we highlight the need for greater collaboration among researchers. The topic on the agenda is sufficiently challenging and relevant, especially for the practice of management, justifying the structuring of a collaborative network, which may even be multidisciplinary. Such collaboration is important so that research does not revolve around discussions that do not generate or promote advances, or even research that is notably biased, concerning researchers' preference for one or another conceptual line. Also, this need for collaboration aims to aggregate other concepts and approaches.

We observed that most of the studied articles were developed considering the Lean Construction concepts. With greater collaboration and dissemination of research, there is room for consideration or inclusion of concepts and theories that can complement and correct any flaws in the mentioned philosophy. This would help to weave, with greater precision and less susceptibility to falsifiability, the theory's structure in question. Developing a theory beyond a philosophy would also contribute to constructing a more uniform system where each part is compatible with its effects.

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Appendix A: Final sample of the systematic literature review

Research method	Reference	Main concepts used	Discussion developed (excerpts taken from the abstracts, introductions and conclusions of the papers)
Case study	Koskela and Tommelein (2009)	Lean Construction; Economic theory of production	Opposition of the conceptual view of the economic theory of production, applied in construction, with lean construction from a case study.
Case study	Saurin et al. (2013)	Lean Construction; Complex systems;	Applying of guidelines for managing complex systems such as the construction sites in a case study.
Case study	Dos Santos et al. (2002)	Lean construction; management theory	<i>“The paper presents the context of production management evolution and assesses the application of some heuristic production approaches within construction sites of Brazil and England.”</i>
Empirical observation	Koskela (2000)	Lean Construction; TFV	Understanding the theory of production in construction as a model based on transformation, flow and value.
Empirical observation	Koskela and Vrijhoef (2000)	Innovation in construction; production theory	<i>“Discussion development based on the hypothesis that the prevalent theory of construction is deficient and implicit, and this is the major barrier for innovation in the construction industry.”</i>
Empirical observation	Koskela and Vrijhoef (2001)	Innovation in construction; production theory	<i>“In this paper, an explanation for the low innovation activity in construction is put forward. The central argument is that the current theory of construction is one root cause for low activity.”</i>
Empirical observation	Koskela and Howell (2002a)	Lean Construction	The paper addresses the use of two management methods: Last Planner and Scrum from a summary of their theoretical foundations.
Empirical observation	Koskela and Howell (2002b)	Project management	Discussion about the general and conceptual aspects of a project management theory.
Empirical observation	Bertelsen and Koskela (2003)	Complexity theory; Chaos theory	<i>“The paper’s objective is to study construction projects poised on the edge of chaos and to explore the forces that may turn projects chaotic in the sense that the project crosses this dangerous edge.”</i>
Empirical observation and action research	Koskela, Ballard and Howell (2003)	Lean construction	Discussion of efforts for changes in the construction sector.
Empirical observation	Bertelsen and Koskela (2004)	Lean Construction; Toyota production system	<i>“The paper establishes an overview of the principles guiding best practice project management today, and argues that lean construction has progressed beyond lean – at least in the sense propagated by Womack and Jones.”</i>
Empirical observation	Bertelsen (2004)	Lean construction; complexity theory; TFV	<i>“The paper proposes that a change in the underlying paradigm is happening and that a new research agenda should be established with an outset in the lean understanding of the construction process as it is known from the construction sites and with a complex system understanding of the nature of this process.”</i>
Empirical observation	Koskela (2004)	Lean Construction; TFV	<i>“The main tenet of this paper is to show that lean construction represents a movement to theory-based construction management.”</i>
Empirical observation	de Valence (2005)	Theory of production; economic theory of production	<i>“The purpose of the paper is to discuss properties of construction production technology in the context of the economic theory of production and the production function.”</i>

Research method	Reference	Main concepts used	Discussion developed (excerpts taken from the abstracts, introductions and conclusions of the papers)
Empirical observation	Pannanen and Koskela (2005)	Project management; Complexity theory	"This paper presents concepts and practices with which project (knowledge) management must foster complexity when it is necessary and dampen complexity when it is unnecessary in order to generate value and control time and costs."
Empirical observation	Bølviken (2006)	Lean Construction; TFV	"This paper is an attempt to comment and further develop the theory of production and construction as presented by Koskela (2000)."
Empirical observation	Koskela and Ballard (2006)	Lean Construction; Economic theory of production	"This paper explores the alternative of subordinating the economics-based theory of project management to the theory of production. A recent synthesis of an economics-based project management approach is critically assessed, and an alternative, production-based approach is outlined."
Empirical observation	Howell and Macomber (2006)	Lean Construction; Language Action Perspective; TFV	"This paper joins the continuing exploration about the nature of projects and their management. The power of lean approaches in the materiel/information domain is well established and rests on solid conceptual foundations."
Empirical observation	Winch (2006)	Lean construction; risk management	"This paper responds to the invitation to debate the theory of production in construction from the advocates of lean construction."
Empirical observation	Henrich et al. (2006)	Lean Construction; TFV	"The aim of the paper is to identify where the most relevant methods used by the construction industry fail, as well as to provide guidelines for the development of new management tools."
Empirical observation	Koskela et al. (2007)	Lean Construction; TFV	"This paper aims at reporting new developments in the understanding of the TFV (Transformation-Flow-Value generation) theory of production. This theory identifies three interdependent angles to production: transformation (achieved by resources workers, machines etc.) oriented (T), materials oriented (F) and customer oriented (V)."
Empirical observation	Bertelsen and Sacks (2007)	Construction physics; complex networks	"This paper looks at the industry and the projects from flow and complexity points of view and observes that the whole industry forms one very complex and dynamic network, whose nature and behavior is poorly understood."
Empirical observation	Fernández-Solís (2008)	Construction industrialization	Philosophy on the classification of construction as an industry.
Empirical observation	Alsehaimi and Koskela (2008)	Lean construction; Project management theory; TFV	"In this paper, a simple quantitative analysis of the findings and recommendations in different studies of delay has been carried out."
Empirical observation	Andersen et al. (2008)	Lean construction; social logistics	"In this paper the authors address the social infrastructure and the company culture of the construction processes as prerequisites for successful improvements in the logistical and economical processes in construction."
Empirical observation	Björnfot (2008)	Lean construction; TFV	"The aim of this paper is to make Lean Construction more accessible for construction participants who are interested in learning more about the advances of Lean Construction theory, but are unable to do so due to the vast availability of associated theories."
Empirical observation	Rooke, Koskela and Kagioglou (2009)	TFV; Organization theory	"A review of types of organization research is conducted and it is suggested that the relationship between theory and data collection provides a more detailed and illuminating taxonomy than a distinction between qualitative and quantitative research."
Empirical observation	Rooke et al. (2010)	Lean construction; TFV	"The authors treated value as a problem for lean knowledge management and offered some suggestions as extensions and clarifications of Value theory."
Empirical observation	Salvatierra-Garrido, Pasquire and Thorpe (2010)	Lean construction; value; value generation	"This paper proposes society is dependent on construction and it should predominate over particular interests, if the construction industry potential is to be fulfilled."
Empirical observation	Tillmann, Tzortzopoulos Formoso (2010)	Lean Consturction; value generation	"The purpose of this article is to explore benefits realisation from a theoretical perspective and highlight its potential contribution for project management, specifically for further developing value generation concept in construction projects."

Research method	Reference	Main concepts used	Discussion developed (excerpts taken from the abstracts, introductions and conclusions of the papers)
Empirical observation	Koskela (2011)	Social science; Management science	"The paper aims at initial understanding of the reasons for this spectacular failure of (general) management research to reach relevant results in the period of 1960-2010."
Empirical observation	Rooke et al. (2012)	Lean Construction; TFV	"The aim of this paper is to establish key issues that a theory of production should address, to conceptualize these issues and to sketch an account of their interaction."
Empirical observation	Koskela and Ballard (2012)	Lean construction	"The authors suggested that the failure to include production in theory has been one major cause for the problematic situation of management science in the last 50 years."
Empirical observation	Bølviken (2012)	Production theory	"This paper reviews the literature on existing ways to categorize production before presenting a new model for such categorization: the Organization-Product-Matrix."
Empirical observation	Biton and Howell (2013)	Lean construction; complex systems; TFV	"This paper traces the journey of Lean Construction theory from its inception by drawing on the work of leading thinkers such as Koskela, Ballard, and Bertelsen and then looks forward to the emerging field of complexity theory and its relationship to projects."
Empirical observation	Pavez, González and Alarcón (2014)	Lean construction	"Describes and analyzes the theory of integral vision, as a framework that embraces different insights, theories and practices in such a manner that strengthen the project management under lean construction perspective."
Empirical observation	Antunes and Gonzalez (2015)	TFV; Lean Construction	"This study develops an in-depth literature review to examine the existing knowledge about production models and their characteristics in order to establish a foundation for dynamic production systems management in construction."
Empirical observation	Ansah, Sorooshian and Mustafa (2016)	Lean construction, Project management	"This paper seeks to establish the fact that lean construction presents a new and robust approach to dealing with the wastes in the construction industry which the current or conventional project management models have failed to control."
Empirical observation	Newton (2016)	Management science	"Philosophical discussion on how forms of knowledge should contribute to the formation of a theory for the management of construction, involving social realism."
Empirical observation	Saurin (2016)	Lean construction	"Discusses how the Functional Resonance Analysis Method (FRAM) can be useful concerning the control of variability."
Empirical observation	Koskela (2017)	Organization theory; Quantitative methods	Discussion about the irrelevance and weak contribution of research on production management over the years and the root cause for this fact.
Empirical observation	Drevland and Gonzalez (2018)	Valor; Production theory	"In this paper, the authors develop an understanding of buildings as production assets from a production theoretical point of view by reviewing relevant production theory in the context of buildings."
Literature review	Henrich et al. (2005)	Production control; Critical chain; Line of balance	Discussion of planning and control methods for different types of construction projects.
Literature review	Clarke and Janssen (2008)	built environment; labour process; production; social relations	Philosophical and historical discussion on production in the built environment.
Literature review	Green and Schweber (2008)	Built environment; Types of theories	Philosophical discussion on the development of a theory for the built environment.
Literature review	Fernández-Solís (2009)	Lean Construction; Conjectures and Refutations Method	Discussion about what aspects of production engineering the construction should be associated, in order to understand its systemic nature.
Literature review	Pasquire and Connor (2011)	Lean Construction	Discussion on the sources of consultation used for the development of Lean Construction articles at IGLC.
Literature review	Ivory (2017)	Management theory	"The article presents a discussion and response to Koskela (2017)."
Survey	Marjasalo et al. (2011)	Production control; Production management	Analysis of the time allocated to the planning/supervision of activities at the construction site.
Survey	Ebbs et al. (2015)	Lean construction	Comparative study of the application of Lean Construction and its impacts on contracts in Ireland.

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