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Operations management concepts applied to offsite construction

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ABSTRACT
The Architecture Engineering and Construction (AEC) industry has been criticized for low productivity, lack of innovations, damage to the environment, lack of improvement. Several innovations have emerged to address these problems and, in this paper, the relationship between operations management (OM) and offsite construction will be discussed. The purpose of this paper is to present a proposal for the application of OM concepts in offsite construction. A research method based on the assumption that construction processes can be analyzed as production systems will be used. The resulting proposal consists of the exploration of potential applications, benefits, and barriers of OM in offsite construction based on the current experience of OM in manufacturing processes. A thorough discussion about the implications of this proposal in a project and supply chain levels are presented. The most important conclusions were related to the need for applying OM concepts in offsite construction projects and the need for more research in this direction to prove the proposed proposal.

KEYWORDS
Lean construction; offsite construction; production system; operations management

INTRODUCTION
The Architecture Engineering and Construction (AEC) industry has been criticized for low productivity, lack of innovations and damage to the environment (Xiao and Yanling 2013). Also, it is well known that the productivity of the AEC industry has stagnated at low levels, with no sign of improvement, as opposed to other industries, such as manufacturing or the automotive ones (McKinsey Global Institute 2017). To address the AEC industry problems, several innovative approaches, methods, and tools have emerged: lean construction, offsite construction, building information modelling (BIM), virtual design and construction (VDC), just to name a few. But more importantly, previous studies showed that there are intrinsic relationships between these innovations that also helps to maximize their capabilities and/or functionality.

Lean construction results from the application of a new form of production management (called lean production) to construction (Howell, 1999). Koskela et al. (2002) defined lean construction as a way to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value. Shah and Ward (2007) defined lean production as: "an integrated socio-technical system, whose main objective is to eliminate waste by concurrently reducing or minimizing supplier, customer, and internal variability". Since its introduction on the book "The machine that changed the World" (Womack et al., 1990), the term

"lean production" has become one of the most widely cited references in operations management (Lewis and Slack, 2003). In this context, operations management (OM) has its core in management of processes, operations that produce goods and services (Krajewski and Ritzman 2002).

Other concept related to operations management is Operations science (OS), which is defined as the study of transformation of resources to create and distribute goods and services. (Factory Physics, 2022). OS focuses on the interaction between demand and production and the variability associated with either or both. OS also describes the set of buffers required to synchronize demand with production (PPI, 2022). Another concept related to OM is Operations Research, which is defined as a systematic approach to solving problems, which uses one or more analytical tools in the process of analysis (Zandin, 2001). These OM related concepts have found a lot of applications in the manufacturing industry, which has been widely documented.

Mostly implemented in the manufacturing industry, OM concepts have proved their benefits in terms of costs, time, and quality. However, despite of the knowledge of its benefits, non previous study has addressed the application of OM in offsite construction yet. On the other hand, offsite construction is a term that has gained a lot of popularity on the last 10 years, offsite construction refers to a construction method that "brings on-site construction works into a climate-controlled facility where advanced machinery and manufacturing technologies can be utilized to prefabricate buildings in a standardized and efficient manner" (Liu, et al, 2017). Offsite construction creates a space for application of lean supply with similarities driven by manufacturing to construction but demands more integrated processes (Fearne & Fowler et al., 2006).

Since the offsite construction projects falls in the intersection between manufacturing (for manufacturing offsite components for these projects on manufacturing shops) and construction (for building and assembling these components on the construction site) industries, it represents a suitable opportunity to apply OM concepts that have already been tested in manufacturing. Therefore, the purpose of this paper is to present a proposal for the application of OM concepts in offsite construction, including the potential benefits and barriers to this proposal considering the nature of the AEC industry.

This is the structure of the paper: literature review about offsite construction improvements, and OM applications in construction will be presented, which will show a gap between OM concepts and offsite construction. A research method based on previously studied assumptions about the conception of construction processes as production systems (similarly to a production assembling line used in manufacturing) will be shown. Results and discussion will show the potential benefits, barriers, and implications at a project and supply chain levels for the application of OM in offsite construction projects. Finally, conclusions will be presented about further applications of this proposal.

LITERATURE REVIEW

It was documented that to obtain better results, the construction industry should shift manual on site activities to a controlled factory environment (Goulding and Arif, 2013), which will allow construction professionals to apply manufacturing concepts on their projects. Regardless of the applicability of manufacturing concepts to construction projects, the construction industry has rejected many ideas from manufacturing because of the belief that construction is different

(Howell, 1999). However, manufacturing provides the elements from which buildings, bridges, highways, and factories are constructed (Ballard and Arbulu, 2004). As we will see, many studies have studied the application of lean-related tools to offsite construction with clear improvements.

Masood et al. (2017) implemented Value Stream Mapping (VSM) as a performance measurement and lean improvement tool for the offsite construction supply-chain for housing projects, which then was enhanced by the use of BIM. Marte Gonez et al. (2021) found many positive interactions between lean tools and the offsite construction housing projects of the UK. There were many lean tools applied such as the Last Planner System, visual management, just-in-time (JIT), and also the application of BIM, which helped to bring several benefits in terms of cost reduction, time reduction, quality improvement, higher performance, etc. Also, previous studies also shown improvements in modular construction.

Innella et al. (2019) analyzed lean strategies for supply chain, transportation, and assembly management in modular construction projects. It was found that adoption of a dependent inventory system based on the JIT principle, integration of simulation tools with VSM, and integration of lean and agile principles may help to lower the waste in the supply chain. Carvalho and Scheer (2019) developed a conceptual framework in which lean is the integrator for developing modular construction, using BIM and integrated project delivery (IPD). These studies give us a reference regarding the integration of technologies with offsite construction, and its relationship with manufacturing processes as part of the supply chain for this type of projects.

Moreover, OM-related concepts have also been studied in the context of the AEC industry, Heiman (1960) stated that operations research may perform for construction management the service it has already performed in many other fields, and it can be expected the examination of problems to seek causes rather than to treat of effects. Tetik et al. (2019) developed the concept of direct digital construction (DDC) as a technology-based operations management practice aiming to improve construction performance through design reuse and diminished human interpretation. The core principle of the practice is to direct the value-adding operations over the building's lifecycle through the digital design model, resulting in increased reusability, project-specific differentiation, automation of designs and processes across projects, and efficiency improvement in the entire supply chain of the project throughout its lifecycle.

Koch (2004) found that operations management in construction is closely related to the conditions of the construction site, have some social implications about the easy in which the operations are developed on the construction site, and several lean construction tools (such as last planner) can be understood better by using the OM lens. Gehbauer et al. (2007) showed that all construction operations are affected by disturbances (due to inherent variability in a construction project context), and by examining these disturbances throughout project delivery, a dynamic system behaviour of construction operations can be developed to overcome these problems. Spearman and Choo (2018) developed a Product-Process Matrix, in which for the purposes of optimizing project execution performance, it is argued that projects can be viewed as networks of production systems.

As we saw, several research has been developed related to lean construction in offsite construction, OM applications in construction processes as well, and the combination of different technologies in any of these contexts. Unfortunately, no study has been done about OM applications in offsite

construction, which is the research gap that this study will start to bridge by providing a proposal that will explain the applications of OM in offsite construction, considering the characteristics of offsite construction projects, and at how extend the current use of OM in manufacturing is applicable to that type of projects.

METHOD

The present study will use the Product-Process Matrix provided by Spearman and Choo (2018) from Project Production Institute (PPI). Figure 1 shows this matrix, which one can identify all the different types of processes as part of construction projects by examining them at a sufficient level of detail. Exampled of these processes in construction projects can be found with more detail in Spearman and Choo (2018).

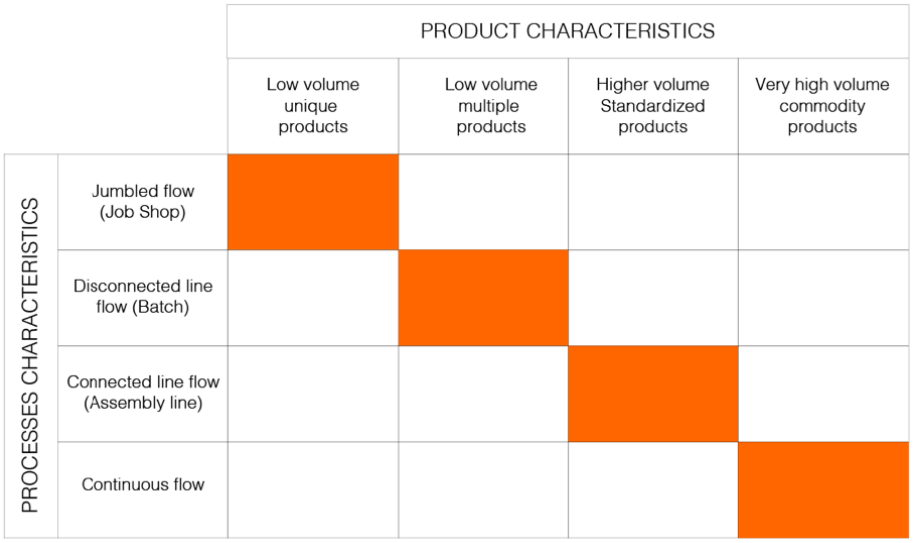

Figure 1. PPI's proposed Product-Process Matrix. Extracted from Spearman and Choo (2018).

Firstly, by using this matrix for a specific construction operation, we can analyze it as a production system, which is a concept studied and understood in the manufacturing industry. In this context, the nature of an offsite construction project suits good for transferring tasks traditionally developed on the construction site to the manufacturer's shop, in which a more controllable environment can be the one in which the final construction component is produced. Secondly, the applicability of OM in offsite construction will be presented taking into account the assumptions for "viewing" a construction process as a production system. Thirdly, potential benefits and barriers of this proposal will also be presented in order to understand the implications of this new approach for offsite construction projects.

RESULTS

Applying tools and methods from a production line to a construction process developed in the field would require significant changes on the way construction managers conceive construction projects, but this is a task that will provide enormous benefits to the AEC industry. Differences such as the location of the labor, controlled environment against a high-variable environment, etc. are the most relevant considerations to take into account when a proposal for the application of OM in offsite construction is made. Nonetheless, these are several ideas to consider:

Applicability of OM in offsite construction

Since much of the work is developed in a production line with a controlled environment, manufacturer of construction components is able to have a more influential participation in the delivery phase of the project. Transferring work from the construction site to the manufacturer's shop will provide more space available on the field, but it will require more coordination between the parties involved during the project delivery. Due to this controlled environment, variability provided by "third party actors" (such a weather, natural disasters, etc.) can be overcome more easily on a shop rather than a construction field. New metrics (cycle time, throughout, work-in-process, % of fill rate) can be used to control the production line based on a better understanding of what the manufacturer's capability is, and therefore provide a more accurate estimate of schedule, and costs.

Transportation of construction components (the end products of the manufacturer) will be extremely important in order to deliver them on a timely manner, as well as the input from the manufacturer's designers since the work will be developed by them, and they are the suitable stakeholders to know how to provide a better outcome considering the project objectives. Early involvement of the owner will play a significant role in how the project is delivered since much of the work is no longer solely developed by the general contractor, but now there are multiple specialty contractors (or trade partners) that will have significant amount of work on their sides. However, the decision of developing an offsite construction project should start by the perception of the owner of how to approach their project.

Analytical tools usually applied in OM in manufacturing can be very useful to offsite construction in order to record data which will enrich the estimates and how the variability is handled, and more importantly, it will provide a non-lost learning curve about the improvements and changes made throughout the production process of several construction components. Simulation tools using OM concepts will be developed not only in the shop environment but also in the construction field environment considering the option of having less steps developed on the field, and therefore less risk of providing an inaccurate estimate of the resources required during the installation process of the construction components developed on the shops.

Potential benefits

More quality in the construction component since its developed on a controlled environment and the design and manufacture of these components can be integrated due to the manufacturer involvement since early on the project. Less exposure to third party actors due to being working on a controlled environment. Safety can be improved due to the less exposure to disturbances commonly found on a construction site. The production of the shop drawings is considered since the beginning of the project as the manufacturer has some impact on the design of the project, and "re-work" due to inconsistencies between the initial design and the detailed design can be reduced. Learning process can be improved, and estimates can be provided more accurately as the repetitiveness is higher than a regular construction project. OM metrics from the manufacturer will affect the OM metrics of the general contractor, who can take advantage of that by formulating its work on site using OM as well. Variability can be measured and understood by OM tools and methods, which will allow a more reliable plan regarding project delivery.

Potential barriers (or challenges to overcome) for implementing OM in offsite construction
There is a lack of knowledge of construction professionals in terms of OM concepts, as lean construction seems to be the dominant concept, but it also presents some gaps in terms of how to link its tools and methods to real sustainable improvements in project delivery. Owners might be reluctant to this change in the approach of project delivery due to many reasons such as local conditions related to the lack of companies providing these services, or lack of manufacturers with this knowledge. AEC industry is fragmentated, and this proposal breaks down this current state by integrating the members of the supply chain to deliver the project by transferring work from the site to the shop, which will require changes on the business models of many companies that will go to this path, and this change takes time. Moreover, viewing the construction operation as a production system and using OM metrics will require to integrate manufacturer professionals to provide a better framework that will work for the conditions of construction projects, but this path seems to be closer by the application of offsite construction.

DISCUSSION

The presented proposal provides many considerations to conceive operations in construction in order to look for optimal solutions in terms of the resources to be used in offsite construction. It has to be mentioned that the opportunity provided by operation processes in this kind of projects generates a more strongly linkage between construction and manufacturing, which allows the AEC industry to benefit from the current improvements done in manufacturing. From the applicability of OM in offsite construction to the potential benefits and barriers we can see so much opportunities for improve the way construction projects are developed, and there are many implications detected at a project and a supply-chain levels.

Project-level implications
Spearman and Choo (2018) argued that projects are properly viewed as networks of production systems, which provide a whole different perspective of this proposal in order to "model" the complete project as the summation of the production systems that governs the modeled project, as we can see in equation 1.

$$Offsite\ construction\ project = \sum production\ systems \qquad (1)$$

Specifically, offsite and modular construction projects provide a great opportunity due to its strong connection with manufacturing process and because (in some cases) most of the project is developed on the manufacturing shops and the work on site in reduced to transportation and assembling operations. Also, it is at a project level that decisions should be taken into account considering not only the commonly known project management metrics such as cost and time, but know operations management metrics should be taken into consideration in order to understand how this production system is behaving and provide a better understanding of how the summation of all these production systems will impact the project as a whole.

Supply chain-level implications
Considering all the supply chain member, the general contractor would work as a "coordinator" of the components delivered by the speciality contractors that develop most of the work in a controlled environment, although this provides a lot of challenges as the construction site remains unique and the project components still need to "flow" through it in a specific order (matching

problem remains). A lot of collaboration is imperative in order to develop this type of approach (OM) with all the stakeholders involved on offsite construction project delivery. Moreover, inventory-related decisions will also be a topic to discuss with the whole supply chain and it should be considered on the contracts between the parties since the idea of providing pre-assembled elements through offsite construction is to install them on their final position as part of the project, and not to be stored similarly to a stock of material. In this context, tools that provide real-time data and allow to interact with other members outside of their respective organizations is crucial for providing feedback constantly and allow iterations between the many scenarios analyzed to optimize the production systems as a whole.

CONCLUSION

This study presents a proposal for the application of operations management concepts in offsite construction projects based on the current approach used in manufacturing. The current relationship between manufacturing and construction industries in the supply chain of offsite and modular construction projects also represents a "suitable" context to apply this proposal as the operations management concepts used are well known by manufacturing companies (which serve the AEC industry). By using similar concepts, its argued that the trades (general contractor and specialty contractors) involved can "sync" their work and production in order to fulfil the production system objectives, which will require trade-offs between the parties involved and make a decision regarding the work of each party.

To enrich this proposal, a framework to rationalize these ideas should be the next step in order to provide some type of "artifact" that will serve as a guideline to use OM concepts, metrics, and more ideas used in manufacturing, but know with the construction environment. In this context, the steps followed when operations research is applied on a shop environment can be used in a construction field environment in order to provide a solution to any current problem in a construction operation. Furthermore, the current supply chain approach must be still considered in order to develop a framework as the production systems in offsite and modular construction projects are not developed by only one trade but is accomplished by the whole supply chain. Further research might explore these ideas in more detail maintaining the supply chain approach, and cases studies to validate these proposals.

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