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PROJECT PULL PLANNING BASED ON LOCATION: FROM CONSTRUCTION TO DESIGN

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ABSTRACT

Construction project management is known for being fragmented and disconnected between the stages of design, supply and construction. Lean construction has a variety of well known production planning and control methods that may be used to integrate and improve the information flow between these stages. These methods and techniques include location-based tools and the Last Planner System (LPS). However, the combined use of location-based tools with the LPS to allow an entire project, including the design, supply and construction, to be pull planned, has not been described in the literature.

This paper presents results of one study in which location-based planning tools were deployed to pull the project planning from construction to design. The study is part of a doctoral thesis which used the design science research as a mode to produce new knowledge. The main contribution of the paper is the model to develop a location-based project management including the use of the LPS in construction, supply and design. The model enables project managers to have a holistic view of the project plan, and structure it as a pull flow from construction to design, reducing work-in-progress and batch sizes between stages, and improving the information flow among project stakeholders.

KEYWORDS

Project management, pull planning, location-based schedule, design, construction.

INTRODUCTION

It is known that construction projects face delays and cost overruns all around the world. The traditional management of projects no longer meet construction demands (Formoso et al., 2002; Moura, 2005). This may be explained by the architectural, engineering and construction (AEC) industry fragmentation and how construction projects are managed. As design and construction phases are conceived separately (Alarcón & Mardones, 1998), it is more difficult to integrate information in the construction industry (Alshawi & Ingirige, 2003 as cited in Dave et al. (2008)). As consequence, there are disconnections

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at the interface design-construction, such as different production sequences and priorities for design and construction, which create delays, rework and waiting for the project's participants, namely, designers, suppliers and builders.

A possible solution is proposed by Dave et al. (2015) who mention that "a better interface between production and design schedule should lead to the release of design information with a pull from the master schedule". Some authors have already applied the pull flow to integrate planning between construction and design from the point of view of a construction company (Bolviken et al., 2010); an engineering-to-order (ETO) enterprise (Viana, 2015); an ETO company in a project with overlap between design and construction phases (Sivaraman & Varghese, 2016); and a construction project also with overlap (Holm, 2014). However, none of these research shed light to the holistic construction projects planning and control using location-based tools and pull flow including the stages of design, supply and construction.

The idea of applying a pull planning from construction to design was put in practice through one case study, in which the approach used to plan construction was the location, by means of the line of balance and takt-time planning. The results suggest that location-based planning might be used for project pull planning, however, in order to maintain the information flow from downstream to upstream activities, it is necessary to plan and control production using the Last Planner System collaboratively.

LITERATURE REVIEW

JUST IN TIME (JIT)

One of the two pillars of the Toyota Production System (TPS) is the Just-In-Time (JIT). A production system in which JIT is applied "makes and delivers just what is needed, just when it is needed, and just in the amount needed" (Marchwinski & Shook, 2003). A JIT production system eliminates overproduction, inventories and wastes.

The JIT pillar is based on three operating elements: continuous flow, takt time and pull system, namely (Marchwinski & Shook, 2003):

1. Continuous flow: also known as one-piece flow, it is the production and moving of "one item at a time through a series of processes", at which each process makes just what is requested by the next one as continuously as possible.
2. Takt time: is the rate at which products are made in a process to meet customer demand or "the available production time divided by the customer demand".
3. Pull system: is a production system where the downstream process signals its needs to upstream process, eliminating overproduction.

Tommelein (1998) applied the pull production, i.e. the downstream process (construction site) sends real-time progress status to upstream process, for the pipes installation. It forced a resequencing of manufacturer's production, which reduced buffers, enabled time for project completion, and increased the productivity.

Viana et al. (2013) implemented pull production in an integrated planning and control system in an ETO company which was responsible for designing, prefabricating components and assembling on-site. The authors used the assembly process on-site to pull the prefabrication of components.

However, in order to develop a pull system in construction it is necessary to master plan the whole production system in a wider point of view: plan beyond construction stage activities. It means that project managers should consider the upstream activities such as the construction supply chain and design, and structure the work in a manner that the pull production method may be applied.

PULL PLANNING

The Pull Planning was incorporated to the Last Planner System to structure the work of a project phase collaboratively among stakeholders (Ballard, 2008). It bridges the master and lookahead planning. The construction phase's milestones that were set up at the project's master plan are pushed to the phase planning. Next, the phase's activities are broken down into tasks and handoffs. A network and duration of tasks are defined by the contractors of the phase using sticky notes (among other means) on a wall (or other physical and digital media). Then, a reverse plan of the phase's tasks is devised, pulling the tasks from the phase deadline towards the phase start date (Alarcon et al., 2004). The contractors define the handoffs collaboratively between the crews and project phases, insert buffers, and guarantee the completion of the work on time (Alarcon et al., 2004; Ballard, 2008; Ballard & Howell, 2003).

The pull plan can be scheduled using traditional tools, such as a Gantt chart (Knapp et al., 2006), or Location-Based Schedule (LBS) techniques, such as Line of Balance (LOB) (O'Brien et al., 1985), flowline (Kenley & Seppänen, 2010) and Takt Time Planning (Fiallo C & Howell, 2012).

The authors of this paper suggest the use of a LBS to prepare the whole project's planning (from construction to design) in a reverse manner.

LOCATION-BASED PLANNING

The term location-based schedule was proposed by Kenley (2004) to designate the techniques that use the location or unit as a basis for the production planning and control. The aim of using LBS is to design a production system with continuous workflow and uninterrupted flow for crews throughout the location units (Moura et al., 2014). To make the workflow smoother and reduce the work in progress, the activities should be planned at only one rate, i.e. in parallel lines (Mendez & Heineck, 1998).

Takt Time Planning

The takt-time planning (TTP) in construction is derived from the takt time used in lean manufacturing. In construction, it started to be used in the Phase Scheduling or Pull Planning (Frandson et al., 2013; Linnik et al., 2013).

To develop a production plan using TTP, it is necessary to define zones and takt time, the trades sequence and duration, and balance their workflow (Frandson et al., 2013). All these steps are devised with the participation of trades and general contractor in an iterative fashion, and the decision is made collaboratively by communicating and exploring production systems alternatives.

So far, in the literature, the LBS techniques are used specifically for the construction stage, ignoring the procurement and design stages.

RESEARCH METHOD

For this investigation, the authors used Design Science Research (DSR) to iteratively develop an artefact (designed solution) based on its usefulness to the organizations and contribution to existing knowledge; and to apply and develop the theoretical knowledge throughout the studies (Lukka, 2003). In this paper, the artefact is a model for project pull planning based on location.

DSR aims to fill the gap between the theory and practice through the development of an artefact (Rocha et al., 2012). This middle ground between practice and theory is necessary in order to develop valid and reliable knowledge to support practitioners in organisational/business to devise solutions to problems (van Aken, 2005).

DSRs might be evaluated in different manners: 1) Internally – made by the researcher through reflections on practice and connections with theory; 2) Externally – carried out by the studies' participants and scholar experts; and 3) Field-testing – through the instantiation of the artefact in an organization.

The study is a case that presents a whole project reverse master plan, which embedded the construction, procurement and design stages. The researcher was an observer of the construction company management practice that deployed the takt time planning to pull production from construction to design stage. It is characterized in Table 1.

Table 1: Case study characterization

	Case Study
Type of Project	Residential – block of apartments
Period of the Project	January 2016 to December 2018
Area	31 residential units totalizing 2,535 sqm
Type of Study	Case study
Time Horizon	Cross-section study
Location	Trondheim - Norway
Design Stages	Developed and technical/detailed
Construction Stage	Foundations and Concrete Structure
Evidence Sources	Direct observation, documents, interviews and focus group
Research activities and participants' roles	2 workshops and 8 interviews with Project Manager; Design Manager; Site Manager; Architects; Structural Engineer; Project Manager
Companies involved	Construction Company; Architecture Office; Engineering Office; Client
Evaluation	Internal and external evaluation with study' participants through focus group
Activities	Project Pull Planning using Takt-Time Planning; Design and Construction Planning and Control using Last Planner System

The study was evaluated internal and externally according to the utility of the model. It was composed by five criteria selected from the literature as reference as best project management characteristics of collaboration, integration and flow; the criteria were broken-down into eight measurable sub-criteria, as depicted in Figure 1. To see the interview questions, access the thesis (Biotto, 2019). It is noteworthy that this paper is focused, mostly, on presenting the last phase of the DSR, namely, the model evaluation.

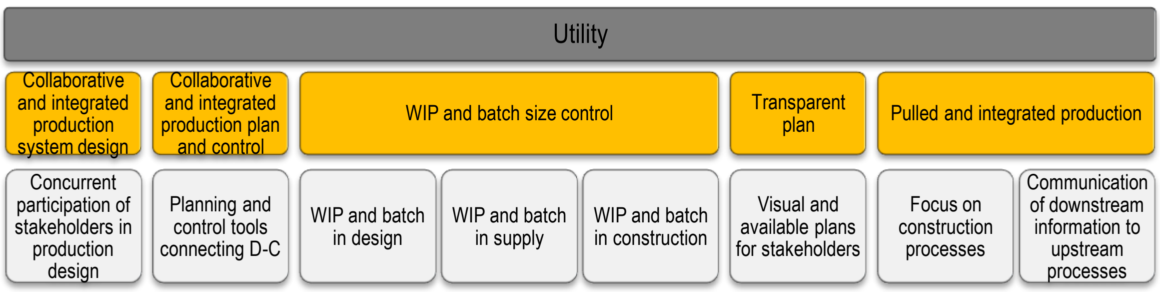

Figure 1: Criteria for the model evaluation.

CASE STUDY

In case study, the project development comprised of three stages: 1) Pre-design; 2) Delivery Stage; and 3) Facility Management. The first stage encompassed a) Idea Phase and b) Concept Phase, whereas the second stage comprised a) Design; b) Detail/Engineering Design; c) Construction; and d) Commissioning. The third stage is Operation and Maintenance. The study observed the project management of the detailed design phase and construction.

The Project Planning and Control System deployed had six levels of planning and control, as depicted in Figure 2:

1. **Level 0 - Project Master Planning**: developed by the Project Manager, Construction Manager, Design Manager and Owner presents the strategical decisions made for the whole product development process, its major phases and deliverables. It is the basis for further planning.
2. **Level 1 - Construction Plan and Purchasing Plan**: represented strategical decisions about construction, procurement and supply, respectively:
    - Construction plan is generated using developed design documentation in MS Project by the Project Manager and Construction Manager. It is the most important plan to pull detailed design plan and supply acquisition;
    - Purchasing Plan is derived from the Construction Plan and contains the majors milestones for supply acquisition.
3. **Level 2 – Detailed Design Plan and Construction Takt Time Plan**:
    - Detailed Design Plan: developed collaboratively by the Owner, Consultants, Design Manager, Project Manager, Construction Manager, Foreman and Designers at the kick-off meeting (see Figure 3). Project Master Plan and Construction Plan milestones are used as reference to pull planning design deliverables. The result is transferred to a MS Excel spreadsheet and used in the lookahead planning;
    - Takt-Time Plan: the construction team studied the workflow, the crew size, buffers and the takt-time for production.
4. **Level 3 - Decision Plan and Design and Construction Lookahead Plans**:
    - Design Lookahead Plan: design project team removed six types of constraints related to 1) client's expectations and requirements; 2) dialogue and share understanding among stakeholders; 3) decisions needed; 4) team capacity and autonomy for decision making; 5) methods and tools; and 6) previous design task according to the required quality;
    - Construction Lookahead Plans: the project had different lookahead planning involving different professionals and different planning horizons; namely, a 8 to 12 weeks plan developed by the Site Manager, Design Manager and Project Manager; a 4 to 8 weeks plan developed by the Operations Manager, and; a 2 to 4 weeks plan developed by the Operations Manager and Foreman. The different planning horizons and meetings are related to the responsibility and power of decision of each sort of professional in removing constraints.

5. **Level 4 – Design and Construction Weekly Plans**:
    - Design weekly plan: tactical and operational levels of planning were developed and controlled in the weekly meetings at the site office. The Design Manager was responsible for drawing up a set of activities to prepare the meetings, and to distribute the information to designers and set the future actions. Figure 4 is the plan used in the meetings that shows the design milestones, detailed design deadlines in accordance to construction batches and sequence, and basic design packages deadlines;
    - Construction weekly plan: the team leaders devise the weekly plan, revising which activities were concluded in the current week, and predicting the next work week according to crew's production capacity.
6. **Level 5** – Daily Plan: occurs every working day on site. The crew's members gathered in the first hour of work to draw over the floor plan what should be executed on the day, considering the previous tasks executed. The researchers did not collect data about daily meetings within the designers' offices.

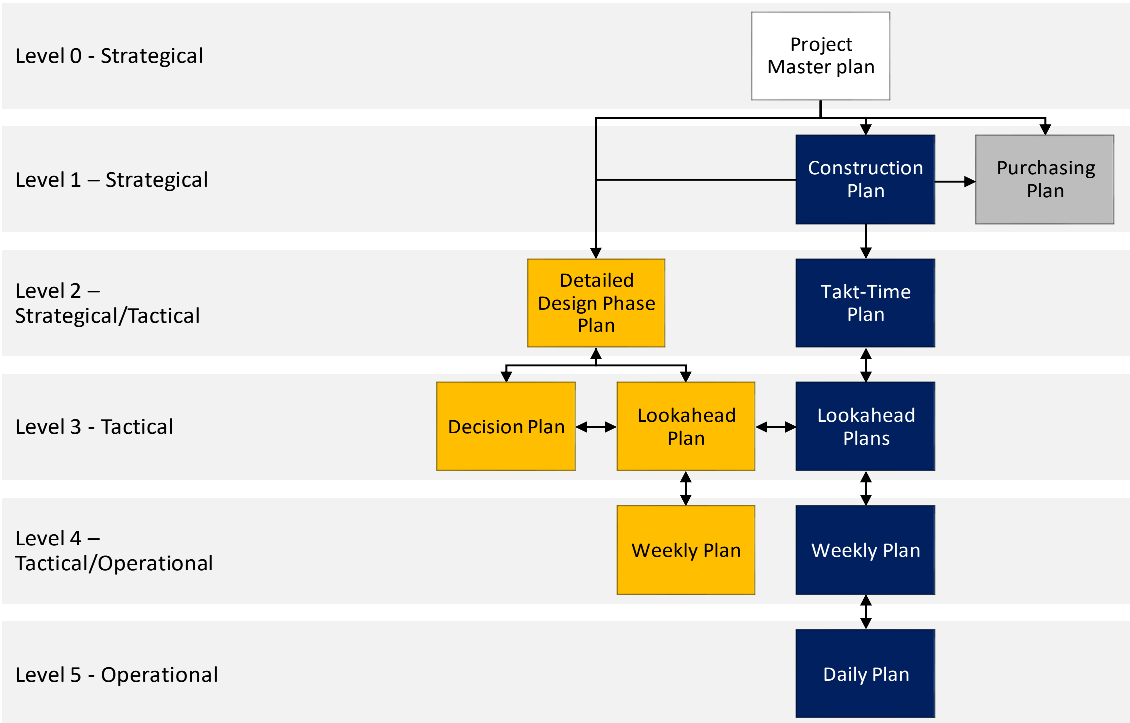

Figure 2: Levels of the project planning and control system deployed.

Figure 3: Strategical Collaborative Planning for Design. Source: Courtesy of Construction Company.

In order to keep the communication flowing smoothly and rapidly, weekly meetings occurred among designers, construction teams, managers and owner. In figure 5, the light grey arrows demonstrate the flow of information from the operational meetings on Mondays until the progression status meetings on Fridays. The blue arrows represented the communication flow from construction, designers to the owner and client of the project. The flow of information had a short update cycle time of only one week. For this reason, the communication of changes, decisions and other information was rapidly transmitted between stakeholders and in a transparent manner.

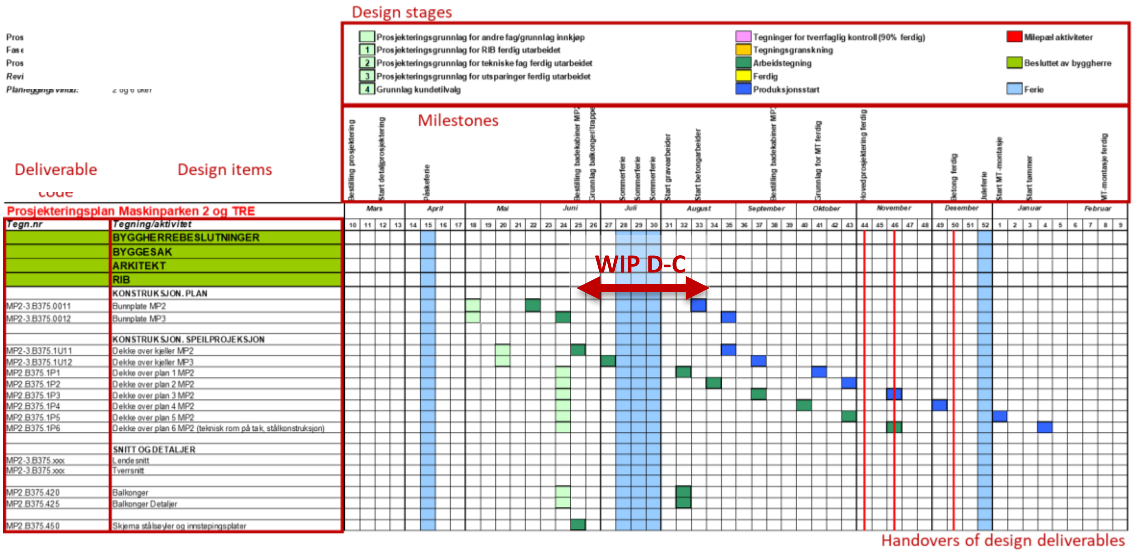

Figure 4: Example of using location-based from construction to pull design. In blue: construction activities from the takt time plan. In dark green: deadline for detailed design delivery. In light green: deadline for design package delivery. Source: Courtesy of Construction Company.

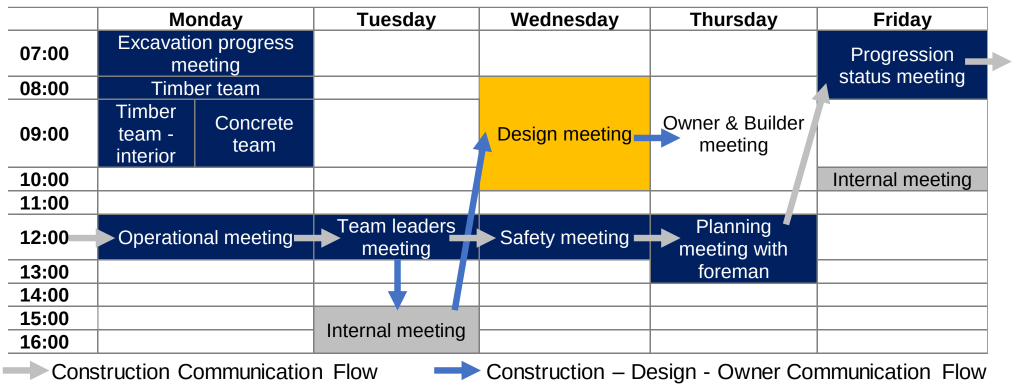

Figure 5: Project meetings structure and the weekly communication flows.

Case Study Evaluation

Case study project planning was characterized by the early participation of stakeholders from design, manufacturers, suppliers and builders in the production system structuring. The project used the takt-time planning as a location-based tool for work structuring the construction, which used the developed design as input information, and prepared the reverse design and supply/purchasing. The internal evaluation of the study is detailed in Table 2, following the criteria specified in the method section of the paper.

Table 2: Case study evaluation

	Case Study
Collaborative and integrated production system design	At the beginning of the detailed design stage, the organizational structure of the design and construction stages is presented to all participants. It defined the planning responsibilities of Design Manager, Designers, Project Manager, Site Manager, Operation Manager, Foreman, crews' leaders and workers.
Collaborative and integrated production plan and control	The Collaborative production planning and control promoted the ownership of plans by its stakeholders, which was boosted by the high transparency of planning.
Work in Progress (WIP) and batch size controls	The WIP between design and construction was small because detailed design batch was the same than construction. WIP was controlled in the design meetings.
Transparent plan	The available plans and weekly meetings stimulated transparency of people's responsibilities, tasks, dependencies, decisions, planning and project goals. In design, it was intrinsically connected with the BIM model's development and construction.
Pulled and integrated production	The developed design was pushed and inputted to the construction master planning. The latter was pulled by the design planning to set delivery milestones. Both design and construction lookahead planning were connected and communicated through the weekly meetings.

It is worth noting that the "WIP and batch size controls", and pull flow were easier to implement in detailed design rather than in earlier design phases. In case study, the construction and detailed design shared the same production batch size, enabling the pulled flow between them. However, when analysing an earlier design stage, its production batch was composed by a set/kit of drawings/models/documents, i.e. a large batch, which was delivered to the next design phase for detailing. Earlier design stages experience constant changes due to clients and designers negotiations and conflicts/clashes solutions, i.e., higher interdependency among stakeholders. As soon as design matures and clashes are solved, the design development focuses on detailing the models; an action that might occur with higher independency among stakeholders. The latter enables the adoption of same size batch between design and construction, thus the pull flow.

MODEL FOR PROJECT PULL PLANNING BASED ON LOCATION

The model presents a project planning and control system composed by construction, supply and design, as shown in Figure 6. The pull production system guarantees the integration of information in the design-construction interface. The model might be implemented by the Project Manager.

The first step to implement the model is to identify the construction demand. In the stream design-supply-construction, the latter is the final internal client. To define construction demand is important to structure the work of designers and suppliers. For that, the construction work structuring should start early in the project development using design documentation and a location-based planning tool. The Construction Manager, or the General Contractor Manager should be responsible for gathering all people and information necessary. As soon as design becomes more mature, it should be pushed to the construction system for decision and planning review.

Consequently, construction location-based plan might be the reference to pull reverse plans for suppliers that will pull a reverse plan for designers. Both Project Manager and Construction Manager might gather the main manufactures and suppliers to participate in the collaborative planning, providing information about duration of installation, fabrication, designing the items. The supply reverse plan sets the milestones based on the same location breakdown structure used in the construction plan. The design deadlines in the suppliers' plan will pull the designers' reverse plan. The Design Manager is the responsible to gather the main design offices' leaders of the project for that.

The idea of using the construction location breakdown structure (batch) for suppliers and designers is to allow the alignment of plans and facilitate the pull flow. Moreover, the LBS might be a facilitator for batch size reduction in construction projects. Suppliers are stimulated to deliver the material/components to construction following the construction batch and sequence in order to avoid waiting, inventory and space interferences on site. However, the manufacturers might find difficult to produce and deliver components defined by construction needs. In this situation, they should resize their batches in agreement with construction managers considering construction site space, logistics and plans.

The same is valid for designers, who should produce the detailed design following the suppliers or construction production batch and sequence. This idea enables a new way of assembling work, and support the continuous flow by pulling only the necessary information, when necessary, which are concepts of the just-in-time (JIT) production system. Thus, the design packages will be composed by a combination of drawings/models of a certain location necessary to be released to the next supplier. The supplier will use this pack of drawings to engineering design (if applicable), and plan the fabrication of components necessary to be delivered to a particular construction location.

The progressive design fixity concept is also behind the model. At the first design phases (conceptual and developed), the design production flow is pushed. At the detailed phase, there occurs the decoupling point, which is the interface between push and pull (PP) flows (Kiiras & Kruus, 2005). It also points to the interface between transdisciplinary and interdisciplinary design production. The interface push and pull was explained by Hopp and Spearman (2011).

However, as construction projects suffers with uncertainty and variability, the whole production planning and control system should be connected. It is suggested that the Last Planner System should be used by builders, suppliers and designers. Through the lookahead planning, the project participants should focus on removing the constraints, updating the reverse plans and, when necessary, replan. The use of LPS is critical in order to confirm with designers and suppliers the right priority of production based on construction status. This idea of confirmation points was suggested by Viana (2015) in her work regarding integrating the planning and control system in ETO companies. However, the integration of the LPS adopted by designers and builders was suggested by Bolviken et al. (2010).

The model enables the articulation of the project production planning and control to integrate decisions and information between participants at the interface design and construction (D-C). The plans are connected vertically and horizontally. In each phase of design and construction, the hierarchy of plans (strategical, tactical and operational) provides information from the upstream plan to the downstream and feedback in the opposite direction. The horizontal integration between the phases D-C occurs at the strategical levels, properly from the construction master plan reversely towards the design master plan. The updates for confirmation of production occurs at the tactical levels, which receive updates from the operational plans in their respective stages.

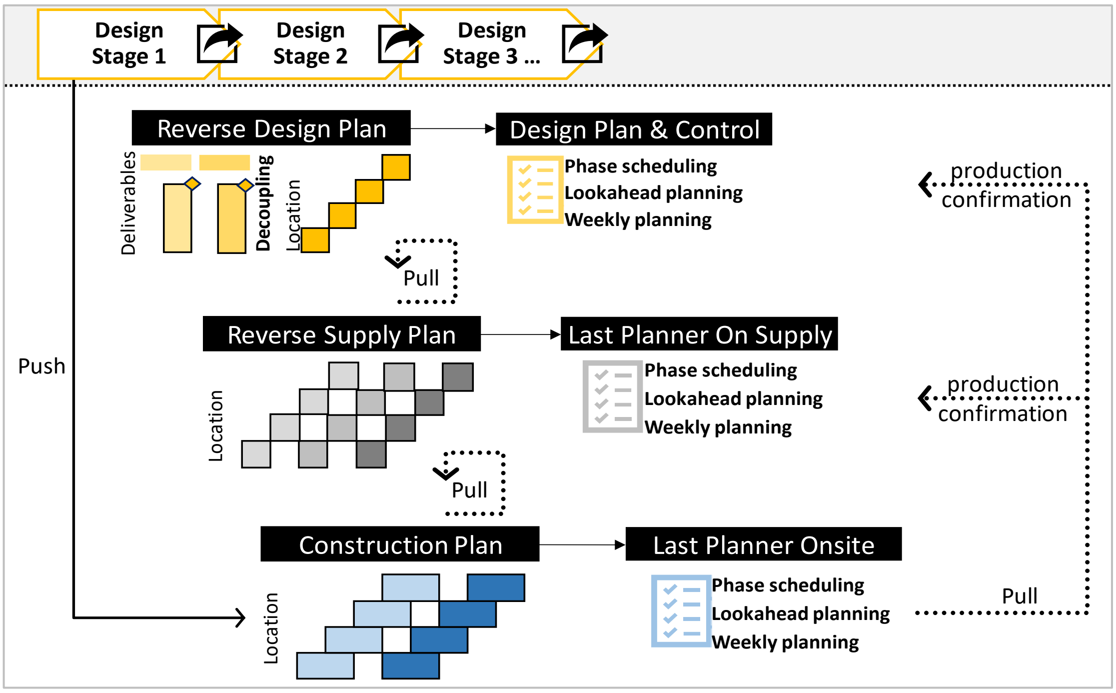

Figure 6: Model to implement project pull planning based on location.

Figure 7 demonstrates the vertical and horizontal connections between hierarchical plans in the D-C interface. This contribution suggests an integrated use of the LPS (Ballard, 2000) to plan and control the stages of design and construction. It also expands the collaborative planning model of Bolviken et al. (2010) to include the suppliers' planning activities.

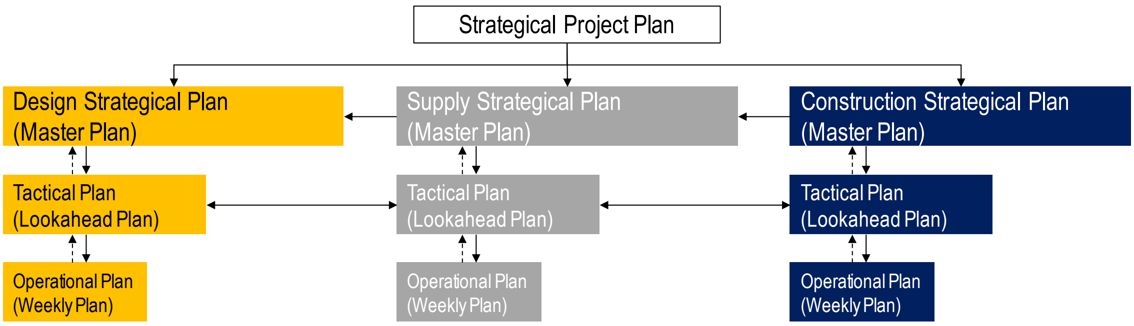

Figure 7: Vertical and horizontal connections in construction, supply and design plans.

CONCLUSIONS

The paper presented a case study in which construction location-based plan were used to pull plan the whole project production, including supply and design. Results were internally evaluated and a model proposed for Project Managers apply pull production at the design-construction interface using a location-based planning and the Last Planner System. The model integrate a variety of lean concepts and tools in different levels of construction project management, i.e., from strategical to operational. It also shed light to the push and pull flows in design production, that must be understood by Design Manager in order to preserve the transdisciplinary development of design solution. The model implicates in reducing WIP and batch sizes in the D-C interfaces when applying a unique LBS.

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