Augmented Reality-Enabled Production Strategy Process

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Abstract –

Disruptive technologies offer avenues to significantly improve the performance of construction project delivery. While the construction industry is often labeled as conservative and unimaginative with regard to technology adoption, significant strides have been made in recent years – specifically, the use of Building Information Modeling (BIM) for information storage, distribution and communication, as well as Lean construction techniques such as production planning and control (PPC). While the implementation of these innovative technologies and practices individually improve project performance, integrating them together can provide still greater benefits. BIM is certainly useful, but it alone is not a satisfactory answer to the paradox: how does one design and visualize a 3D product in a 2D space? Augmented Reality (AR) is a disruptive technology that can help address this challenge. AR is both an aggregator of information and an information publishing platform which allows users a spectrum of capabilities to 1) passively view displayed information, 2) actively engage and interact with published content, and 3) collaborate with others in real time from remote locations. No extant research effort has comprehensively investigated the opportunities and benefits of the integrated use of AR, BIM, and Lean in the planning process to improve project performance. This paper addresses precisely this research gap. Using insights gained from real-world construction projects, this paper examines the current state of production strategy process (PSP) development – an integral part of PPC, identifies pain-points and opportunities for process re-engineering using AR, and develops an AR-enabled PSP future state.

Keywords –

Augmented Reality; Building Information Modeling; Lean Construction; Production Planning and Control; Production Strategy Process; Takt Time Planning

1 Introduction

The construction industry is poised for significant growth. [1] forecasts that by 2030 the global expenditure on construction and related activities will reach $15.5 trillion. While the construction industry is quintessentially a factor in the prosperity of nations, it is fraught with waste and inefficiencies. Since the 1960s, manufacturing, service, and other industries have steadily and significantly increased their level of productivity, and consequently realized improved quality and better profitability [2]. There are several factors that play into construction's stagnant productivity: its project-based nature prevents the same holistic improvement that a process-based manufactory can achieve; the supply chain in construction is not consistent and is constantly in flux; the industry operates at a high level of complexity; there is a high level of heterogeneity; and construction is subject to the whims of international markets [3]. Per [4], a single instance of rework can cost on average 10% of the total project cost (in the United States). The volume of waste in construction has been estimated at between 25% and 50% of total project cost. This figure stems from inefficient control of labor, materials, interactions between trades, and the site in general.

The information-intensive nature of construction projects is a significant contributor to inefficiencies and losses in the industry. Between $17 billion and $36 billion are lost annually due to omitted information when design documents are translated into construction documents. [5] noted that on average only 55% of work planned and promised to be completed each week was actually completed. Other studies that focus on construction efficiency have documented 25% to 50% waste in coordinating labor and management [6].

In an effort to respond to these issues, significant strides have been made over the past two decades to improve construction planning, collaboration, and integration. These methods include Lean Construction via Production Planning and Control (PPC) and Information and Communication Technologies via Building Information Modeling (BIM).

Both these initiatives are radical in and of themselves, and their impacts on construction have been far reaching and documented by multiple researchers.

[7] analyzed possible interactions between 24 principles of Lean Construction and 18 BIM functionalities. They identified 54 points of direct interaction, 50 positive and only 4 negative. Their conclusion was that implementing BIM and Lean alongside each other was optimal, as the functionality of BIM improved Lean processes significantly.

[8] contended that traditional delivery systems, like Design-Bid-Build (DBB) preclude proper implementation of these innovative practices, and instead recommended the use of Integrated Project Delivery (IPD). IPD is a construction contracting approach which promotes trust, collaboration, team chemistry, team alignment and maximizes value – key support mechanisms for the implementation of innovation [9]–[11].

Construction leaders have recognized this need for innovation, and have taken measures to transform their operating procedures. These leaders have realized benefits that put them ahead of other competitors in the construction sector – which given the competitive nature of the industry is a distinct advantage [11]. Thus, in order to remain competitive and support further growth, companies must successfully innovate to the point that they differentiate themselves from their peers. Early adopters have already realized benefits and brought the industry along, but must now ask: what comes next? [12].

Researchers argue that disruptive technologies have the potential to significantly improve project performance. One such technology that is currently gaining increasing traction is Augmented Reality (AR).

This paper will explore the new frontier that AR offers to construction companies, and how these firms may best exploit it by leveraging existing innovations (BIM and Lean) in an AR space to improve and innovate PPC, specifically the Production Strategy process (PSP).

2 Research Objectives and Methodology

The principal objective of this paper is to propose a new, AR-Enabled Production Strategy Process (AR-PSP). Our approach to achieving this goal entails the completion of several sub-goals: (1) investigate via literature review and expert interviews the current state of PPC and BIM integration in the industry; (2) identify current challenges and choke points in the current state PPC; (3) identify leverage areas for the integration of AR; and (4) define an AR-Enabled PSP future state. The research tasks and outcomes are described in the remainder of this paper.

3 Background

The notion of innovative production philosophy originates in Japan in the 1950s with the Toyota Production System (TPS) [13]. [14] defines this philosophy as a management philosophy for manufacturing, as well as a method of enhancing corporate vitality which aims to totally eliminate waste and achieve the maximum possible quality with the shortest possible lead time. In the early 1990s, the term ‘Lean’ production was introduced to contrast with ‘mass’ production [15]. The operational prerogative of Lean is the reduction of waste and maximization of value, and as such it has quickly become popular in healthcare, service, administration, production development, and construction [13], [16].

Lean as applied to construction was first discussed by [13]. In 2000, Koskela explained that Lean construction projects should be viewed as production systems, with the output being the built product [17]. This departs from the traditional view, or the transformative view, in which construction production is performed through individual activities that transform inputs (raw materials) into output (built product). Koskela put forth the Transformation/Flow/Value (TFV) theory, which prescribes that construction be viewed as the transformation of resources (raw materials), flow of materials and people, and the creation of value. In this system, construction projects are considered temporary production systems, with three pillars: eliminate waste, collaborate, and optimize the value-added chain [17]. The crucial challenge to construction is the spatial and scheduling coordination of the vested parties and disciplines. As such, innovative PPC methods like Last Planner System and Takt Time planning have come to the fore.

3.1.1 Last Planner™ System

The Last Planner System (LPS) was initially developed by Glenn Ballard and Greg Howell as a PPC system to improve construction predictability and reliability by bringing ‘last planners’ forward in the process [18]. The last planner is the project party who is responsible for the control of operative tasks – typically trade foreman. As such, the LPS involves these foremen with general contractors, architects, and owner’s representatives to bring site knowledge and practical experience to the table, making plans more realistic [19]. LPS decentralizes management tasks and improves cooperative work [20]. There are four chronological phases to LPS, as follows [21]:

1. Master Scheduling is a front-end planning process that produces a schedule describing the work to be carried out over the project duration.
2. Phase Scheduling generates a schedule covering each project phase, such as foundation, structural frame,

overhead, in-walls, or finishing. In a collaborative planning setup, the project team defines these phases and their various activities and uses pull planning to schedule the activities backward from the milestones.
3. Lookahead planning is the first step in production control (i.e., executing the work) and it usually covers a six-week time frame. At this level, activities are broken down into the level of production processes, constraints are identified, operations are designed, and assignments are made ready.
4. Weekly work planning is the most detailed plan in the system, and covers the particulars of work to be performed each week.

3.1.2 Takt Time Planning

The traditional view of construction considers a project as a conglomeration of various tasks and focuses on optimizing the process by which each task transforms its inputs into outputs. The shortcoming of this view is its lack of consideration for the dynamics and interdependencies of construction tasks [22].

[23] stressed the importance of considering space as a resource when planning construction projects. One space planning method that has been previously explored by academicians and professionals is Takt-Time planning. Takt is a German word which means 'beat' or 'rhythm.' It is applied to Lean Production to establish flow [24]. Implementing Takt into processes prevents overproduction, reduces lead times and inventory, stabilizes processes, optimizes workflow, and improves production capacity [25].

Within Lean Construction, 'Takt Time' is the unit of time in which a product must be produced (i.e. supply rate) to match the rate at which the product is needed (i.e., demand rate) [26].

Takt-time planning thus breaks work down into individual, manageable, chunks and determines their demand and supply rates [27]. [28], [26], [29] presented various methodologies to implement takt-time planning in construction. The current study presents a generic framework for implementing Production Strategy through the synthesis of the aforementioned methods with existing practices via industry expertise.

3.1.3 Integration of Last Planner System and Takt Time Planning

As noted by [30], LPS does not presuppose any specific work structure. The authors indicated that work structuring happened before project control – i.e., before lookahead planning could occur. However, location-based work structures like Takt-Time planning have been successfully integrated with LPS. [31] demonstrated the complimentary nature of Takt-Time and LPS, noting that Takt-Time introduces a standard, continuous flow of work that the LPS then is able to control, and LPS allows the flow of work to remain when obstacles emerge and must be adapted to.

[32] added a stage to the LPS: Production Strategy. Its three principal goals are: 1) implementing sequence and flow analyses, 2) defining production areas, and 3) designing production using takt-time principles to achieve stable and predictable construction flows.

Production Strategy is the portion of the PPC which has the highest potential for AR integration given its high volume of information and necessary level of communication and understanding.

3.2 Building Information Modeling

BIM has transformed the traditional paradigm of construction industry from 2D-based drawing information systems to 3D-object based information systems [33], [34]. For more than a decade, BIM has been one of the most important innovation means to approach building design holistically, to enhance communication and collaboration among key stakeholders, to increase productivity, and to improve the overall quality of the final product [35]. BIM's greatest strength is its ability to represent in an accessible way the information needed throughout a project lifecycle, rather than being fragmented [36]. BIM serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its lifecycle from inception to commissioning and beyond [37].

3.3 Augmented Reality

In the context of this research, Augmented Reality (AR) is characterized as both an information aggregator and a data publishing and visualization platform. As such, it allows the user to 1) passively view displayed information, 2) actively engage and interact with published content, and 3) collaborate with others in real time from remote locations [38], [39].

AR's market share is anticipated to reach $63 billion by 2021 and has found application in many domains such as gaming, medical, military, and manufacturing [40]. [41] described AR as the bridge between digital and physical realities; a new information delivery paradigm which permits consideration of both physical and digital information simultaneously. [42] found that AR facilitates a more thorough understanding of project documentation, construction progress, and communication between stakeholders. [3] stated that AR has great potential to improve the scheduling software.

3.4 Cross-Pollination of AR, BIM, and Lean

[38], [42] have developed several frameworks and prototypes that support the integration of BIM and AR

using different platform (i.e., Head Mounted Displays, smartphones, etc.). [43] noted that BIM and AR have a direct relationship with what Koskela defined in 1992 as construction integrated by computer and automatization in construction. [8] highlighted the potential use of AR for collaborative planning to improve predictability and reduce waste. [3] developed a framework and a mobile application, AR4Construction that integrated BIM and AR with Lean Construction methods, particularly Location-Based Management System to support the efficient management of construction works on site. Most existing literature focuses on implementing AR on the construction site. Our research focuses earlier in the project delivery process, and explores opportunities for integrating AR with PPC, such that it is used before construction begins, particularly with the PSP.

4 Production Strategy Process Current State

Before embarking on any process re-engineering effort, it is important to gain a sound understanding of the current state of practice as this will allow those involved in the innovation initiative to develop a shared basis for the improvement [44]. As such, this section describes the five principal steps of the PSP as it currently stands, using the example of an IPD project. The current PSP is illustrated in Figure 1.

Step 0 – Prerequisites

Prior to the Production Strategy, the project team (including last planners) must have set the expectations for the project and identified the major milestones for the project in the Master Scheduling phase. The project team then must divide the project into phases (such as overhead, in-walls, exterior finishes). Each phase should contain a series of activities performed by different trade partners. In the Production Strategy level, the project team works together to develop a production plan for each phase using the following four steps:

Step 1 – Perform Sequence and Flow Analysis

The project team reviews the 2D construction drawings of each phase, identifies repeatable and non-repeatable work, agrees on the linear sequence of construction activities of the corresponding phase, determine flow and non-flow areas, and finally determines the direction of the flow (i.e., work to be performed from North to South, East to West, etc.). The output of this step is a set of 2D construction drawings highlighting the flow and non-flow areas and indicating the direction of the flow for each phase.

Step 2 – Gather Information

The General Contractor (GC) conducts one-on-one interviews with the Trade Partners individually. For each activity within the corresponding phase, the GC provides the last planner of the corresponding trade partner with the 2D construction drawings. The last planner is then asked to use color markers to highlight the 2D drawings and show how much work they can complete in one day based on their ideal crew size. This is referred to as daily production. The last planner uses the direction of the flow identified earlier for the corresponding phase as a reference to identify their daily production. The GC acts as a facilitator. A 2D color-up construction drawing will be created for each activity within this step. Color-up drawings are not quantity takeoffs, as they require the last planner to think about how the work will be performed, by whom, where and in what sequence [26]. The GC then asks the last planner from each trade partner to use the color-up drawings and divide their floor plan into production areas. The production area, also referred to as Takt area, is a collection of individual daily productions. For example, if the last planners are asked to develop one-week takt areas, then each area should include five days' worth of work (assuming conventional schedule), or five daily productions. It should be noted that the precise mechanism of determining takt time is beyond the scope of this research. One week is used as a threshold since it is consistent with the weekly work plan phase of the LPS. The output of this second phase is a set of 2D drawings with production areas for each activity assigned to the corresponding phase.

Step 3 – Develop common areas

The GC collects the individual 2D production areas drawings, overlays them and attempts to identify common areas. The objective is to develop common areas within which the scopes of work of all the different activities are balanced.

Step 4 – Define Production Strategy

Once common areas are determined by the GC, the GC will determine the scope of work for each trade in that area and identify which trade(s) will bottleneck. The objective is to balance workflow such that all trades finish their work in an area within takt time for that area. The workflows are balanced either by adjusting crew size and hours or by adjusting work area. This process should go through multiple iterations to produce a cohesive strategy.

Step 5 – Validate the Production Strategy

The GC circulates the initial production plan to trade partners for feedback, which is collected and used to inform updates and revisions. Once a working plan is agreed upon, it should be documented via a convenient mechanism (e.g., an Excel spreadsheet).

5 Challenges in the Current State and Augmented Reality Opportunities

As is evident from Section 4, PSP is information-dense, lengthy, and iterative. The lynchpin of this process are numerous sets of 2D construction drawings, which are the conventional means of communication

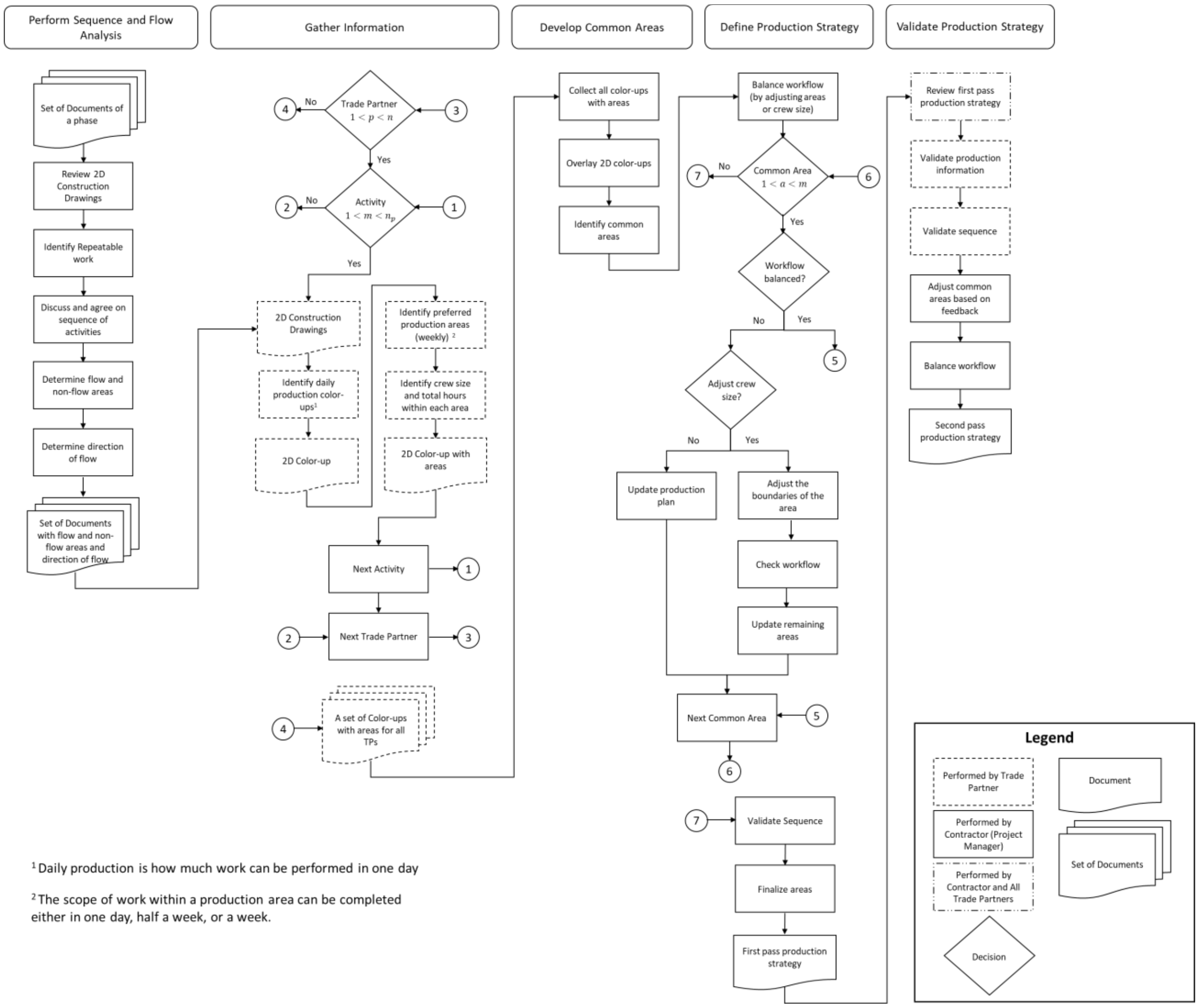

Figure 1. Current state of the production strategy process

between different contracting parties [45]. However, they present an individual view that is subject to individual interpretation [46]. Based on the 2D drawings, a last planner must visualize the built product, which will exist in 3D space. This presents a difficulty, as some information will not correctly translate (e.g., flat pipe vs. inclined pipe). Furthermore, another challenge that pertains to this phase is software diversity (i.e., 2D drawing packages may be prepared in numerous different CAD suites which are incompatible).

During the planning process, there is a lack of centralized information storage – necessary data is often stored in various forms (hard copy, spreadsheets, email chains, etc.) across different devices or locations.

As such, a challenge emerges in making sure last planners fully understand what work they are committing to.

Furthermore, the current process does not effectively consider safety, which should be a perspective from which the plan is validated.

In addition, this process requires project team to be available in the same space.

These challenges result in numerous iterations and mixed coordination of data, which ultimately increases the chances of miscommunications and associated non-valued added effort.

Opportunities to Integrate Augmented Reality:

Using augmented reality as the delivery mechanism for drawings and production information during the planning process has several advantages. First, it allows more advantageous use of BIM, as AR can operate in 3D space. Second, it creates a living single source of information, reducing miscommunication. This allows for an overall improvement in collaboration and communication, permits the last planner a better understanding of scope of work and as a result produces more reliable commitments, allows for safety analysis in more real space, improves spatial cognition, and allows an iterative tracking system. According to [41] the use of AR eliminates the need to mentally translate two-dimensional information into the three-dimensional world, and elaborate that this improves the ability to absorb and interpret information which leads to better decision making, and tasks being executed faster and more efficiently. A study by [47] noted that AR eases information retrieval for those working in information-intensive environments, and increases the efficiency of the working processes through avoiding information overload. Finally, using AR facilitates standardization of the process to a single governing data point and citation.

6 AR-enabled Production Strategy Process Future State

We envision an AR-enabled PPC process in which the BIM model is used as the guide and chief reference for production strategy development. Thus, BIM is a precursor to implementing AR-PPC. The following five steps define the process by which AR-PPC can be implemented.

Step 1 – Perform Sequence and Flow Analysis

The project team:

1. collectively uses the 3D model as a guide and reference to visualize the corresponding construction phase(s) and its activities
2. interacts with the 3D model and selects repeatable work
3. interacts with the 3D model and collectively develops the sequence of activities and identifies potential safety hazards, thus improving the decision-making process in a collaborative environment
4. interacts with the 3D models and collectively discuss flow and non-flow areas
5. interacts with the 3D models and collectively assess the project and determine the direction of flow.

AR helps project participants from diverse trades better understand each other's scope and flow of work, facilitating better collaborative decision making. The output of this step is saved within the 3D model and accessible at any later point by the project team. This central information repository is more efficient than traditional methods, and provides additional transparency – all participants are provided the same information.

Step 2 – Gather Information

Last planners will be among the project team participants with access to the information generated in Step 1. Integration of BIM and AR allows 3D visualization of the scope of work, and improves visual understanding by providing an interactive solid model of the whole project. Within the augmented environment, the last planner:

1. selects to only visualize their scope of work
2. performs their daily production for the entire phase in a virtual environment, which in addition to generating 3D color-up drawings, will also create quantity takeoffs. The last planner can also investigate the space for any safety problems and adjust their daily production accordingly
3. creates production areas virtually. This allows the last planner to automatically visualize the scope of work within each area, obtain the total quantity of work to be installed, and input production information (such as labor hours, crew size, working days, constraints, etc.). This information can be easily retrieved by the last planner.

Each last planner can create their production areas and save them to the same source, allowing project managers to coordinate and check for trade clashes

Step 3 – Develop Common Areas

The GC retrieves the results of the last planner's work from step 2. Their production areas are overlaid, allowing visual creation of common areas.

Step 4 – Define Production Strategy

The GC, once common areas are developed, retrieves the production information that was input pertinent to each scope of work. This facilitates the performance of workflow balancing in an environment that updates in real-time, improving efficiency. AR thus acts as a decision support tool for the GC as they create the production strategy plan draft.

Step 5 – Validate Production Strategy

Once the first-pass production strategy is complete, the team meets in the augmented environment to review it. This greatly enhances collaboration, as it facilitates meetings that do not require co-location of participants, as well as changes that are visible in real-time to all parties.

The production plan created in AR can be used during project execution to visualize the work to be installed and to track performed work. Project Percent Complete could be then calculated more accurately and effectively.

In summary, AR has the potential to transform the current state of the PSP. It provides a common source of truth which enables a higher level of collaboration among the participants of the PSP when working in the same space or in remote locations. The AR-enabled PSP is a centralized reference that encompasses the different types of information used during the PSP. AR enables the users to interact with the built product in real-time, thereby enhancing visualization, space perception, and decision-making. The technology also allows last planners to identify potential safety hazards during planning and integrate safety more effectively into the production strategy.

7 Future Work

Based on the framework for an AR-enabled PSP that we have defined in this paper, we are developing a proof-of-concept application on a wearable display. Using BIM models from real-world construction projects, we are validating the reengineered future state PSP and the associated benefits.

8 Conclusions

Most literature which was reviewed focuses on the avenues to integrate AR into site operations (visualizing blueprints, safety, etc). However, this paper and research effort considers integrating AR into PPC, and specifically into the Production Strategy Process. A process map was presented which highlights the current state of the practice based on previous research and industry expertise. Challenges which exist in the current method were then presented, and opportunities to address these challenges via AR were explored.

Finally, a conceptual future state of the Production Strategy was described. The principal advantage that AR-enabled PSP has is its centralization of information and increased collaboration over traditional PSP.

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