The Impact of Integrating Augmented Reality into the Production Strategy Process

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Abstract –

Although execution is generally the phase during which challenges faced by the construction industry become apparent, it only represents the tip of the iceberg. Execution depends on the effectiveness of construction planning and control – an area identified by researchers as in need of improvement. Production Strategy is a fundamental step and a critical component of production planning and control where decisions are collectively made to properly allocate and deploy resources to achieve project objectives. The Production Strategy Process (PSP) involves a massive information transfer and requires a high level of communication between the project team members. The increased complexity and sophistication of construction projects along with the rapid advances in emerging technologies has fueled construction companies' interest in technology as a source of innovation. One technology that has gained great interest in recent years is Augmented Reality (AR). AR, a pillar of the fourth industrial revolution, offers powerful capabilities to enable the next generation of PSP and provides companies significant opportunities to maintain their vitality and competitive edge. This research investigated the integration of AR with PSP and the impact that AR can have on the process. An AR-enabled PSP prototype was developed for the Microsoft HoloLens headset and was validated on an ongoing construction project. The results showed that AR has the highest impact on PSP in three areas, namely analytical, tracking, and informational.

Keywords –

Augmented Reality; Prototype; Production Strategy; Re-engineering

1 Introduction

While the importance of the construction industry as a main contributor to the prosperity of nations has been well documented, volumes have been written about the long-standing challenges facing this industry. The daunting decline in productivity, cost and schedule overruns, costs of rework and waste, loss of information when design documents are translated into construction documents, and inability to execute according to the plan are, to name a few, some of the major challenges that researchers have been investigating [1].

One common trait with the above-mentioned problems is that they all occur during execution, which depends on the effectiveness of production planning and control systems – an area identified by researchers as in need for improvement [2].

Construction researchers noted that major issues in production planning and control are caused by the 1) inadequacy of traditional project management theory and 2) improper applications of information technologies (IT) [3]–[5], [2], [6]. Inspired by innovations in manufacturing, the application of Lean Production and the advancements in Information and Communication Technologies (ICT) have been at the core of addressing the deficiencies in the traditional planning and control system. New innovative production planning and control systems such as the Last Planner® System (LPS) emerged and were empowered with the integration of Building Information Modeling (BIM) [7]. While the implementation of LPS results in a more predictable workflow, a greater degree of team-building, respect, and reliable delivery of tasks, the system does not presuppose any specific work structure [8]. Researchers have investigated a location-based work structure, namely Takt-Time Planning. Takt is a German word that means 'beat' or 'rhythm' and is a Lean concept used to establish flow [9].

The complementary nature of Takt-Time Planning and LPS was investigated and studied by various researchers. The concepts of Takt-Time Planning were then added to the LPS in the form of a new stage, named Production Strategy [10].

Production Strategy is an integral part of production planning and control and is essential to developing a reliable and balanced production plan [11]. [1] noted that The Production Strategy Process (PSP) involves a massive information transfer and requires a high level of communication between the project team members.

The increased complexity and sophistication of construction projects along with the rapid advances in emerging technologies has fueled construction companies' interest in technology as a source of innovation [12]–[15]. One technology that has gained great interest in recent years is Augmented Reality (AR). AR, a pillar of the fourth industrial revolution, is described as 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 [1]. AR offers powerful capabilities to enable the next generation of PSP and provides companies significant opportunities to maintain their vitality and competitive edge. This paper builds on the work of [1], which proposed an AR-enabled PSP future state.

2 Research Objective and Methodology

This research investigated the integration of AR into PSP and the impact AR can have on the process. The methodology employed to achieve the research objective consists of 1) reviewing the current state of PSP and its challenges, 2) exploring the capabilities of AR, 3) identifying how the AR capabilities can address PSP challenges, 4) developing an AR-enabled PSP prototype for the Microsoft HoloLens headset, and 5) validating the prototype on an ongoing construction project through a survey and analyzing the impact of AR on PSP.

3 Production Strategy Process

3.1 Current State

[8], who noted that LPS does not presuppose any specific work structure, indicated that work structuring happened before project control – i.e., before lookahead planning could occur. [10] introduced PSP as the third step of LPS. Therefore, Production Strategy is implemented after the project team has set the expectations for the project in Master Schedule level (step 1) and has broken down the project into phases (such as overhead, exterior) and identified the activities to be carried out in each phase in the Phase Scheduling level (step 2). The Production Strategy level is where the project teams collectively develop a production plan for each phase. [7], [1] interviewed subject matter experts on PSP and provided a detailed explanation of the process. The authors explained that PSP consists of a prerequisite step and five other principal steps.

The prerequisite step highlights the importance of collaboration among the project team which consists of the General Contractor and Trade Partners (also known as Subcontractors). PSP is, thus, best implemented on an Integrated Project Delivery (IPD) project. The five steps consist of:

- Step 1 – Perform sequence and flow analysis of a phase: Project team reviews 2D construction drawings for a certain phase and agree on the sequence of construction activities and identify the direction of the flow.
- Step 2 – Gather information: The General Contractor conducts one-on-one meetings with the last planners of individual Trade Partners and ask them to 1) highlight on the 2D construction drawings how much work they can perform in one day (daily production), and 2) to group the highlighted daily productions into production areas with five days' worth of work.
- Step 3 – Develop Common Areas: The General Contractors collect the documents produced in Step 2 from each last planner, overlays them, and attempts to identify common production areas.
- Step 4 – Define Production Areas: The General Contractor works with each last planner to ensure that the scope of work within the developed common areas can be completed within five days. Depending on the situation, the last planner might need to adjust their production information or the General Contractor might need to adjust the common areas.
- Step 5 – Validate the Production Strategy: The General Contractor shares the initial production plan with all Trade Partners and solicit their feedback. The production plan is then revised and updated.

3.2 Current Challenges

[7] noted that PSP is information-dense, lengthy, and iterative and identified 11 challenges associated with the current process, namely:

- Collaboration: The lack of effective visual rendering in the traditional 2D drawings does not support collaboration.
- Communication: 2D drawings, unlike 3D models, do not embed detailed information on building components, which can result in misunderstanding and miscommunication among different stakeholders, leading to inefficiencies in the PSP.
- Decision-making: Specific information needs to be extracted from these drawings and processed to

formulate the necessary knowledge for making decisions and taking actions. The nature of the existing PSP does not support the rapid and right decision-making.

- Detection of Errors: 2D drawings do not allow for efficient design coordination, which can lead to inaccurate production input.
- Documentation: The documentation of the current PSP is decentralized where necessary data is often stored in various forms across different devices or locations.
- Efficiency: The one-on-one meetings with the last planners of each activity and the iterative process to develop common production areas and balance the workflow are time-consuming.
- Information Access: A variety of information and data is needed to feed the production plan. Project Participants often need to review multiple documents and software to access the needed information. For example, while 2D drawings are useful to illustrate the spatial arrangement of a project, numerical information is often not represented.
- Information Flow (Navigation): 2D drawings and paper-based information storage that planners rely on often hinder information flow.
- Input Accuracy: Some information depicted on the 2D drawings may not be current or consistent, which complicates the decision-making process of PSP participants. Therefore, when last planners highlight their daily production capacity, they are not provided with the actual quantity of their daily production.
- Interpretation of Plans (Spatial Cognition): 2D drawings present an individual view that is subject to individual interpretation.
- Safety: It is not easy for engineers to discuss and identify construction safety problems and considerations based on 2D drawings.

4 Opportunities to integrate AR

4.1 AR Capabilities

[16] explained that opportunities for supporting a process with Information technology (IT) fall into nine categories. The opportunities to integrate AR – an emerging and promising technology in the realm of IT – into PSP can be also grouped into those nine categories, defining the capabilities of AR, as explained (in alphabetical order) below:

- Analytical: Data analytics and AR build off one another. AR can provide real-time in-situ information visualization of multi-dimensional data [17]. AR brings a new dimension to present and visualize and interact with big data. The technology also offers a new medium that supports users in analyzing data [18]. AR enhances the perception of the user which leads to a better cognition and an enhanced understanding of the environment. Better cognition results in more processed information, wider understanding, and more effective learning leading to more successful and accurate decisions. AR supports the decision-making process by displaying the needed information and enhancing collaboration between those involved in the process [19].
- Automation: AR systems allow the automation of processes. Information can be automatically generated in real-time and displayed onto the real environment [20].
- Disintermediating: With the transition to the digital era, technologies such as AR has the potential to disrupt industries and intermediate and disintermediate processes [21]. AR overcomes the big hurdles of data capture, storage, processing, and integration and therefore creates a new kind of disintermediation.
- Geographical: One of the greatest potentials of AR is the development of new types of collaborative interfaces. AR can be employed to enhance face-to-face and remote collaboration where remote participants can be added to the real world. AR enables a more natural co-located collaboration by blending the physical and virtual worlds to increase shared understanding. Researchers identified five key features of collaborative AR environments: 1) Virtuality – objects that don't exist in the real world can be viewed and examined; 2) Augmentation – real objects can be augmented by virtual annotations; 3) Cooperation – multiple users can see each other and cooperate naturally; 4) Interdependence – each user controls their own independent viewpoints; and 5) Individuality – Displayed data can be different for each viewer [22].
- Informational: AR overlays digital content and contextual information onto real scenes which increases the perception the user has of reality. Furthermore, information can be captured from the user and saved for later analysis [23].
- Integrative: AR is a new source of context-rich data that allows the user to connect the dots between cross-functional teams [24].
- Intellectual: AR supports tacit knowledge exchange. A remote expert can transfer their tacit knowledge through AR via demonstration. Graphics, audio, and video could be used to effectively transfer tacit expert knowledge through AR [25].

- Sequential: AR systems support the performance of activities/tasks in parallel. This is also enabled with the remote collaboration feature that AR provides [20].
- Tracking: AR can visualize BIM data along with the real world of each construction activity and therefore, the status of the activity (complete, in progress, delayed) can be monitored and tracked, allowing the generation of an automatic report to check the progress of an activity [26].

4.2 Matrix of AR capabilities and PSP Challenges

Once the capabilities of AR have been identified, ways of integrating AR to overcome the challenges of the current PSP listed in the previous section are discussed. The nine impact areas laid the foundation for exploring opportunities to address the challenges encountered in the current process. A matrix was created to identify how each challenge will be addressed using the AR impact areas (as shown in Table 1). A detailed description of how AR can address each challenge is provided as follows:

- Collaboration: AR can be used to create a unique collaborative experience. Co-located users can see shared virtual objects (3D and 2D) that they can interact with. AR has the potential to augment the face-to-face (local) collaborative experience and to enable remotely stationed people to feel that they are virtually co-located [27]. AR allows multiple users to be actively engaged in the PSP.
- Communication: [28] reported that AR facilitates communication and discussion of engineering processes in real-time. AR supports the broadcasting of the user's view into a different screen allowing other users to freely exchange information.
- Efficiency: [29] showed that AR can improve performance time and mental effort in collaborative design review. AR can be a proactive approach that enables efficient re-planning [26].
- Decision-Making: [30] stated that using AR can result in better planning by reducing wastes of overproduction, waiting, unnecessary movement, and unnecessary inventory. AR can be used to make a well-informed decision on resource allocation and dynamic adjustment. AR has the capability to process real-time graphics which allows the user to process data faster and more effectively [31].
- Detection of errors: [30] mentioned that the integration of AR and BIM allows subcontractors to immediately recognize the interdependencies between activities. BIM provides the capabilities to identify activities and their interdependencies, and AR serves a visualization tool that provides a context for the work that needs to be performed in the field. AR also displays singular and integrated views in real-scale, context, and time and allows the planners to accurately recognize design errors, which can, therefore, minimize repeated work.
- Information Access: While BIM aims to consolidate and archive all relevant information related to the project, the merge of AR with BIM improves the information search and access. Users can also filter the 3D model by enabling and disabling different construction phases, levels, activities, and components. Users can also select elements in the 3D model and extract information corresponding to that element. Furthermore, an AR system can be connected to other databases that contain other planning and relevant information that the user can search for and extract.
- Information flow: Replacing 2D drawings and paper-based information storage with data-rich 3D models projected using AR facilitates a seamless flow of information from one stage to the other, providing planners with the needed information at the right time.
- Input Accuracy: AR allows the last planners to better recognize inter-relationships and links between activities. Furthermore, information can be associated with each element, and the user can select a certain component and visualize and read its corresponding information (such as properties, the material used, geometry, etc.). BIM can identify the interdependencies between the various activities, and AR offers a powerful visualization tool to supply such information to the last planner who is directly involved in the execution phase. AR can make the interdependencies between activities more explicit [26].
- Interpretation of Plans: AR can display any chosen single view or integrated view into the real view of the user. The challenge to construct a mental model can be alleviated with AR because 3D models are visualized [26].

Table 1. Matrix of AR Impact Areas and PSP Challenges

	C1	C2	C3	C4	C5	C6	C7	C8	C9
Collaboration	✓		✓	✓	✓	✓	✓		
Communication			✓	✓	✓	✓			
Decision-Making	✓				✓		✓		
Detection of Errors	✓				✓		✓		✓
Documentation		✓			✓	✓	✓		✓
Efficiency		✓	✓			✓		✓	
Information Access		✓			✓	✓			✓
Information Flow						✓			✓
Input Accuracy	✓	✓			✓		✓		
Interpretation of Plans	✓				✓		✓		
Safety Integration	✓				✓		✓		✓

*C1 – Analytical | C2 – Automation | C3 – Disintermediating | C4 – Geographical | C5 – Informational | C6 – Integrative | C7 – Intellectual | C8 – Sequential | C9 – Tracking

5 Prototype Development and Implementation

Developing a prototype is a way to simulate and test the operations of the new process [16]. Instead of describing the new process, prototyping allows the user to visualize and experience it. The prototype developed in this research is a small-scale, quasi-operational version of the AR-enabled PSP.

The AR-enabled PSP prototype is developed for the HoloLens, one of the most widely anticipated display devices for the AR market. Additionally, a study conducted by [32] surveyed 128 construction professionals and showed that Microsoft HoloLens is the device that is most commonly used in construction.

The cross-platform Unity 3D game engine was used to build a proof-of-concept of the AR-enabled PSP. Developing for the Microsoft HoloLens requires the use of the Universal Windows Platforms (UWP) to create 3D (holographic) applications. Such applications use Windows Holographic Application Program Interface (API). Therefore, Microsoft recommends the use of Unity to create 3D applications for the HoloLens.

The 3D model used for the prototype was a Navisworks model of an ongoing healthcare project that was acquired from a construction company. The model had a Level of Devolvement (LOD) 350. From the moment the 3D model was acquired to the time when the validation phase would take place, it was anticipated that the construction team would be developing the production strategy of the overhead to the third floor of the project. Therefore, a series of selection sets were created in Navisworks to only show the overhead work of the third floor. Figure 1 shows the first view that is displayed to the user and consists of the user menu and the section of the 3D model that was used.

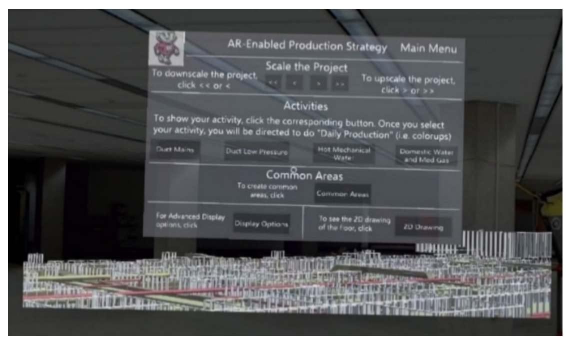

Figure 1. User's First View of the menu and the 3D model

6 Prototype Validation

Once the prototype was fully developed and implemented, it was validated on the ongoing healthcare project. A short presentation was delivered to participants to introduce them to the research topic, review the steps of the PSP, explain the technology (AR), outline the research objective, and provide an overview of the demonstration software. Participants were also provided with short tutorial videos that demonstrated the functionalities of the prototypes and asked to familiarize themselves with the software and its capabilities. In addition, the means of interacting with the prototype (gaze and air-tap, and tap and hold gestures) were explained and demonstrated to the participants.

Participants were first asked to test the prototype and were then asked to complete a survey to capture their feedback. Physical and digital copies of the survey were distributed and a total of 20 surveys were obtained.

6.1 Participants Information

Participants were asked to select their age category. 45% of participants were between 18 and 34 years, 35% between 35 and 44 years, 15% between 45 and 54, and the remaining 5% between 55 and 64. Participants were also asked to specify their current job title. 5 out of the 20 participants are Project Managers and 3 participants are Field Engineer. Single responses were collected from participants with the following titles: Project Engineer, Project Technology, Virtual Design and Construction (VDC) Specialist, Project Manager/BIM Manager, Steamfitter Foreman, Foreman, Mechanical/Electrical/Plumbing (MEP) Coordinator, Senior Project Manager, Director of Production Planning and Innovation, Production Engineer, BIM Coordinator, Member of the Performance and Innovation Resources Team.

The respondents' expertise in construction ranged from 2 years to 27 years, with average expertise of over 13 years. Collectively, the respondents totaled 248 years of experience in construction. During their years of experience in the construction industry, the number of projects that the participants worked on ranged from 2 to over 100 projects. Out of these projects, participants were asked to identify the number of projects on which they have been involved in PSP. The respondents' experience with PSP ranged from 1 project to over 20 projects.

6.2 Technology (AR) Evaluation

The survey included two sets of questions to solicit participants' opinions and feedback regarding the capabilities of AR as a promising technology in PSP. The first set of questions asked participants about their level of agreement with four statements using a five-point scale of strongly disagree (1), disagree (2), undecided (3), agree (4), and strongly agree (5). The results displayed in Figure 2 show that, on average, respondents agree that AR enhances their cognitive understanding of the process, facilitates the decision-making process, provides the user with the needed and desired type of information, and allows for a natural way to interact with the displayed information.

The second set of questions asked participants to rate the impact of the nine AR capabilities on PSP using a five-point Likert scale of very low (1), low (2), moderate (3), high (4), and very high (5). The results are reported in Table 2.

k-means cluster analysis was then performed to identify the capabilities that have the highest impact on PSP. Cluster analysis is a statistical method used to group data by comparing each candidate AR capability, for example, to the other AR capability already in the cluster. If the difference between the candidate AR capability and the other AR capability already in the cluster is significant, then the candidate AR capability is assigned to a different cluster.

The cluster analysis grouped the nine AR capabilities into three clusters based on the participants' average impact, with each cluster encompassing three areas. The three areas of Cluster 1 are the areas where AR has the highest impact on PSP and are as follows: Analytical (3.95), Tracking (3.79), and Informational (3.74).

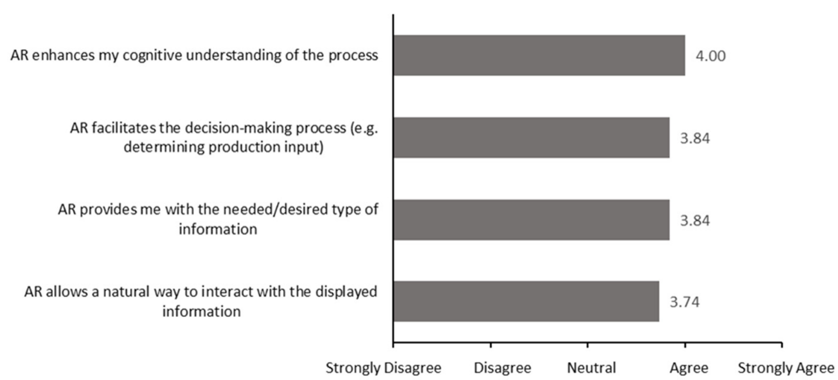

Figure 2. Technology (AR) Evaluation Criteria

Table 2. Clustered Table of the impact of AR Capabilities on PSP

AR Capability	Explanation	Average Impact	Clusters
Analytical	Improving the analysis of information and decision making	3.95	
Tracking	Closely monitoring process status and objects	3.79	Cluster 1
Informational	Capturing process innovation for purposes of understanding	3.74	
Geographical	Coordinating process across distances	3.63	
Integrative	Coordinating between tasks and processes	3.58	Cluster 2
Sequential	Changing process sequence or enabling parallelization	3.47	
Automation	Reducing human labor from a process	3.16	
Disintermediating	Eliminating intermediaries from a process	3.16	Cluster 3
Intellectual	Capturing and distributing intellectual assets	3.05	

6.3 User Experience

Another question in this section asked respondents to describe their experience using the AR-Enabled PSP. Figure 3 shows that participants saw this experience as engaging, interesting, innovative, fun, and easy.

Figure 3. User Experience (generated with WordItOut)

7 Conclusions

As interest in AR continues to grow, this paper explored the impact of AR on PSP – an information-intensive process. The current state of PSP and its challenges were first reviewed. Then, nine AR capabilities were discussed and a matrix was developed to explain how these capabilities can address the PSP challenges. Next, an AR-enabled PSP prototype was developed for the HoloLens and validated on an ongoing healthcare project. Twenty construction practitioners were asked to test the prototype first and then completed a short survey. Survey results showed that participants agreed on average that AR enhances their cognitive understanding of the process, facilitates the decision-making process, provides them with the needed and desired type of information, and allows for a natural way to interact with the displayed information. According to participants, the average impact of the AR capabilities varies between high and moderate with Analytical, Tracking, and Informational being the areas with the highest impact (cluster 1). Overall, participants saw this experience as engaging, interesting, innovative, fun, and easy and recognized the value AR can add to the PSP.

While this paper focused on integrating AR into the production planner process, further studies can build upon this work and study the integration of AR throughout the entire production planning and control system.

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