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Knowledge Management Framework for Integrated Project Delivery

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Abstract
Knowledge has become pertinent in this digital age, especially with the advent of Industry 4.0. Various forms of knowledge are continuously collected for use in the construction industry to overcome its fragmentation and many inefficiencies. Integrated Project Delivery (IPD) has been promoted as a delivery method because it relies on the involvement of all stakeholders during the project stages to successfully deliver a project with the highest value to the owner and lowest waste. This necessitates that all information must be shared with the stakeholders in a timely manner for swift and informed decision-making. Therefore, this paper proposes a framework for Knowledge Management (KM) in IPD projects using the Internet-of-Things (IoT). Firstly, the knowledge components in an IPD are discussed and classified into KM pillars. The framework is then delineated and discussed, which consists of four stages: data acquisition, data integration, knowledge management, and visualization. This framework is beneficial to IPD participants because it promotes the collection and storage of tacit and explicit forms of knowledge to create an inclusive repository. It also promotes real-time sharing of information for value-based decision-making.

Keywords
Knowledge Management, Integrated Project Delivery, Internet-of-Things.

1. Introduction

Integrated Project Delivery (IPD) has gained momentum over the years as a suitable delivery method for construction projects. It is a collaborative delivery method that aims to increase value to the owner, reduce waste, and maximize efficiency. Although IPD has many merits, it still faces similar challenges to other construction project delivery mechanisms. These relate to the fact that the construction industry is fragmented and project-based, which hinder the collection and dissemination of knowledge (Forcada et al. 2013). While IPD provides an appropriate platform for the disparate disciplines involved in a construction project to work collaboratively in the delivery of a facility, there are still limitations in the mechanisms for knowledge management at this project organization level.

The data-rich era in which construction projects currently operate is characterized by a greater volume, velocity, and variety of data, which is captured (often in real-time) using a wide range of sensors, unmanned aerial vehicles (UAVs) and other data acquisition technologies from construction sites and project repositories. This makes it imperative that project teams have appropriate mechanisms for managing data, information, and knowledge emanating from increasingly complex construction projects. This requires the implementation of a 'project organization' level knowledge management system (Anumba et al., 2005; Anumba, 2009) that comprises both technologies and techniques (Ruikar et al, 2007), and enables the 'live' capture and reuse of project knowledge (Tan et al, 2010). The availability of project knowledge would create transparency among all the participants to avoid any information asymmetry, and minimize the problems associated with lessons learned by some project participants not being communicated to all members of the project team. Hence, this paper proposes a knowledge management framework for IPD projects. This framework is intended for practitioners procuring projects through IPD and aims to provide a structured method for knowledge collection, sharing, and storage.

2. Knowledge Management

Knowledge Management (KM) is defined as identifying, creating, organizing, and disseminating information that can be used for decision-support, research, or learning (Harris et al. 1998). Other knowledge management definitions include the following:

- Knowledge management is the discipline of creating a thriving work and learning environment that fosters the continuous creation, aggregation, use, and re-use of both organizational and personal knowledge in the pursuit of new business value as defined by Xerox Corporation (Source: Cross (1998));
- Knowledge management is 'any process or practice of creating, acquiring, capturing, sharing, and using knowledge, wherever it resides to enhance learning and performance in organizations' (Scarbrough et al, 1999).

Within the context of this paper, Knowledge Management (KM) can be simply defined as a systematic process of capturing, transferring, and sharing knowledge to add competitive value (Drucker, 1993; Skyrme and Amidon, 1997) and to improve performance (Robinson et al, 2001; Robinson et al, 2004). It aims to synthesize and refine data from multiple sources to create a repository of knowledge. According to Uden and He (2017), the most important asset an organization has is knowledge.

The construction industry is plagued by the inefficient management of information in its projects (Xiet et al. 2019) and some of this can be attributed to the fragmentation of the industry in terms of processes, participants, tools, etc. As such, construction knowledge needs to be captured, structured and managed for maximum utilization. Knowledge management can be divided into four main components: organizational culture, knowledge acquisition and dissemination, policies and strategies, and training and mentoring of employees (Bozbura 2007). These areas are not always utilized in all construction projects.

Knowledge can either be tacit or explicit, and the combination of both forms is needed to understand the entire picture (Khallaf et al. 2018). Explicit data includes contract documents, drawings, or specifications, while tacit data includes know-how, experience, and competence. Much of the training and experience of construction professionals is based on a balance between codified (explicit) knowledge and tacit knowledge (Anumba and Pulsifer, 2010). Specialized expert knowledge and problem-solving know-how are the real products of knowledge-intensive industries (Egbu and Robinson, 2005) such as construction. Zhang et al. (2013) found that tacit knowledge sharing among the IPD team leads to flexibility and better connections among the participants. It is also important for IPDs because of its cooperative nature and the need to create new methods to reach the target cost. A structured KM framework is needed to combine all forms of knowledge for ease of use. Effective knowledge management can lead to various benefits including streamlined processes, accelerated knowledge creation, and increased profitability.

Knowledge Management Systems (KMS) are tools that help manage the knowledge available. They typically consist of a set of tools, made up of technologies (IT Tools) and techniques (non-IT tools). Both technologies and techniques are equally important to support different KM processes (Anumba et al, 2005). KM technologies rely on an IT infrastructure and can be in various forms that include databases, repositories, online platforms, or context-specific retrieval systems (Uden and He 2017). KM techniques do not depend on IT and include brainstorming, communities of practice (CoPs), face-to-face interactions, post-project reviews, recruitment, mentoring, apprenticeship and training (Ruikar et al, 2007). Thus, a KMS is composed of both physical and digital assets, and a set of techniques which can facilitate knowledge transfer between project stakeholders. It can also provide real-time visibility and traceability for the stakeholders involved. The following section will introduce IPD and the flow of knowledge throughout the projects.

3. Integrated Project Delivery

The Integrated Project Delivery (IPD) method relies on the joint participation of all stakeholders for the successful delivery of a project. These stakeholders include the owner, designer, contractor, and subcontractors. Among the challenges that face IPD adoption are integration of information and lack of knowledge management systems (Roy et al. 2018). A major source of delay in projects is from locating and transferring data (Fischer et al. 2014). In the traditional project delivery approach, project data is usually scattered among the participants and is not openly shared. However, in the IPD approach, since all participants are expected to work together, project information must be shared to avoid any delays or information asymmetry between participants. This involves a large volume of information that can pertain to resources, operations, or labor. This information is then converted to knowledge (by the addition of contextual information), which can aid in reducing waste and increasing the amount of value-added work throughout the project.

For an IPD to be successful, open communication and knowledge sharing between parties must occur. To foster collaboration, many tools and techniques have been developed and used for construction projects. These include the Last Planner System (LPS), Building Information Modeling (BIM), Internet-of-Things, and many more. Previous research have mainly focused on using LPS and BIM for IPD projects. Reda and Khallaf (2019) proposed a framework for LPS adoption in Egypt. Fischer et al. (2014) proposed a framework based on integration of the product, process, and organization. Ilozor and Kelly (2012) studied the interactions between BIM and IPD and their combined effect on the design and construction processes. Ma et al. (2017) proposed a collaboration platform for IPD participants to motivate the use of this method by reducing the need for constant physical presence. However, there are unexplored technologies that can support IPDs such as the Internet-of-Things (IoT). According to Hickethier et al. (2013), information is not equally distributed among all participants and that some participants will have more information than others. Although increasing the information available to everyone is aimed at increasing the efficiency, it can also backfire from information overload. This reinforces the need for a unified framework to collect and share knowledge among participants across all disciplines/teams to increase project success. Robinson et al. (2010) explored the issue of governance and knowledge management in public-private partnership (PPP) projects and made several important observations and recommendations that would translate well to the IPD environment. This paper builds on some of these by proposing a framework for knowledge management in IPD projects that leverages the emerging IoT technology. The next section introduces IoT and the tools available for construction projects.

4. Internet-of-Things (IoT)

4.1 IoT in Construction

The Internet-of-Things can be defined as interoperable objects, whether physical or virtual, that are connected together. These connected ‘things’ enable the collection, storage, and distribution of data over a network. Sensors are used to enable the transmission of real-time data through wireless networks. This real-time data can be shared amongthe project stakeholders such as the owner, contractor, and vendors for quick decision-making (Uden and He 2017). Real-time monitoring of physical assets such as buildings or infrastructure systems can also be performed. IoT has been used for monitoring different things such as smart libraries, transportation, smart cities, energy, industrial automation, and tower crane safety monitoring (Bai et al. 2012; Gul and Bano 2019; Xie et al. 2019). They have alsobeen used to monitor the physical environment (or facilities) in buildings for the lighting, security, firefighting, air, ventilation, room temperature, and energy (Xie et al. 2019). This can help in understanding the current conditions andpatterns, and in proposing modifications for the future. It can also minimize the need for physically checking the assets or performing unnecessary scheduled maintenance.

Tools for IoT

According to Ben-Daya et al. (2017), the collecting and processing of data, especially in a timely manner, has been an issue. This can be solved by utilizing new technologies like IoT. The Gartner Institute estimates that the number of interconnected devices will reach 20 billion in 2020 (Gartner Inc, 2017). These devices include sensors, Global Positioning Systems (GPS), Radio Frequency Identifiers (RFIDs), actuators, and mobile phones. RFIDs enable automatic object identification and location and can be used for product identification, data acquisition, and tracking. RFID tags can be placed on the procured materials to label them and ensure quick retrieval and installation. For example, placing these tags on window panels can help in determining where to install each one, thus increasing productivity and reducing costs (Li 2018). They can be used to sense the location of an object, building component, equipment, or even personnel. This can help in determining the crew’s productivity and the number of hours of use for equipment or its downtime. Thus, proactive or condition-based maintenance can be performed instead of prescheduled maintenances that may hinder operations if unnecessary. GPS can be used for spatial positioning while GSM/GPRS are used for wireless transmitting. Mobile phones can be used for their Bluetooth connectivity or to transmit real-time information from the site personnel to the rest of the team. Using a combination of these tools/technologies can be effective for streamlining operations in an IPD.

Many studies have found that construction can benefit from emerging technologies such as IoT and cloud computing (Anumba et al, 2020). This connectivity enables quick knowledge sharing and asset management. There are many benefits to using IoT for KM; these include: (i) collecting data from real-time sensors; (ii) generating more data from diverse outlets; (iii) enabling the automation of decisions and autonomy of applications/devices; (iv) predicting future behaviors; (v) measuring on-site progress; (vi) offering visibility for the entire supply chain; and

(vii) providing early warning for conditions that require immediate intervention. The use of IoT can then help in the creation of a knowledge-based decision system for construction projects.

5. Knowledge Management Framework for IPD

5.1 Knowledge Components

Knowledge consists of the information and data as well as the methods through which it is processed and the context for its use. An IoT framework is needed to streamline the processes in construction and reduce non-value-added work. This paper proposes a framework for knowledge management for IPD projects based on extensive literature review conducted. The framework uses the concept of the Internet-of-Things to collect, store, and analyze the data. This framework can enable the sharing of real-time information between all parties involved. It can also reduce the amount of waste occurring from non-value-added work, rework, errors in design, ordering excess material or ordering material earlier than needed. The proposed IoT framework can provide a repository of information that enables diagnostics and analytics throughout the project phases.

Figure 1 shows the knowledge components of an IPD. These knowledge components can either be from tacit or explicit sources. Another classification depends on the medium through which a component is conducted, which can be divided into physical and non-physical. Physical components include templates, plans, or drawings, while non- physical components rely on people such as huddles, workshops, and big room meetings. Another example is A3, which is a structured process of framing a problem, solutions, and action plan (on an A3 paper). Kanban boards are another project management tool used to visualize the work to be done and the flow. The QA/QC, safety, lean, and design plans are all grouped into 'Plans' (in Figure 1). Four KM pillars were identified according to Ahmed and Elhag(2017), which are people, process, technology, and information. Each knowledge component was assigned to one or more KM pillar depending on its application. For example, dashboards are created for project information to be shown using technology and the 'Big Room' refers to the physical location where all project participants meet as well as the collaborative process.

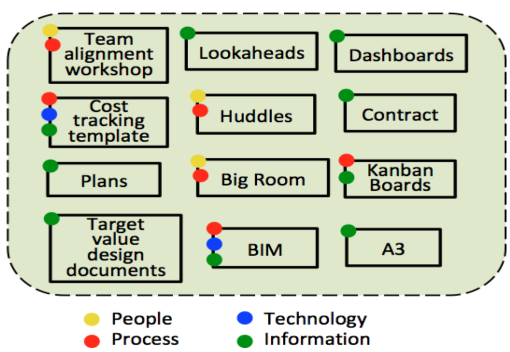

Figure 1. Knowledge Components in

5.2 Knowledge Framework

A knowledge framework is typically composed of multiple layers that structure how knowledge will be captured, managed, and disseminated. Figure 2 shows the knowledge management framework for IPD projects. The user layer shows the three contractual parties: the owner, designer, and constructor. These are the main participants, although there are sub-participants under them. For example, there are 'Cluster Groups' who are co-located and operate in cross-functional teams and can be under any of the three parties (Hickethier et al. 2013). These members are supervised by the 'Core Group', which is composed of an executive committee. The framework is composed of four layers:

1. The first layer is the data acquisition layer where the required data and technology are identified and acquired. Two types of sources are recognized: physical objects and non-physical sources. The non-physical sources are the meetings,

team alignment workshops, and user expertise. During these events, the users discuss project information and convert it to knowledge through the use of A3 and Kanban boards to visualize the information. The information obtained includes both vertical and horizontal information. The technologies used in this layer include sensors and RFID tags and inter-equipment connection can also be enabled. The two physical sources suggested are:

a. Sensors: can be used to collect data on the physical environment such as temperature, which may affect inventory.
b. RFID tags: can be used on equipment (to determine the location, utilization, and downtime), on materials (to determine the location, available inventory, and rate of use), and on personnel (to determine their location and productivity). This information can be used to find the production rate for each activity and the productivity of crew. This can then be used to predict estimates for future activities and suggest modifications to lookaheads based on previous/current situation.

The data from these physical objects can be used for space management and planning. It can also be used to track the procurement loop from delivery to installation, hence overlooking the entire cycle. Data on equipment and worker location and their movement across the site can be captured. This can be linked to progress made on an activity, which can also be linked to visual data captured using unmanned aerial vehicles. This would enable streamlining the acquisition and sharing of data among parties to an IPD, which would improve the project delivery process.

2. The second layer is for data integration and storage through a wireless network. This layer collects the transmitted information and stores it to be sent to the computing layer for processing. Data such as activity progress, material levels available, and equipment usage are stored here.

3. The third layer is the knowledge management layer that is responsible for the processing of data. Analytic tasks such as diagnosis, assessment, or prediction can be done using artificial intelligence. For example, machine learning can be used to determine patterns related to work package durations and reasons behind delays in activities. Data can also be stored in the cloud to allow for remote access. A cloud-based intelligent monitoring and control system can then be adopted for the projects.

4. The fourth layer is the visualization layer. Here, the data is translated to readable text and displayed visually using tools such as dashboards, BIM, and Virtual Reality (VR) or Augmented Reality (AR). These tools can be used during the design or construction phase. During the design phase, BIM can be used not only to visualize the project, but also to monitor the cost, schedule (from Last Planner), and sustainability issues for a holistic view of the project. Virtual/Augmented Reality are a step higher than the 3D view from BIM and can offer a full immersive experience for the participants. Using VR, a virtual model can be constructed, which can aid in visualizing the product at an early stage and making changes to it. Both VR and AR can be used for safety training before/during construction. They can also be used to show details of the final facility/building to make decisions on it instead of having to construct a real-life mockup. Additionally, they can be used to evaluate alternatives and choose between them. During construction, a dashboard can be created to view project control data or real-time work package data. It can be used to track progress, expended resources, and to keep track of the budget. After construction, BIM can be used to create as-built drawings for facility management during the operation and maintenance phase post project delivery.

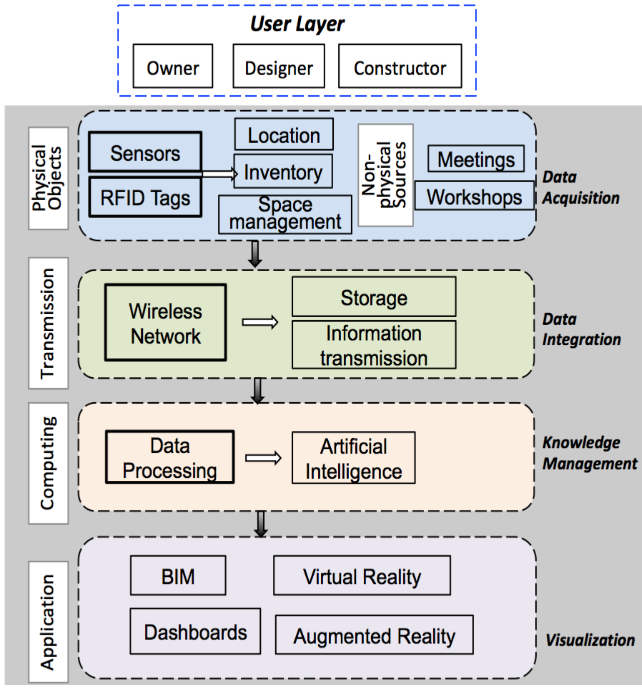

Figure 2. Knowledge Management Framework for IPD

Although there may be variations to the contractual methods in an IPD, the most common one is the single multi-party contract between the owner, builder, and constructor. Additionally, one commonality between all IPDs is the partnership and relation between all contracting parties regardless of the contract type. This partnership allows them to work together for a fixed contract amount whilst sharing risk and reward as well as responsibility.

The knowledge components (from Figure 1) can be shared among the participants through the user layer thus converting the data from tacit (through meetings or huddles) to explicit. The knowledge obtained from the users (tacit) and physical objects (explicit) is combined to create the full knowledge repository. The proposed framework can allow remote access to project participants so that it is not necessary for them to be physically located on-site at all times. It also serves the integration of four KM pillars in a project, which are people, process, technology, and information. It can support the just-in-time ideology for procurement to reduce inventory and can aid in real-time cost planning and quantity measurements. Additionally, it supports the dynamic nature of IPD and the quest for continuous improvement and innovation. This will also ensure alignment of business objectives and strategies between the various parties from the beginning of the project. All this data can be stored in a searchable lessons-learned repository after the successful completion of the project to be used for future projects.

6. Conclusions

The use of IoT for KM has many potential benefits. It can enable the collection and analysis of large datasets and informed decision-making based on multiple data sources. It can also enable predictive and prescriptive analytics. This is especially beneficial to IPD because of the unique nature of projects that require the presence of all participants throughout the project phases. IPD is seen as a solution for many of the problems that face the construction industry; however, it needs a structured framework to foster efficient and effective collaboration and knowledge management. The proposed framework aims to connect all participants, achieve effective knowledge transfer, foster collaboration, and foster human-machine interactions that can lead to automated/semi-automated procedures in the future. Smart technologies can also be used in the construction phase and added to the framework, such as autonomous equipment. Finally, this framework takes into consideration four main KM pillars, which are people, process, technology, and information. Further research can be conducted on each of these factors to identify their specific components and their effect on the knowledge management process in IPD projects.

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