Improving the Delivery of a Building

Vince Thomson and Xiaoqi Zhang

Abstract There is a great difference in the effectiveness of product industries and the construction industry in the use of technology for better execution of development projects. This paper discusses some recent technologies that are able to create a better environment where construction companies can partner to share the cost-benefit of product information in order to optimize the cost and timeliness for building construction. The basis of this improvement is the use of active products that can update their own information. Products as intelligent operators have the greatest effect by automatically changing product data.

Keywords Construction · Part tracking · Intelligent object · Change management

1 Developing New Products

1.1 Product Industry

In today's environment, a product manufacturer usually designs and makes a complete product, or at least, controls all the processes for design and manufacture. An integrated product development team (IPDT) creates a design in a CAD (Computer Aided Design) system and manages the design with a PDMS (Product Data Management System) and/or a PLM (Product Lifecycle Management) system. This allows product management from the point of view of product design, part lists, part creation processes and assembly. Product information is integrated with ERP (Enterprise Resource Planning) systems (also known as Enterprise Resource Management Systems (ERMS)) to control product manufacture and supply chain processes. The cost and timeliness of product creation are predicted and controlled by the IPDT.

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It is the integration and sharing of information that allow the control of cost and timeliness [3]. A company that designs and makes its own products controls the cost-benefit of creating and using product information and of controlling the schedule and supply chain to make timely products. An example is Apple, who completely controls the designs of processor, hardware, operating system, application software and related cloud services as well as retailing stores [16]. For products that are developed in partnership, the OEM (Original Equipment Manufacturer) creates a team along with terms and conditions that incentivize the IPDT to share information and to optimize cost-benefit across product components.

In today's product information systems, products behave as both passive and active actors regarding their information [15]. Usually, a product does not carry its own information, but it carries identification (bar code, RFID tag (Radio Frequency IDentification), etc.), which provides a connection to its information stored in a set of databases. Much of this information is 'active' in that a change to a product datum automatically triggers changes to other data about the product in terms of design, manufacture or supply, assembly process, maintenance, etc. [5]. This level of integration of product data and associated automation with regard to product change has been continuously developed over the past 50 years since the first CAD systems. Nevertheless, although integration of product information is beneficial to the design process, most of the benefits accrue during the later stages of a product life cycle: part production, product assembly and maintenance, that pay for the high cost of integrating product information.

1.2 Construction Industry

Even though CAD systems for architecture, engineering and construction (AEC) were developed about the same time as CAD systems for other types of products, the drive for integration of product information and the accompanying automation for managing change have not occurred in the construction industry as it has in product industries [10]. The reason for this is that most of the time the overall process: the design, part production and building assembly procedures, are not controlled by any one company or group of companies, and thus, there is a mismatch between the cost of the integration of product information during the design phase and the benefits which occur mainly downstream during construction and maintenance. Typically, you have the architect and engineer who develop the design, and the general contractor, major contractor, and sub-contractor, who actually cooperate to construct a building, but in the process all partners act as individuals who optimize their own cost and activities due to marginal incentives to optimize overall cost and respect timeliness.

As a consequence, there is rarely an overall product model, and at best, there may be small, limited models created by individual companies. In general, the construction industry does not use IPDTs, rarely has group incentives to drive project goals, and does not use arrangements to collectively achieve goals for building construction. One major reason is due to different operating environments for product and construction industries. The construction industry uses contract bidding at each tier of the construction process, which actually inhibits cooperation towards integrating information.

There are some exceptions. One such example is the construction of the Sutter Medical Center (136 bed) project in Castro Valley, California. Project management was able to group together partners such that they shared project profits. This allowed the formation of an IPDT that created a single building information model (BIM), which facilitated the evaluation of alternative designs as well as the management of design and schedule change [12]. As a consequence, building permit approvals were obtained in record time; building construction was delivered at the guaranteed minimum price, and had an accelerated schedule that was 30 % faster than a conventional schedule [6]. Construction change orders and requests for information for structures were less than 15 % of estimates for comparable hospital projects in California [2].

1.3 Paper Objectives

The goal of this paper is to convey that some recent technologies are able to create a better environment in the construction industry where companies can partner to share the cost-benefit of product information in order to optimize the cost and timeliness of building construction, and that the basis of these improvements is the use of active products that can update their own information. Section 2 describes technologies that have recently entered the market or that their price and functionality have been significantly improved. Section 3 discusses the advantage of the technologies with regard to reducing project cost and improving timeliness. Conclusions are stated in Sect. 4.

2 Technologies for Improving the Delivery of a Building

2.1 Product Information System

The heart of any construction activity is the bill of materials for a building from which a schedule for part creation or supply and building assembly is made. ERP systems store information about a building and the pieces and devices in it. ERP systems also accommodate change management in terms of part alternatives and modifications to schedules and suppliers. The bill of materials flows from a building design. There are many systems that can design a building and create a BIM. The BIM is a digital representation of the physical and functional characteristics of a facility. The goal is to use the BIM as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle (conception to demolition) [7]. Moving from concept to BIM for a large building requires the cooperation of many partners and the integration of much data from each partner.

The greatest issue with regard to managing product information stored in a BIM, ERP, PDMS, etc. is defining, confirming and executing change. Recent research into change management has shown that it is possible to define the chain of change propagation and to manage the execution of changes in a design and manufacturing plan [17]. The management of the change process by the IPDT is another issue, and not covered here. Systems that can manage procedures for changing a design greatly reduce the effort for all the partners; for, one of the major cost drivers during product development is boundary management, i.e., the use of coordination mechanisms to assure the delivery of material and information across organizational boundaries: internal and external [3]. The process of managing change uses a lot of resources and causes much delay, where there can be instances of a design document being exchanged over ten times until it is finalized [14]. The more automation can be brought to bear on this process, the better. Thus, having available a methodology modifying product data when there is a change to the product or its circumstances greatly reduces the cost of the production process.

ERP systems are readily available. They range from generic, highly functional systems, such as SAP, to AEC specific systems, such as COINS, which provides traditional ERP functionality along with design functions to create a BIM and applications for construction specific analysis. The price for such systems is continuously being reduced. Even though this is resulting in wider adoption, the construction industry still does not have the adoption rate of product industries [1]. Thus, it is about taking advantage of automation to reduce one of the main cost drivers in building construction: change management.

2.2 *Part Identification and Tracking*

Delivering the thousands of parts for a large building is a very difficult task. This usually involves hundreds of partners and thousands of deliveries into a cramped construction site. RFID is a great tool that allows the identification of parts and their tracking at the manufacturer and at the construction site. There are several options.

- There is simple identification of parts with an RFID reader when using an RFID tag. The tag can be found at any time; however, the RFID reader only determines that the part is in its range. It does not provide location. A short search is needed.
- An RFID tag can have memory where the user can store not only part identification, but also other design and construction parameters.
- The majority of RFID tags are passive, i.e., the energy to transmit data comes from the radio frequency signal scanning a tag, and so, range is limited. There

are active (scheduled transmission) and passive (on demand) battery-assisted tags where local power allows transmission of radio signals over greater distances. Battery-assisted tags are more expensive, but allow automated tracking of parts when there is a lot of movement and/or distances are large.

Several companies use RFID tracking to their advantage. Examples are given below.

Armtec is a company that supplies precast, corrugated steel and HDPE products. In 2010, Armtec was awarded a $Cdn 43-million contract from the Toronto Transit Commission (TTC) to supply 58,000 subway tunnel, liner segments over a two year period. "This job requires handling hundreds of pieces per day," said Phil Sheldon, operations manager. "The tracking of those TTC pieces would have been very difficult to do without RFID technology." [8] Armtec used a combination of barcode and RFID embedded tags along with a GPS (Global Positioning System) to track and locate pieces, and to store the information.

At Armtec's Woodstock site alone, the estimated cost of missing inventory was $Cdn 260,000 per year, including $Cdn 60,000 in annual penalties for late deliveries where suppliers were fined up to $Cdn 3000 per hour for causing delays at job sites that resulted in construction crews being idle [8]. In addition to reducing missing inventory and late delivery penalties, Armtec saved money by reducing the many hours spent searching for pieces in its 20-ha site. TTC is now using the technology to identify and locate damaged tunnel segments quickly, thereby saving time and providing better maintenance.

Similarly, JV Driver, who provides industrial construction services to the resource sector in western Canada, uses RFID tracking technology to find pieces on its construction sites, where piece average search times were reduced from 30 to 5 min [11].

During the building of the 200,000-m^2 Metlife Stadium, Sanska USA Building (Parsippany, New Jersey) used RFID to track 3200 precast pieces to form the 84,000-seat bowl of the stadium. A just-in-time delivery system where tracking information was fed into a BIM meant that Skanska could identify which pieces had been manufactured and their quality status, what jobsite areas needed to be prepared, and what pieces were already incorporated into the building [9]. Skanska did not need to establish a laydown yard, but instead relied on a small holding area. For the precast pieces, Skanska estimated the tracking solution accelerated the construction schedule by 10 days and created $US 1 million in savings [9].

2.3 *Part Location*

Objects can be identified and located by using real time locating systems (RTLS). These systems can use active or passive RFID or infrared tags along with multiple readers. Items can be identified and positions located as precise as 5 cm using algorithms such as triangulation and technologies such as ultra-wide band [4].

Absolute positions can be obtained by use of a GPS or local tags with known position.

A RTLS reduces the search time for parts, allows for 1 piece flow from supplier to assembler, and permits time information for placing a part into its final location. Continuous part location reduces the labour due to continuous checking of delivery and assembly schedules as well as the supply chain for parts. An RTLS can be used as part of an information change process to update product information.

In the $US 10-billion Clair Ridge project by BP, a global oil and gas company, hundreds of suppliers took part in the construction of a new offshore oil platform by delivering components from two consolidation centres in Europe to the building site in South Korea. BP used an RTLS system consisting of both RFID and GPS technologies to track parts and to minimize delays. The RTLS system allowed real time visibility of parts moving from suppliers to the construction site, and helped BP to reach zero material loss and to significantly improve the planning process [13].

2.4 Self-organizing Wireless Microrouters

Routers are devices that use IEEE 802.11 communication protocols to allow connections among devices and between devices and networks. Of interest are those devices that can form self-organized networks, i.e., automatically making their own network. They do not need to be connected to a formal network or the Internet. Each device acts as a wireless microrouter that can establish peer-to-peer connections and relay messages from one peer to another. So, peers form a network and they relay messages such that they reach their final destination. Thus, a microrouter only needs to be connected to one other router, not to all routers. Self-organizing wireless microrouters form a true network topology, not a star. If one device is connected to a network, all microrouters have access. If one device fails, the other devices repair the network.

At a construction site, devices with an RFID tag and self-organizing wireless microrouters along with access to an RTLS can form a self-identified network, i.e., a peer-to-peer network where each device knows the identity and location of every other device. One device can download a location map of all devices into a database on schedule or on command. Part locations can be checked against the construction plan (BIM) and schedule for any deviations, and the data in an ERP can be updated.

2.5 Self-integrating Objects

Traditional networks of devices are defined by standards for connectivity. The host system provides this connectivity, and the software for communication protocols, for access to data, and for execution of special algorithms is provided by applications in the host system. These applications are loaded into the host, and if modifications occur in an attached device, a new application needs to be acquired.

A new approach is to have devices that are intelligent, understand the topology required for network integration, able to communicate on a network, and contain their own applications. In this approach, devices deliver applications to the host system during integration. If a device is changed (options made operative, upgrade), the device acquires a new application itself or self-modifies its present application. Then, negotiation is made with the host to install the new application.

This architecture makes a system device (product) responsible for its own information in addition to its own integration into a system. It provides a product with the communication and negotiation capability to resolve issues with the host system.

Consider an HVAC system in a large building. There is usually a central system which receives information from local controllers throughout the building to balance the overall system and to create the desired environment. Each controller usually has multiple sensors and functions. Although the original building plan determines the number of sensors, area controllers and their functions, allocates the number of interface connections, and sets the specifications for the host software, there are always changes: more or different sensors, different functions for area controllers, as well as significant change to control software. This causes a sea of changes in the HVAC system, which adds considerable effort to the building construction and maintenance.

If each area controller had a self-contained application and could effect its own changes by negotiating with the central system, then the impact of change would be highly reduced due to the automated change mechanism. Even if different devices are used than planned, the automated negotiation and integration of interfaces greatly reduces the effort due to change.

3 Discussion

At the beginning of the paper, the difference between product industries and the construction industry with respect to the greater use of technology by product industries for product data integration in order to reduce overall cost and to improve the timely delivery of products was described. In the construction industry, the capability of part tracking to reduce material handling cost and to deliver better timeliness for building assembly was shown. However, it is the use of technology that allows products to change their own product data that greatly improves the use of product information in the construction industry, since this type of automation greatly reduces the amount of labour and time. With this technology, collaboration among partners increases since the improvement in construction information has increased benefits for all partners.

The updating of part location can provide the status of part delivery, jobsite location and final position in building assembly. Moreover, besides providing this data, parts need to act as intelligent operators and transparently change their data in an ERP or BIM. It is the automated initiation of change by a building piece or device through networked systems that reduces the cost of building assembly, maintenance and future data integration. Technologies such as self-identifying objects, RTLS, and wireless microrouters provide the basis for making device initiated change a reality. However, it is being a self-integrating object that allows a product to be an intelligent operator, which can respond to its environment and update its information.

When reviewing projects such as the construction of the Sutter Medical Center, there are three main reasons for achieving the high level of success: the agreement by partners to a single, collaborative contract which outlines partner responsibilities and the sharing of cost and benefits; the use of technologies like BIM; and the use of Lean project principles [2, 12]. This paper has discussed the use of technology to automate change in design and operations. It is also clear that this use of technology needs to be built upon best practices in the forming of partnerships and in project management.

4 Conclusion

There have been many successful projects that use an IPDT as well as create a BIM to share building information, and thus, they have been able to create synergies that have reduced cost and have delivered buildings on time. Unfortunately, to date, these cases have been limited and the methodologies have not been widely adopted. This paper has described some technologies that allow building pieces and devices to be intelligent operators such that they can act to automatically and transparently update product data in order to improve cost and timeliness during building construction. The technologies are inexpensive and readily available. Overall, the construction industry needs to combine the use of smart devices as intelligent operators and the use of best management practices during building projects in order to improve productivity.

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