IMPROVING BUILT-IN QUALITY BY BIM BASED VISUAL MANAGEMENT

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ABSTRACT

Efficient and flawless information management plays a key role in successful execution of construction projects, but it has been difficult to implement in the traditional document-based environment. A root cause for waste in construction projects is inaccessible, inadequate or missing information. Necessary information is produced by several parties and it is often fragmented, inconsistent or in an impractical format. A lot of time is wasted - meaning that value is destroyed - in searching information needed for activities on construction site due to the fact that even if the information exists somewhere in the documents, it is not easily available. Visual control systems defined in Lean methodology strive for improving the value added flow. Building Information Modelling (BIM) can facilitate organisation and visualisation of information for specific needs in the process. This paper explores how combining principles of Visual Control and BIM could improve information delivery from information producers to information users to reduce waste in searching and processing the information. The methods of literature study, Value Stream Mapping and Root Cause Analysis are used. Software-based Standardised Model Views (SMVs) and their automated creation from BIM, based on predefined use cases and end-user needs are proposed and illustrated. The use of SMVs facilitates Lean information management, thus reducing rework and time spent on waiting, increasing built-in quality and enhancing flow in production. Evaluated savings in a single subcontractor's work time are at least 10% when SMVs are used.

KEYWORDS

Lean, BIM, VDC, Visual Control, Information Management, standardised model views, Built-in Quality, Waste

INTRODUCTION

This article introduces a novel way to improve information management and information sharing within a project team from the client to the smallest subcontractor in a construction project. The idea of utilisation of Standardised Model Views (SMVs) has arisen from the practical need to enhance information management in order to reduce non-value added work: the proposed solutions to facilitate new innovative way of working are based on observations in a construction project and findings from

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numerous BIM field tests during the past year. Analysis and the proposed solutions have been developed by combining principles of Lean and BIM.

The SMVs are simple and visual, easily understandable packages of project information. The data content of SMVs are always customized based on the information needs of the information users in a predefined process. The foundation of the views are in project's Building Information Models (BIMs) to which other type of project information is combined in a suitable format using annotations in the view, model properties, attachments or links, temporary colouring of the model components based on their status, etc. The purpose of a model view is to 1) reduce the time used in searching of the information, 2) ensure more consistent and up-to-date information delivery to project participants, and 3) provide only the necessary information to the users in a visual and easily understandable format in the right place at the right time by using mobile solutions such as tablet computers. The unnecessary parts of the BIMs and other data are excluded to streamline information reviewing and interpretation thus minimising the waste in navigating and searching relevant information.

METHOD OF RESEARCH

The research was conducted by observing and analysing the case project on site for one year. The data is based on on-site observations and interviews of the participants in the studied working package. A3 problem solving (Liker 2012) was used as a tool for collecting and analysing the data during interviews. The Value Stream Mapping (VSM) was implemented to study the actual process, workflow in the work package and especially to highlight the points where value or waste are created. When conducting on-site observations in the case project 15 different causes for waste were detected. An information management framework presented by Hicks (2007) was used to characterise the identified waste. Critical points in the process were identified and analysed by using Root Cause Analysis (RCA) method in order to reveal instances of waste.

A comprehensive literature study was conducted to better understand the nature of waste and as a method to categorise the waste factors in terms of Lean waste types. Field tests and literature study were used to find ideas to solve the identified problems.

The proposed solutions of SMVs were developed by combining the case project analysis and findings in the literature study. Examples of the solutions were created and they were presented to the project participants. Based on the feedback proposed solutions were improved and edited further. Finally, the results were evaluated by presenting each category of waste and efficiency of corresponding solution.

RESEARCH BACKGROUND

Productivity in the construction industry has steadily declined over the past 30 years (Khanzode et al 2006, Teicholz 2001) and on-site studies reveal only 30% of work being productive while rest of the time is spent in waiting, moving materials or looking for the right equipment (Elfving 2007). In order to improve productivity in construction projects many initiatives have been proposed. Two profound and globally relatively widely accepted initiatives in the construction industry are Lean Construction and BIM or VDC (Virtual Design and Construction). These two concepts are discussed further in the following chapters.

The construction industry has defined building code systems, CAD standards and BIM specifications to organize information in a logical way. These standards have not fully resolved the challenge of information being still fragmented, inconsistent and not easily manageable. The current state-of-art in information management on construction sites could be compared to the way Liker (2004) describes car manufacturing plants outside Japan before Toyota's Production System (TPS) was created: a mess where it is impossible to tell whether items are in place or out of place and where problems were seen only when they resulted fire-fighting crisis. Although ways to improve information quality in the construction phase have been studied and some novel solutions are proposed (Hewage et al 2009, Sacks et al 2013), the time spent in interpreting design intent by reviewing several drawings simultaneously or in searching the right piece of information from multiple design documents remains unresolved. Construction industry, which relies heavily on subcontracted work, suffers from lack of trust between different stakeholders as well as greatly varying organisational capabilities. In order to improve the information management it is crucial to understand the importance of integration of three core areas, namely people, process and information systems (Dave et. al 2008). Those companies, which have already recognised this and are implementing the integration, are on their way in transforming from good to great companies (Collins 2001).

LEAN CONSTRUCTION

Lean Construction originated from TPS and Lean which define waste as a non-value-added activity (Liker 2004). One of the key factors causing waste and leading to inefficient production in construction projects is poor information management. Although Information Technology (IT) is widely used by the participants in construction projects, the information delivery and information exchange between them is not utilising the full capacity and methods IT could facilitate (Fischer and Kunz 2004). Also according to Dave et al (2008) IT implementation in construction industry has not been successful and has not improved the core business processes due to failure to integrate people, process and technology when selecting and implementing the IT solutions.

Within the concept of Lean, there are eight types of waste (Womack and Jones 1996). Hicks (2007) argues that information management systems are analogous to manufacturing operations and production environments by terms of value-flow model, but the waste and value are less visible and more subjective than they are in manufacturing. Built-in Quality is one of the ways to reduce waste. It strives for producing the things right at the first time and is a method to detect defects when they occur and making sure the problems causing the defects are found and the process improved accordingly (Liker 2004).

According to Liker (2004) the strength of visual control is in its ability to see abnormalities at a glance and to work as a communication device that tells immediately how work should be done and also facilitates flow of work. Good visual controls minimise the need for interpretation and reduce the need of studying the information by providing immediate and clear understanding to the user about the visualised issues. Visual management is making use of visual control methods to manage for example activities on site on daily basis (Liker 2004, Brophy 2013). The benefits of a well-developed visual control system are increased productivity, reduced amount of defects and mistakes, improved communication and safety, cost-efficiency, better control for the workers over their environment and better performance in meeting deadlines. According to Tezel et al (2009) Visual Management is an efficient information management tool because the information can be divided into different functions and this simplification provides an effective way to present filtered, high-quality information for specific tasks.

When reviewed from the information management perspective, the principles of Visual Management are difficult to apply to information flow in digital systems and control abnormalities of information. Therefore detecting the waste in information management system is problematic compared to management of material flows. According to Hicks (2007), the five key principles of Lean are applicable to information management and provide similar framework in which the waste can be understood and studied. In the context of information management, there are four categories of waste, namely 1) flow excess, 2) flow demand, 3) failure demand and 4) flawed flow, which can be mapped directly to four traditional types of waste; overproduction, waiting, extra processing and defects. Remaining three types of waste, i.e., transport, inventory and motion, are not clearly identifiable when considering digital systems, such as BIM. However, they are still present in digital-physical system and affect in particular to the behaviour of the end-users. In information management domain, the remaining categories of waste are 5) mass electronic communication, 6) legacy databases and file archives and 7) gatekeepers/single seat licences (Hicks 2007).

BIM AND VDC

In this article term BIM is used in the same meaning and same context as in the BIM handbook (Eastman et al 2011), which defines BIM in its glossary as *"a verb or adjective phrase to describe tools, processes, and technologies that are facilitated by digital machine-readable documentation about a building, its performance, its planning, its construction and later its operation."* This definition is expanded by notion presented by Sacks et al (2010): *"The result of BIM activity is a "Building Information Model"*.

CIFE has developed the concept of VDC as a way to utilise BIM and modelling of the information flows by using symbolic representations of Product, Organization and Process (POP) and detecting and analysing the interaction between the three in the aspects of Form, Function and Behaviour (Khanzode et al 2006).

Industry Foundation Classes (IFC) is a neutral and open specification for BIM that facilitates interoperability between different software applications in the construction industry. It is supplemented by the Information Delivery Manuals (IDMs) which aim to define a standard information content for exchanging computer interpretable data between different parties in a certain construction process phase and task (Karlshøj 2011, Zhang et al 2012).

Sacks et al (2010) have defined at least 56 interactions between Lean Construction principles and BIM. However, the concept of SMVs is not listed as one of the interactions; instead the concept requires combining several of the earlier defined interactions.

CASE PROJECT

The Case Project Lahden Sairaalaparkki was around €13 million Design&Built project located in Lahti Finland. The building facilitating space for 600 cars and 5000 gross-m2 office space was finished in January 2014. The design including all design disciplines was executed using BIM. Integrated BIM was used daily on site in several ways, e.g. to coordinate the MEP installations, to facilitate the communication in project meetings and to extract the quantities for ordering materials.

CURRENT STATE OF INFORMATION MANAGEMENT ON CONSTRUCTION SITE

In the case project a single trade contractor needed information from 40 different project documents in order to execute his work. Additionally this contractor’s workers needed to carry with them multiple documents and simultaneously interpret them in order to successfully complete the installation work. Another example of the current poor state of information management on construction sites is presented in Figure . This example shows how a trade contractor manages the supply chain of the precast concrete and its installation schedule on site by highlighting the installed precast parts with pink to the blueprint drawings to visualise the current status of the work. Highlighting the blueprints is a well-known and widely used approach to manage and enrich the construction data. The benefit is the fast and easy understanding of the status in the visual representation just by looking the plan. The problem is that the information is available only on the bulletin board in a site office of trade contractor’s foreman without the possibility to share it with other team members.

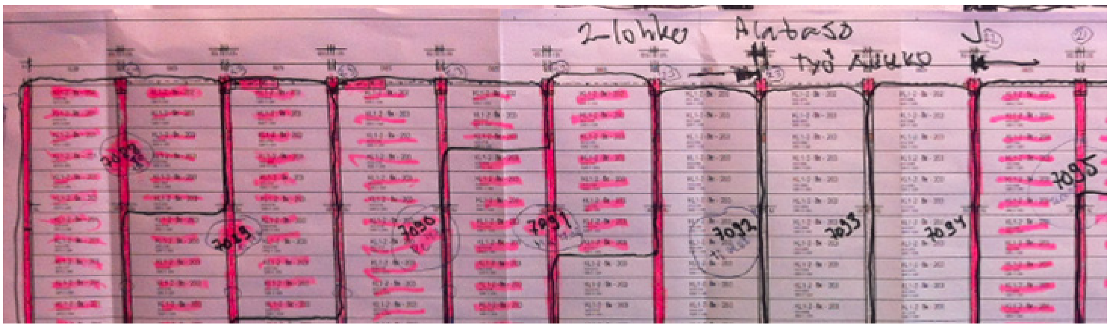

Figure 1: Image of how the actual installation schedule of precast concrete is documented and managed in Toriparkki construction project.

LEAN CONSTRUCTION AND LEAN INFORMATION MANAGEMENT

Identifying and categorizing different causes of waste is vital in order to remove knowledge and information dependent waste from construction process. Hicks (2007) presents 8 fundamental barriers to improve information management in SME (Table). In the context of the construction process, which is implemented in subcontracted business ecosystem consisting mostly of SMEs, the 15 different causes of waste were identified in terms of information management framework and different types of waste were identified in terms of Lean. This categorization is needed for further analysing the results of working packages VSM and RCA.

Table 1: Information management barriers and causes

	Domain		
	Manu-facturing	Information management and users	Identified causes of waste in the case project
1	Over-production	Flow excess	Information was generated too early: (1) instead of needed plans, (2) based on insufficient initial information or (3) information which was subject to change
2	Waiting	Flow demand	Waiting for information: (4) Information is generated and delivered too slowly, or (5) it is scattered into systems and documents resulting time wasting search.
3	Extra processing	Failure demand	Re-processing information: (6) re-planning due to inadequate or impractical customer requirements or (7) over-processing (fastidious details)
4	Defects	Flawed flow	Incorrect information causing (8) defects and inappropriate downstream activities, corrections and (9) unnecessary verifications
5	Transport	Mass electronic communication	(10) Unnecessary changes of format, (11) replication of data (may decrease quality of information and/or cause errors)
6	Inventory	Legacy database and archives	(12) All information which is not used for the customer project (e.g. for planning, constructing, maintaining etc. of the building)
7	Motion	Gatekeepers/ single seat licences	(13) Unnecessary movements and acts by people needed for retrieving information
8	Under-utilisation of skills	-	(14) Obscure information or user interface: people are unable to improve the information with their ideas or creative input or (15) frustrated unnecessarily due to impractical information or user interface.

VSM AND RCA – LOCKING AND IRONMONGERY WORK PACKAGE

The construction project is a combination of several work packages often conducted by specialized subcontractors. To analyse the information flow of the case project and to find possibilities to reduce waste by improving built-in quality we selected the locking and ironmongery work package for three reasons: 1) The particular work package has interface with several other work packages (electrical, access control, automation, interior metal doors, shell metal doors, interior wooden doors). 2) The required design and planning has to be done by several different parties (Architect, Electrical Engineer, Automation Engineer, Fire Safety Consultant and Locking Subcontractor). 3) Based on the site observations, a wide variety of waste is present during project management, design phase and execution of this work package.

The analysis of the information flow in the case project was conducted in three phases. First the actual work and information flow was depicted by using the Value Stream Mapping (VSM) method. The value stream mapping identified seven main points where the information flow was discontinuous; information management failed, caused waste and decreased quality. These points were analysed further by using Root Cause Analysis (RCA).

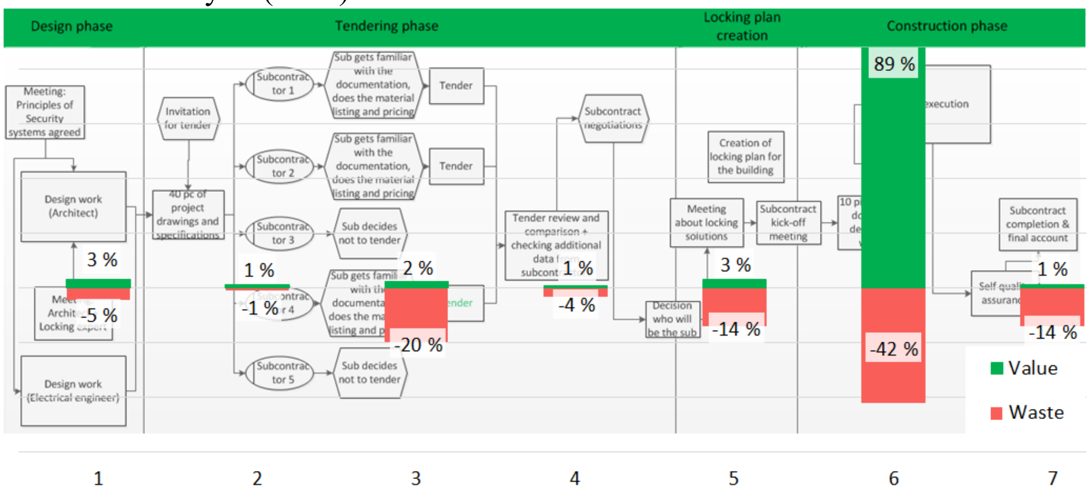

Figure 2: VSM of locking and ironmongery work package. Seven detected discontinuity points and their proportion of the total waste and value in the process.

As a result of the analysis the root causes and relating waste factors were identified. Additionally, the waste factors were further classified into the main Lean categories and root causes were arranged into different domains. Based on this classification following root causes for waste caused by failures in information management in working package and attending waste are in Table 2:

Table 2: Problem area: Information management does not support the process

#	Root cause	Type(s) of waste
1	Non-visual format: customer and designers cannot perform functionality review for the whole building with reasonable effort.	waiting, extra processing, under-utilisation of skills
2	Scattered information: defects and inconsistencies in the design can pass the verification and are found when completing the work on site.	defects, waiting
3	Non-structured information: most of the information is in documents and therefore representation is fixed to one format only.	defects, transport
4	Digital format and devices unsuitable for execution: work on-site is difficult without using printed and laminated blueprint drawings and any update requires unnecessary work.	motion

- Similarly, failures in implementing the correct process to conduct work package related activities is causing waste and decreased quality (Table 3):

Table 3: Lack of co-working skills and knowledge

#	Root cause	Type(s) of waste
5	The required functionality is not properly communicated between the client and other project participants.	Under-utilisation of skills
6	The level of detail in design documentation is partially wrong compared to the design phase.	Overproduction, extra processing

- Three additional root causes for waste were revealed when the process was studied in more detail in order to understand why some subcontractors were not changing their working methods even though the impact of changes would have been very positive. According to Dave (2008), the implementation of ICT will not increase productivity if the actual production process is as fragmented and even chaotic as it is in construction industry. Results from the RCA support this statement.

Table 4: Conflict of interest between contractors

#	Root cause[1]
7	Opposition to change: fragmented nature of subcontractor chain prevents necessary changes in processes and therefore facilitation of new information management tools and devices is not worthwhile.
8	Business model causes sub-optimisation: there is no common incentive to design and deliver fully functional system, which meets the customer requirements. Subcontractors are only installing subsystem or delivering parts for it.
9	Cost for change is too high: Developing the process would require contribution from several project participants and the benefits for an individual contractor are not beneficial compared to the required effort.

PROPOSED SOLUTIONS

Root causes 1-4 were related to the way information is currently structured and presented. Additionally the waste of motion was found in the construction phase and waste of over-processing, meaning searching for the right information and interpreting the design intent from the existing information, was detected in tendering phase, locking planning phase and construction phase.

BIMs and other databases can facilitate reviewing of information if they are properly structured and provide multiple different ways to see the information, whereas mobile devices facilitate use of extensive amount of information on the go when needed. Despite of the use of BIM on site the problems of information management and defects caused by it remain the same as found out in the case project which reduces built-in quality. The detected reason for this is that the full potential of

[1] Categorisation of waste type was not applicable, since these root causes were not directly affected by information management.

BIM and other advanced IT systems can only be utilised if processes and practices change. Technology as such does not solve problems and increase quality. It can only provide tools for the new processes.

The benefits of Visual Control and Visual Management observed in other industries could support resolving many of the detected problems in the construction industry. The difficulties faced in the IT industry to visualise the flow of information can be resolved in the construction industry by using BIMs which as such are visual presentation of the product.

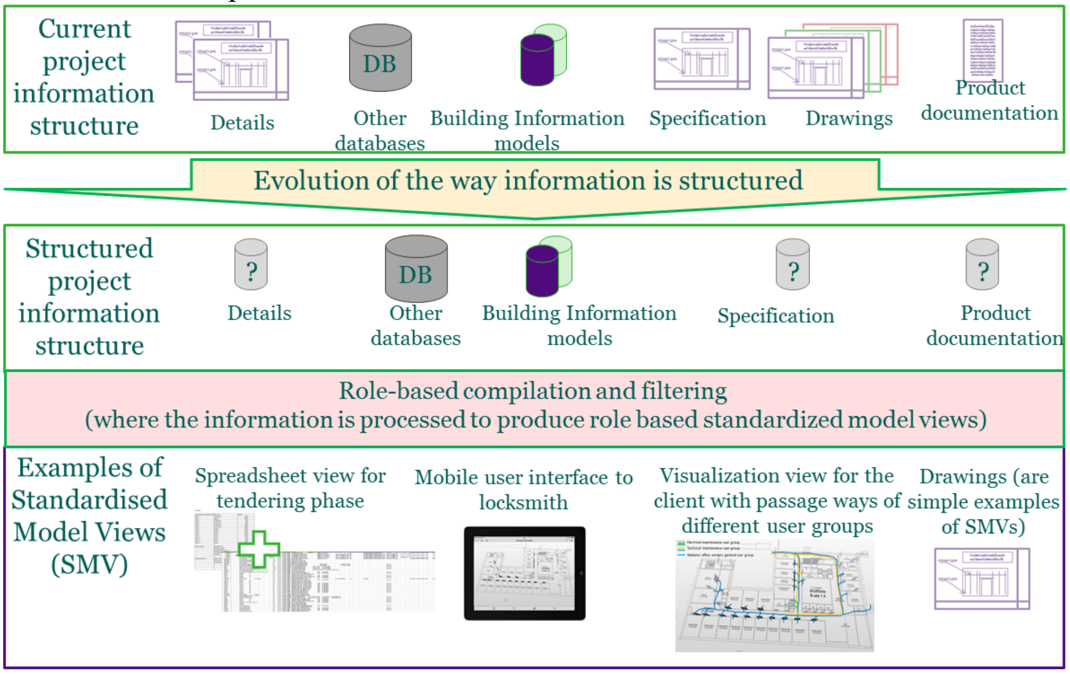

Figure 3: Creation of SMVs requires change in information structure. The role-based views are created by compiling and filtering information.

The development and use of SMVs is proposed as a solution to above mentioned problems. SMVs are customised based on the needs of the information consumer. Only the information which is relevant for the user is presented in such format that the need to search and interpret information is reduced and errors in the complete solution and its functionality can be avoided. Accurate and error-free information is an enabler for built-in quality in information dependent process. The SMVs diverge from IDMs because they combine information from several BIMs as well as other project information which in many cases is not even in IFC-format (Figure 3**Error! Reference source not found.**), while IDMs are defining the information exchange requirements between two individual parties using IFC-format.

To demonstrate and further develop the proposed solution, example views have been created based on the case project's data. An example view (Figure 4) was created of one floor for the locksmith. This view contains all the doors of the selected floor. These doors are combined with the plan drawing view created from the model and door objects contain required information about each door in order to execute the locking and ironmongery installations. The detailed design card (from the door schedule) for each door and installation instructions of the machinery for the automated swing doors are also linked to the door objects in the view. The SMV can be reviewed on a mobile device on the go and the excess model data is removed from the view to minimise the need to navigate in the model to find the correct door. Another example (Figure 5) presents a visualisation where three different user groups have access in one floor. The doors containing access control and the automated doors are marked to the view to provide overall understanding of the access solution in a selected floor.

Figure 4: SMV on a mobile device showing the doors of a floor and an opened door specification.

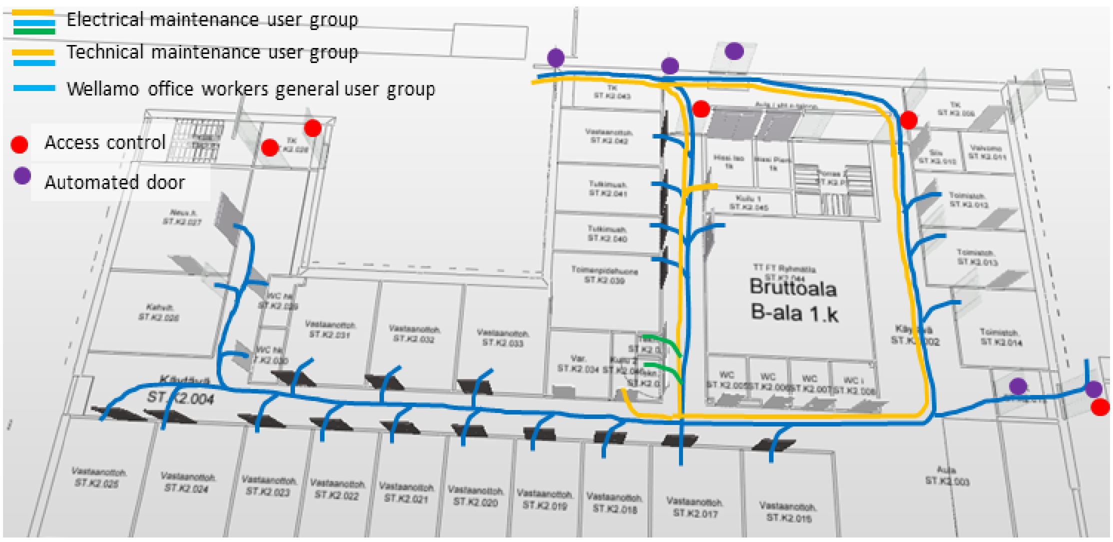

Figure 5: View on a mobile device showing access principles of a floor

DISCUSSION, CONCLUSIONS AND LIMITATIONS

Three SMVs were designed and tested in the case project. Visualisation view for the client with passage ways of doors provided significant improvement in reviewing the design and thus reduced waste types of waiting, extra processing, defects and under-utilisation of skills. According to the subcontractor's comments use of a mobile user interface for the locksmith would ensure having up-to-date design information when executing the installations. In addition, it would make the work of the subcontractor's project management easier because installation guidelines and other relevant data could be provided easily to the workers. As a result waste types of defects, waiting, transport and motion would be reduced. Spread sheet view for tendering phase would cut the time needed to do a tender by 50% and would improve comparability of the tenders provided by different contractors. This would reduce the following waste types: defects, waiting and transport. In summary, by using SMVs through the whole project, the waste detected in VSM would reduce 10% of the working hours for a single contractor. From the main contractor's perspective, the standardized model views would enable delivery of built-in quality by the subcontractors.

However, the use of SMVs is a solution only to a part of the detected root causes for waste and decreased quality. They are extremely efficient in those cases where new working methods or processes are accepted because of their benefits for individuals or single companies. Remaining problem is the change required for the whole network of subcontractors, since it would require designing and deploying a relatively large number of SMVs and each subcontractor should change their processes and train their personnel simultaneously. However, the smaller a subcontractor is, the less interested he is in accepting any extra costs. The most efficient way to change the incentive for participating companies is changing the business model of the construction industry. Relatively new contracting models, such as IPD and Alliance, provide a totally different type of earning logic compared to currently popular hard-bid contracts where the participants are interested to minimise their own work rather than optimising the value of the whole project. A change in earning logic could create the much needed common incentive for renewing both processes and information management, which is mandatory for built-in quality.

Also, construction industry practitioners need to concentrate to integrate technology, people and processes in order to find efficient solutions to manage information and to get full benefits of currently available systems. Importance of the consistency of the produced information cannot be emphasised too much. The processes should be constructed so that they would support built-in quality of the information production. In addition, verification and control of the information quality should be conducted before it is delivered. Information management should be reviewed from the building life-cycle perspective and partial optimisation of any part of the process should be avoided.

However, it should be noted that this article is based on a study conducted so far in one project and by observing one work package only. Thus the results provide only very limited evidence. Confirming and generalising the results requires collection of data and testing in several other projects and multiple work packages before we can estimate the true impacts of the use of SMVs and can move forward in supply chain wide implementation in our industry.

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