Assessing Digital Information Management Between Design and Production in Industrialised House-Building – A Case Study

H. Eriksson[a], M. Sandberg[a], J. Mukkavaara[a], G. Jansson[a], and L. Stehn[a]

[a]Department of Civil, Environmental and Natural Resources Engineering, Luleå University of Technology, Sweden
E-mail: henrik.2.eriksson@ltu.se, marcus.sandberg@ltu.se, jani.mukkavaara@ltu.se, gustav.jansson@ltu.se, lars.stehn@ltu.se

Abstract –

Managing digital information in construction is commonly described through Building Information Modelling (BIM), which advocates seamless chains of information, increased coordination between different actors and a life-cycle perspective on information management. However, low adoption outside the design phase entails that handling information in production is in many cases manual and paper-based, which increases vulnerability for upstream errors materialising downstream in production. Furthermore, issues with interoperability surround many areas when managing digital information. For industrialised house-builders, the transmitter and receiver of information are in many cases integrated within the same company or based on long-term collaboration. This affects their ability to manage information and utilise design information, which implies that their strategy for digital information management (DIM) might benefit from being addressed differently compared to more traditional BIM-based approaches. In this paper, we describe and discuss an implemented DIM-solution at an industrialised house-builder in order to address the benefits and challenges with DIM when managing information from design to production. The results imply that in order for several different functions within the company to reap benefits, a customised DIM-solution adapted after the company's specific needs is a well-suited approach forward to avoid sacrificing functionality when utilising design information.

Keywords –

Digital Information Management; Industrialised house-building; Information utilisation; Tailored interoperability; Building Information Modelling

1 Introduction

Utilisation of design information is crucial for planning and execution in production. The sequential nature in which a construction process is carried out poses however challenges for the continuity of the information flow, partly because different phases can be divided over longevity of time but also distributed amongst various actors with different responsibilities. Further complexity is added when these phases are carried out in a sprint-like manner where the previous ends as the sequent begin [1].

Paper-based documentation (e.g. printed drawings) constitutes the main container for generated design information during production. However, with the digital evolution, questions regarding its suitability as a main source to manage the amount of information generated during design has been raised [2]. Paper-based information is surrounded with limitation in regards to its lack of flexibility, meaning that changing prerequisites are difficult to address in production, partly due to information flowing unilaterally from design to production and rarely vice versa. Effects thereof can lead to vulnerability downstream in production when errors, or rather the rationale behind errors generated in design, are difficult to assess, and iterative bi-directional communication between design and production is rarely supported [3]. Most commonly, proposed solutions stress the importance of Building Information Modelling (BIM) to advocate seamless information management. BIM has for a long time been discussed as a solution to obtain information traceability and to minimise information losses over a building's life-cycle. However, there has been a concentration on the use of BIM during the design phase and less focus on BIM use during production [4]. In recent years, critical voices regarding BIM has also been raised, where the utopia of BIM as it is addressed today is being questioned [5]. Among identified challenges, interoperability stands out, both in its occurrence found in literature and with various frameworks containing proposed solutions [6]. Commonly, open and globally standardised schemas such as Industry Foundation Classes (IFC) serves as the backbone to resolve issues linked to interoperability. There are however differences between construction companies in terms of their capability to handle information in a standardised way which could be connected to their level of industrialisation. In this paper, we discuss how industrialisation affects the need to conform to traditional BIM-approaches to resolve e.g. interoperability.

Increased industrialisation can be obtained by integrating otherwise sub-contracted activities into a controlled concept or moving value-adding activities upstream in the value chain (e.g. by moving on-site production to an off-site setting) [7]. This increases the use of pre-engineered solutions with standardised work procedures [8]. In a study, Johnsson [9] mapped core capabilities at four different case companies with various production strategies regarding pre-engineering, i.e., different levels of industrialisation. Companies with a full product offer (i.e. delivering turnkey buildings) and higher levels of pre-engineering exhibited core capabilities in areas wider spread along the construction value chain in comparison with more traditional project-based construction companies. This aligns well with the notion that industrialised house-builders tend to own or control a larger portion of the value chain, reaping the benefits of repetitiveness from pre-engineering and standardisation in several phases of construction.

It is argued that the benefits with BIM should be far greater within industrialised house-building in comparison with traditional construction [10]. Regardless of if this is true or false, when applying the lens of BIM as a tool for coordination and communication of digital information between different actors, this statement at least needs diversification to be adapted for the specific context of industrialised house-building [11]. Value chain control, pre-engineering of products and standardisation of work procedures, positively affects the possibility to manage information and presents an opportunity to assess information in a controlled environment [12] with less need for actors coordination. This is essential, as it implies that handling digital building information could benefit from being addressed differently compared to a more traditional BIM-approach. The software solutions and the work procedures determining how information is managed could be unique and tailored in that sense that they are adapted to the specific needs and circumstances visible at each company rather than there being a one-size-fits-all solution readily available off the shelf. It might also imply that challenges with managing digital building information are different within industrialised house-building compared to traditional construction. Furthermore, focusing on the notion of BIM, a single unified definition does not exist and the concept has different meanings depending on the situation or application. To avoid preconceptions, it was therefore in this paper deemed useful to broaden the perspective and address how information is being managed between design and production more generally.

The area of information management (IM) [13] describes how information is acquired from its sources to a format that can be distributed to those needing it until its disposal to an archive or to a trash bin. Although IM stems from the development of information technology as a managerial field of how organisations, for example, should get the best use of storage formats, ranging from early technology like punch cards and magnetic tapes to today’s cloud services, it can still be of value to have a subfield named digital information management (DIM). In this subfield, we would specifically focus on IM based on digital technology. For construction, this would include BIM-tools with links that work as a glue [14] by enabling automation functionalities between different software. In this way, a sort of tailored interoperability between different IT-systems can be enabled, for communicating information between domains, such as design and production within construction companies. In this paper interoperability with BIM is exemplified in the specific context of industrialised house-building, but addressed using DIM.

There is a shortage of studies demonstrating the interplay between IT systems and work procedures linked to IM in construction, as well as studies reporting on the benefits and challenges of the tool implementations.

The purpose of this research is twofold, firstly to, through a case study approach, describe digital information management between design and production at an industrialised house-builder. This is exemplified through structures for information utilisation, a DIM-solution for linking software used in design and production, and how different departments have adapted their work procedures after implementing a DIM-solution. Secondly, the purpose is to discuss benefits and challenges with digital information management, from a perspective of flexibility in managing information and rigidity imposed by a digital solution. With the standpoint that flexibility and rigidity are opposing properties when managing information.

2 Research approach

This study was conducted as a single case study at an industrialised house-builder during the spring and fall of 2018. The research was explorative in the sense that no clearly demarcated research questions were set prior to the study other than focusing on exploring digital information management between design and production. This influenced the course of the study, as gathered input guided the direction along the way. The main method for collecting data was through semi-structured interviews with representative persons with different insights into how information is managed and handled between design and production. The interviewees consisted of the project manager for implementing the DIM-solution at the case company; the head of the design department; an employee at the pre-production department with particular insights in the structures and systems within the DIM-solution; and finally, an employee from the production department with responsibility over integrating and managing the control system for machinery used in production. As a supplement to interviews, archival material, participation in a workshop, observations, and observed demonstrations by operators were used to collect data. In total, four interviews were conducted which lasted from circa 45 minutes to 1 hour and 30 minutes. Questions posed during interviews were mainly specific since facts rather than opinions were of interest. The first author transcribed the interviews verbatim. Since facts in regards to an already existing IT-solution was in focus, little regards were focused at interpreting the responses collected during the interviews and no thematic analysis were performed. The workshop was recorded with image and audio. Findings gathered from workshop notes as well as from reviewing the recording was later discussed in a separate meeting with key participants (said meeting was recorded and transcribed) and used to formulate a process map of the information flow from design to production. The process map was iterated back and forth until the case company deemed it representative for their process of managing information. Although the process map itself is excluded as a result from this paper, due to its size and level of detail, experiences thereof were used to compliment the interviews in the case description.

Determining the choice of case company was important for the purpose of the study. The case company, CC, is one of the leading actors on the Swedish market for industrialised house-building. CC offers customisation in each building project, not relying on a catalogue of pre-engineered buildings whilst maintaining a high level of standardisation in their work procedures for designing and producing buildings. CC regularly competes in tendering against construction companies which applies traditional building design processes and on-site production which means that narrowing the customer segmentation would affect CC's market position adversely. Mitigating the effects of adapting to customer requirements puts stress on how information must be managed in order to maintain efficient production. How CC balances pre-engineering, standardisation, and customisation whilst simultaneously controlling the construction value chain are therefore significant characteristics for this study.

In order to give a broad perspective on the many aspects which together forms contemporary experience on DIM within industrialised house-building, the case description has been allowed to take up the major part of this paper. The scarcity of published work with a similar focus or approach to describe information management between design and production for industrialised house-builders is also a reason for why this structure was deemed relevant.

3 Case CC

CC produces multi-family dwellings consisting of wooden-frame modules. They enter the construction process as early on as possible and takes full responsibility from the entrance to a completed building. The modules are manufactured off-site, elements, i.e. walls and slabs, are primarily based on pre-engineered components but the modules they form and the module's interrelated composition in a completed building are unique for each project.

Within CC, sales, design, purchasing, logistics, pre-production, factory-set production, and on-site assembly are all integrated departments. Their design process bears many resemblances with a more traditional construction design process in that different actors, e.g. architects, HVAC engineers, and structural engineers, both in-house and procured, has to be coordinated for each project due to the high level of customisation. The isolated tasks needed to be performed in order to complete a building design are however the same or very similar for each individual project. The pre-production department operates in midst of design and production, with a role to serve as a bridge between these two. Their main assignment is to feed information to production in the corresponding production sequence, acting as a funnel and a filter so that the right information gets delivered at the right time to production. In production, there are different production lines for elements which are later combined into modules, sequent work (i.e. electricity, HVAC, mounting etc.) is carried out by a skilled workforce in a one-piece takted flow. In conjunction with starting up a new production facility, CC initiated a project to digitally integrate their information management systems (DIM-solution) and exchanging printed paper drawings for a Manufacturing Execution System (MES) to display information in production. Previously, CC relied on physical deliveries of drawings and documentation used in production. The sheer size of their new production facility together with an aim for a decrease in takt-time rendered this approach infeasible.

The overarching aim with implementing a DIM-solution was to reduce the amount of time passed from the point information was needed in production to when it could be retrieved, i.e. a solution primarily focusing on the needs of the operators in production. However, in order to facilitate utilisation of design information and obtain a broader perspective on DIM, work efforts and changes affecting many departments at CC were needed. In lieu of a strict top-down or bottom-up process, an interplay between adapting to the current way of working whilst simultaneously adapting this so it fits in a digital environment rendered CC to have more of a middle-out approach. Instead of buying an off-the-shelf software solution, CC decided to customise the solution on their own by integrating new and existing software. The implemented DIM-solution was mainly aimed at providing the factory-set production lines with digital information but derived functionality for supporting functions, such as purchasing and logistics, was also obtained.

The work procedures related to how information is managed and the system solution are interrelated with each other. DIM at CC is not fully automated, meaning that workers interact and adapt to the procedures stipulated by the system solution. It is therefore of importance to describe how work procedures are affected as well as describing the DIM-solution itself. This research did not partake in the actual development of any solutions, and at the time of this study, the DIM-project was in a start-up phase, meaning that functionality existed and was, for the most part, implemented but still in a run-in period.

3.1 Information structures for information utilisation

In order to utilise digital information generated during design, three separate but related information structures were identified during the course of this study.

3.1.1 Article-based information

In order to determine what articles (e.g. boards, studs, insulation etc.) are needed in production within a digital system, building information had to be broken down and sorted in an article database with a standardised nomenclature. At this stage, this is only done for information linked to elements such as slabs and different types of walls. The DIM-solution is prepared however to handle information related to e.g. installations (HVAC, electrical etc.) furnishing etc. Communicating defined article objects forms a vital part for information utilisation since it enables article identification along the entire information chain for different functions and departments. With information on an article level, customised bills-of-material (BOM) can be formed, readable to both man and machine. In this case, a BOM contains information about every article that together forms each element. This includes studs, noggins, boards, etc. with related metadata such as dimensions and type of material, but also relations between articles, elements, modules, levels, and buildings.

3.1.2 Sequence-based information

The second key aspect for utilising digital information was to incorporate the production sequence, hence attending to the aspect of in which order work procedures should be performed and when information is needed, thus enabling detailed planning and scheduling. The factory production sequence is ruled by the assembly sequence on the construction site. The key to deducting a corresponding factory production sequence is to work backward from building orientation onsite by modules to component assembly in elements production. This is possible as production is executed with a one-piece takted flow, meaning that production work is organised following one line of modules through the factory. Slabs follow the module sequence so that two slabs, forming the floor and ceiling of a module are completed prior to module assembly. The various types of walls used to enclose a module (inner, outer, apartment separating) facilitate that production of wall elements can be optimised so that as many similar walls are produced as a long wall segment, which later can be separated into different wall elements.

3.1.3 Operational-based information

After incorporating information in a sequence, the next step is to further enrich the data with information on work procedures and instructions on how they should be performed. Descriptions of standardised work procedures are communicated through Standardised Operation Sheets (SOS). The SOS documents describe in a step-by-step fashion accompanied with images what, how and why an operation should be performed. The idea of developing SOS is to enrich the knowledge of production by the use of experience. The novel approach is to link this information on parts level by incorporating it with the BOM, which entails a digital representation of what work procedure should be performed on an article. This is done automatically during design due to each article being defined and based on where a specific article is located in the element. When linking a particular work procedure to a particular article, detailed planning and resource allocation in production are enabled.

By addressing these structures and incorporating them into a DIM-solution, the ability to combine and digitally incorporate several functions and departments within the value chain enables a wide variety of information utilisation.

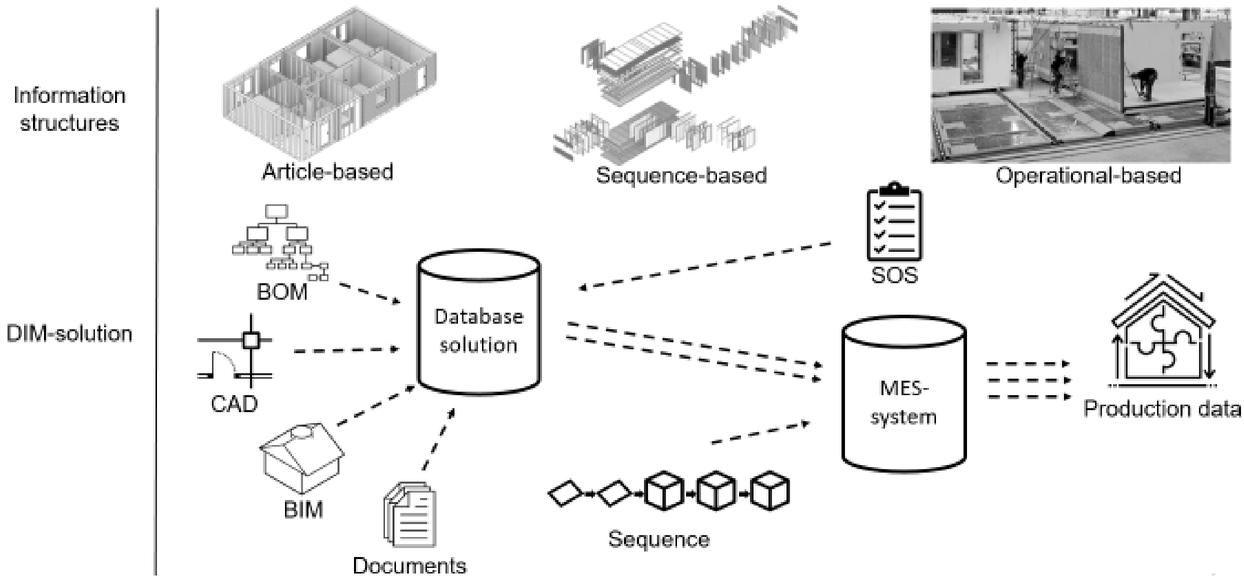

Figure 1. Illustration of information structures and DIM-solution

3.2 DIM-solution at CC

No suitable off-the-shelf IT-solution to accommodate presented needs at CC were found. Placed amidst between manufacturing and construction, CC's demands for a software solution for managing information are specific. Adapting to a proprietary solution had also in this case been associated with risk since a number of related systems would have had to change at once to make them interoperable with each other. Building design is performed using two different software applications. One of which is a BIM-software adapted for supporting element and module design within industrialised house-building, and one CAD-software for designing module features, e.g. kitchen layouts, wardrobes, etc. The latter is currently used for 2D-drawing. In production, an MES was introduced to track and document production data as the material is converted to finished modules along the production lines, as well as distributing the relevant information to the operators at each work-station. Their solution was to customise a database solution (DS) to operate as a link and a translator between the CAD/BIM-software's used in the design and the MES used in production. This was needed since interoperability between these is lacking. Functionality for digitally supporting sequence planning, as previously explained, was added as well. Figure 1 illustrates the different information structures as well as a schematic outline of the DIM-solution. The figure is illustrative in that sense that its purpose is to assist the reader by complementing the text provided in this paper rather than the other way around. As prime input to enable information utilisation, DS takes the bill-of-material (BOM) in a spreadsheet format from the BIM-software. Once imported into DS, a hierarchical structure is formed with parent-child relations for parts into elements, elements into modules, modules into floors and floors into buildings. Apart from structuring material, links to drawings from both CAD-software as well as additional documentation relevant for the project are created in DS. Models from the 2D-CAD-software lack possibility to trace each object on an article level, the generated drawings are however being funnelled through the database solution. In this case, the DIM-solution serves as an intermediary step to avoid printing drawings on paper. The generated links are semi-dynamic, meaning that it requires that the name and location of each file are syntactically correct in order with a standardised nomenclature and file system structure. The links are imported according to the right production sequence by the MES together with necessary additional documentation e.g. SOS, room data sheets etc. In this case, the MES is serving as a document manager for production, supplying production data in the right sequence to work station operators.

3.3 Impacts on work procedures

Implementing a DIM-solution affects how the workforce manages information, however, depending on the level of abstraction, the overarching process before and after the implementation of a DIM-solution has remained basically the same, albeit the processes are adapted to fit in a digital environment. These differences are highlighted in the following section, the headlines marked in bold are presented in a chronological (from a project perspective) order and an attempt to clarify the utilisation of the DIM-solution between the different departments step-by-step has been made.

Design: As previously stated, building design follows a rigorously monitored and standardised process. In implementing the DIM-solution, the design department´s work procedures are adapted so that it affects where information is retrieved and in what form it is received and delivered, previously printed documents are now managed digitally. Templates for modules and parts from pre-engineered rules and dimensions generate information in relation to CAD and BIM-tools.

Pre-production: The most notable changes in work procedures is visible at the pre-production unit. Previously, upon completed building design, pre-production used to receive design information digitally from the design department and print, e.g. drawings and material lists on paper. A vital and time-consuming task was to sort and order drawings and documentation in sequence for production. As production is based on standardised work-procedures and split up on multiple stations, the number of drawings needed can be quite considerable. A single floor element can require around six different drawings to mediate all views necessary for each layer and work-operation. Apart from printing drawings and necessary additional information, pre-production also used to audit element drawings in search of non-frequent occurring articles, which are parts for structural rigidity, e.g. lifting posts. This operation was important to enable a high pace in production where time to review drawings in detail is limited. This was done by manually marking on the drawings to clarify for the right recipients in production. In time for production, pre-production previously physically delivered drawings and additional information to the logistics department. For pre-production, the tedious task of manually printing and auditing drawings for non-frequent occurring articles could be removed due to the DIM-solution. The objects formerly marked manually on drawings are now listed objects in a parts database. Manually sorting drawings in sequence and physically delivering drawings and enclosed documentation is also rationalised. The imposed change is first and foremost time saving (at least for pre-production), but since a manual audit of drawings can be considered error-prone in comparison with an automated solution, the quality and precision has also been positively affected. On the other hand, the time-consuming task of auditing drawings also served as an extra opportunity to detect errors made in design which are better off being discovered prior to, rather than during, on-going production.

Logistics and purchasing: Pre-production's main point of delivery is the logistics department, they receive information that they use to prepare and supply workstations with material. The material is cut-to-fit and kitted in the corresponding production sequence. Enhanced overview over the production sequence provided by the DIM-solution enables logistic preparations to be more on par with the flow of the production lines.

Purchasing takes place during an extended period in parallel with design, pre-production and almost up until production. The level on which the DIM-solution can be utilised is related to the overall progress in the project. Early on, prior to detailed design, purchase might need analogue documents (e.g. printed drawings or lists) and as information gets entered in the system, the possibility to utilise DIM increases. Previously, various articles e.g. timber used for studs and noggins and plaster boards was bought in bulk based on visual inspection of the stock. This ad-hoc approach to purchasing was made redundant when article based information was made available through a DIM-solution. The ability to retrieve tailored bills-of-material sorted by production sequence enables purchasing of smaller batches with the right material delivered more in sync with production.

Production: Just prior to production detailed planning and dividing of specific tasks on different operators working on the production lines take place. This could previously be done explicitly through markings on drawings. For production, the main difference after implementing a DIM-solution is related to how information is received and read. Where paper drawings previously were used, there is now monitors and portable display devices to communicate all information required for them to carry out their work. Through the monitors, linked documentation describing for example how the current work task is to be performed (SOS-sheet) and functionality to support reporting errors or deviations is also available. Detailed production planning previously performed by marking on a physical drawing are now performed by balancing the required operations with available operators aided by time studies for work operations in a spreadsheet distributed to all operators.

4 Discussion

Production in a one-piece takted flow requires that there is detailed knowledge on *what* needs to be done, *when* it should be done, and *how* a specific work procedure should be executed in order for production to run smoothly. DIM does not add the possibility of answering these questions, at CC these questions were already addressed prior to extending DIM. Adapting to how information should be managed digitally rather suggests that these questions need to continue being addressed in order for production to work properly. This is highlighted when assessing how element information is managed in relation to module information. The latter is not yet detailed enough to obtain the same level of information utilisation, as individual objects cannot be queried within the system. This hinders, for example, purchasing from extracting information with the resolution needed to purchase off a customised BOM.

For CC, the opening of a new production plant spurred the initiative to rethink how information was managed and distributed from design to production. As side effects rather than their main objective, digitally integrating the systems for managing information enabled added functionality. Both in terms of ability to log production data for quality control and analysis, as well as a possibility to perform production simulations to verify constructability or to optimise resource allocation in the production line to name a few examples.

Different challenges exist which span over a wide range of perspectives. Moving information from humans to computers in an existing organisation requires workers to adapt to new procedures and routines. Enforcing a new system upon a workforce is, therefore, a considerable aspect to handle. Furthermore, a digital system exhibits less inertia when comparing it to managing paper-based information. In this case, inertia can be seen as the momentum needed to send or receive information between two entities (i.e. from computer to human, computer to computer, or human to human). This entails a following responsiveness when sending and retrieving information which presents itself as both part of the solution as well as an associated risk. In cementing a confined digital solution, the flexibility enabled by a skilled workforce, possible to adapt to whatever problem is presented, was decreased. Changed prerequisites which previously could be managed ad-hoc now requires implementation (adding of new functionality) in a system in order for the function as a whole to be maintained. The same responsiveness also implies that errors entering the system quickly spreads and affects both vertically and horizontally within the organisation. At CC, the DIM-solution is still dependent on a manual step being performed between design and pre-production, namely exporting and importing the BOM from the BIM-software to DS. The remaining steps are automated, provided that information is placed and named correctly. A side effect from this manual step is that some inertia is introduced to the system. In a practical sense, this means that information is compiled and audited by the design department before being pushed into DS instead of being pulled on demand by pre-production. To further the understanding of what role inertia plays in a digital IT-system is an interesting aspect for future studies. Balancing this inertia could serve as a strategy to mitigate risks associated with responsiveness in a semi-automated system for managing information where there is an interplay between a system, and the work-force operating the system.

At CC, a trade-off between the DIM-solution's flexibility and information quality was visible. This means that the enrichment (e.g. increased use of metadata to enable purchasing) and precision of information (e.g. reduced dependency on manual auditing) increased. Although no time studies have been conducted, by rationalising the time-consuming step with printing, auditing and physically delivering drawings in pre-production, there are also implications that the total expenditure of time for managing information has decreased. These preliminary benefits are achieved at the expense of increased rigidity in how information must be managed. Albeit these results are preliminary and this single case cannot be used to generalise, it is a noteworthy aspect that risks and constraints associated with managing information digitally needs to be assessed and weighed against the benefits rather than digitalisation being an end in itself.

At CC, the DIM-solution was tailored, meaning that CC avoided adapting to an off-the-shelf proprietary software solution and thus managed to better adapt their DIM-solution after the organisation rather than the other way around. This could be very important for already existing organisations striving towards digitising their information management and where a top-down process could be associated with risk since it might affect several parts of the organisation simultaneously. For industrialised house-building, it is reasonable to argue that adaptations and tailoring of DIM so it fits the existing organisation is required. In part, because they depend on technology-intensive manufacturing equipment to support automation in production to a higher degree than in comparison with traditional construction. Nailing portals, robots, and conveyors which are utilised in production are delivered from a wide range of suppliers and interoperability is not guaranteed. Machinery used in production is also often delivered as unique products to each customer due to spatial- or requirements adaptations at each industrialised house-builder, which makes reusing solutions for DIM between different industrialised house-builders complex. At CC, introducing an MES sorted out the interoperability between machinery in production. However, in order to broaden the perspective and better utilise design information to establish links between production, design and support functions such as logistics and pre-production, a tailored DIM-solution was required to avoid sacrificing functionality. The authors have not encountered such a solution readily available off-the-shelf, addressing similar needs as those presented at CC.

Owning or controlling the value chain [9] alleviates the threshold for successfully implementing a solution with a broader perspective on information management, spanning for instance over several departments within an organisation as exemplified in this paper with information being managed between design and production. The system also encompasses a digital bi-directional link between design and production in comparison with the usual mono-directional link between different trades [1]. Results imply that utilising BIM-data for information management in the specific context of industrialised house-building could benefit from being addressed with a strategy adopted for the unique traits visible for these companies. Value chain control, or ownership, minimises the need for adapting to commonly proposed strategies to obtain system interoperability, such as open format schemas (IFC). This encompasses a wider solution space with the ability to choose optimal software solutions for each sub-department, not needing to worry about systems interoperability to the same extent since this could more easily be tailored alongside the solution itself.

5 Conclusion

This paper focuses on the (digital) information management between design and production in industrialised house-building. A case company was studied to describe and discuss benefits and challenges with implementation of a solution for digital information management (DIM). The main conclusions from this study are:

- Characteristics visible in industrialised house-building, such as value chain control and the possibility to standardise work procedures, affects how information can be managed compared to traditional construction.
- Effects thereof imply that a tailored solution, adapted for the specific company, as opposed to an off-the-shelf proprietary solution could be a viable way forward to extend information utilisation.

References

[1] I. D. Tommelein, D. Riley, and G. A. Howell, “Parade game - impact of work flow variability on succeeding trade performance,” *J. Construcit. Eng. Manag.*, vol. 125, no. 5, pp. 304–310, 1999.

[2] R. Howard and B. C. Björk, “Building information modelling - Experts’ views on standardisation and industry deployment,” *Adv. Eng. Informatics*, vol. 22, no. 2, pp. 271–280, 2008.

[3] S. Alsafouri and S. K. Ayer, “Review of ICT Implementations for Facilitating Information Flow between Virtual Models and Construction Project Sites,” *Autom. Constr.*, vol. 86, no. August 2016, pp. 176–189, 2018.

[4] J. D. Goedert and P. Meadati, “into Building Information Modeling,” *Constr. Eng. Manag.*, vol. 134, no. 7, pp. 509–517, 2008.

[5] R. Miettinen and S. Paavola, “Beyond the BIM utopia: Approaches to the development and implementation of building information modeling,” *Autom. Constr.*, vol. 43, pp. 84–91, 2014.

[6] R. Santos, A. A. Costa, and A. Grilo, “Bibliometric analysis and review of Building Information Modelling literature published between 2005 and 2015,” *Autom. Constr.*, vol. 80, pp. 118–136, 2017.

[7] J. Lessing, L. Stehn, and A. Ekholm, “Industrialised house-building - Development and conceptual orientation of the field,” *Constr. Innov.*, vol. 15, no. 3, pp. 378–399, 2015.

[8] G. Jansson and E. Viklund, “Advancement of platform development in industrialised building,” *Procedia Econ. Financ.*, vol. 21, no. 15, pp. 461–468, 2015.

[9] H. Johnsson, “Production strategies for pre-engineering in house-building: Exploring product development platforms,” *Constr. Manag. Econ.*, vol. 31, no. 9, pp. 941–958, 2013.

[10] F. H. Abanda, J. H. M. Tah, and F. K. T. Cheung, “BIM in off-site manufacturing for buildings,” *J. Build. Eng.*, vol. 14, no. March, pp. 89–102, 2017.

[11] X. Li, P. Wu, and T. Yue, “Integrating Building Information Modeling and Prefabrication Housing Production Automation in Construction Integrating Building Information Modeling and Prefabrication Housing Production,” *Autom. Constr.*, vol. 100, no. January, pp. 46–60, 2019.

[12] G. Jansson, H. Johnsson, and D. Engström, “Platform use in systems building,” *Constr. Manag. Econ.*, vol. 32, no. 1–2, pp. 70–82, 2014.

[13] M. Hinton, *Introducing information management: the business approach*. Routledge, 2006.

[14] M. Madiajagan, “Interoperability in Component Based Software Development,” *Proc. World Acad.*, vol. 2, no. 10, pp. 68–76, 2006.