Approach for Automated Planning Using 5D-BIM

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Abstract
Early planning decisions are usually dependent on time-demanding, manually produced cost estimations and schedules. There is a trend in the construction industry to use 5D-BIM to speed up these processes and automated approaches can be used to further improve effectiveness. This research aims to investigate how to create an automated 5D-BIM planning process when using industrialized building systems. We propose an approach that combines a BIM manual with predefined databases based on the building system and its properties. A case study at one of Scandinavia's largest construction and property development companies was conducted where the presented approach was tested. The findings show that planning using 5D-BIM is possible to partially automate through our approach but that there are challenges for a fully automated process in the standardization required and assuring that the quality of data in each step is adequate.

Keywords: 5D-BIM, automation, industrialized house-building, building system

1 Introduction
In early stages of house-building design processes it is important to keep close communication with the customer regarding solutions and alternatives. This puts demands on tools used to present and communicate the current state of the project. Extending three-dimensional BIM to a fourth (time) or fifth dimension (cost) can deliver benefits in these early stages of a project when it comes to acting as a means of communication with the customers (Mahalingam et al 2010; Eastman et al 2011). The process of doing both scheduling and cost estimation from a BIM model can however be time consuming, and in early stages where changes are frequent this process needs to be fully or partially repeated several times. An automated approach for this process could improve customer communication in the early stages and thus become deeper implemented as a part of the design process.

Though there is research done on automating the process of both 4D and 5D using methods like ontologies (Zhiliang & Zhenhua 2012) and genetic algorithms (Faghihi et al 2014), a perspective of automated planning for industrialized house-building is yet to be found. Using an explorative approach our aim is therefore to describe automation of planning using 5D-BIM when used with building systems in industrialized house-building.

2 Background

2.1 3D, 4D and 5D BIM
In the architecture, engineering and construction (AEC) industries building information modeling (BIM) has been one of the most important developments in technology over the past few years

(Eastman et al 2011). Using BIM includes a technology with associated processes where the construction of virtual models of a building is used to support production, communication and analysis (Eastman et al 2011). Using BIM models usually entails that it is in a three-dimensional state but it is possible to incorporate further dimensions, thus creating nD models containing information during the course of a building project lifecycle (Fu et al 2006). By adding time as a dimension, 4D-BIM has the possibilities of being utilized for scheduling and simulations that facilitates evaluation of building construction. Integrating yet another dimension, cost, creates 5D-BIM which has the capabilities of being used for estimations and financial representations. There are several values to be obtained from integrating BIM and employing concepts of nD models. Marshall-Ponting & Aouad (2005) concluded that nD models have great values to provide when used as a means for communication and Mahalingam et al (2010) showed that benefits from integrating time as an additional dimension can be found in several areas of a project lifecycle.

In order to identify and organize building elements within a BIM environment, especially when dealing with nD models, classification systems can be implemented. They can be used to map features and create relationships in order to exchange information between different tools. Firat et al (2010) points out that a classification system is one of the critical factors in model-based quantity take-off. Monterio & Martins (2013) also points out the importance of structured identification systems when dealing with automated approaches and model-based quantity take-off. Currently in AEC there is a wide variety of classification systems including MasterFormat, OmniClass, Uniformat II and BSAB. These classification systems are usually based on a composition through a Work Breakdown Structure (WBS) which is a hierarchical structure in where the project scope is defined based on deliverables and where each level in the structure represents an increase in detail (PMI 2001). Depending on the application and use of the classification system, it might need to be extended to allow for more detailed elements to be described, like in the case with BSAB (Ekholm 2001).

In a context where a standardized workflow is desired, it is important that information created in the BIM model is done to the correct specification. This is to ensure that information flow both within the BIM tool and to external tools, such as 5D software, complies with the set standard. If a classification system is to be used to identify elements in order to facilitate exchange of information between different systems, the implementation needs to follow assigned classification rules. One way of working towards this goal is to use guidelines for creators of the BIM models to follow. That can be done in conjuncture with premade templates that contain default values, attributes and elements.

2.2 Building systems in industrialized house-building

If the processes within BIM and flow between the different dimensions are developed to be automated, standardization can be seen as one of the pillars on which this is achieved. Eastman et al (2011:281) points out that "Automation begins with standardization" and that this entails that there is a need for standardized building components and the attributes that are associated with these. One of the trends that is growing in the Swedish construction industry, that can be incorporated into this kind of standardization, is industrialized house-building and with that building systems (Lessing 2006). These building systems are a collection of knowledge and experience in how to realize construction projects, and can be implemented through standardization of both technical solutions and related construction methods (Söderholm 2010). The content within these building systems significantly vary between companies (Söderholm 2010), which affect the level of predefinition as well as project unique solutions. A building system can be predefined with rules how to produce the building both for off-site and on-site production. Also engineering predefinitions as dimensions like span length, wall height and slab thickness can be implemented. The engineering predefinitions of the building system are often in conjunction with predefinitions of how the production or the erection of the building, as work resources, to find cost efficient solutions (Lessing et al 2015).

## 2.3 Approaches for automation of 4D and 5D

There has been a variety of research done on automating both scheduling and cost estimation. Faghihi et al (2015) presented in their review on automation in construction scheduling approaches including knowledge-based, model-based, neural networks and genetic algorithms. Furthermore,

both Zhiliang & Zhehua (2012) and Lee et al (2014) presented methods using ontologies to enable automation of cost estimation. These methods however tend to approach the problem in a context where information needs to be searched for or created. A method where information is presumed to be known in forehand and that can be adapted to such a scenario is one of the model-based approaches to structuring information in regards to scheduling and cost estimation presented by Firat et al (2010). In this approach a building construction information model is defined as a composition where a building product model (BPM) is used to store building elements, spaces etc. and is then accompanied by a building resource and cost model (BRCM) and a building process model (BPrM) that stores resource requirements and activity relationships respectively (Firat et al 2010). According to Firat et al (2010) this approach allows for semi-automatic generation of both cost estimates and schedules.

3 Proposed approach

Our approach is a workflow based around utilizing standardization in order to enable automation. In order to provide the standardization needed, our approach is targeted for scenarios where there is a use of building systems as seen in industrialized house-building, with high levels of predefinition which should include the necessary building elements needed for construction of the intended building types. Since detailed construction and associated construction methods are known from within the building system, information on cost, activities and activity sequencing can be derived. Information extracted from the building system can then be used to create databases that can be utilized for both scheduling and cost estimation using software with 5D support.

An overview of this approach is shown in Figure 1 where the building system serves as input for databases that in turn provides activities within a 5D-BIM workflow with information. This is managed through a classification system which is used to map each element and their corresponding information sets.
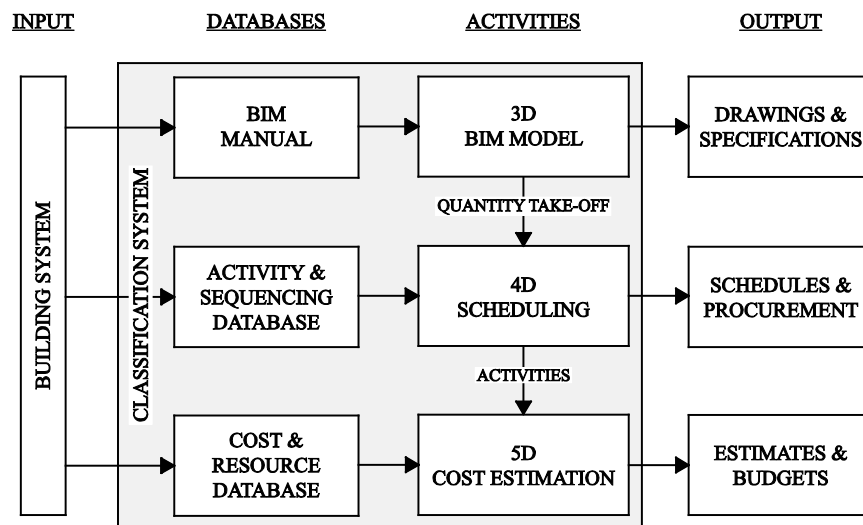
Figure 1 Overview of the proposed approach based around the use of a building system for automated planning using 5D-BIM.

Looking closer at the databases that can be seen in our approach, we can divide them into the following three parts:

- BIM manual: Intention of the manual is to ensure that input from the BIM model to both 4D and 5D activities is adequate and follows certain conventions. Described conventions in the manual should be based around the building system and describe how the classification system work, what elements and objects are allowed to be used, how these are labeled in various BIM tools using the classification system and other conventions surrounding more specific modeling techniques if necessary. Creating a BIM model based on the BIM manual produces a product of the building system and classification system which should have only

the endorsed elements inserted and all these elements should follow the rules of the classification system.

- Activity and sequencing database: In order to create scheduling using our approach, elements and their quantities from a BIM model needs to be mapped to corresponding activities and their sequencing needs to be defined. Detailed construction and related construction methods should be found within the building system and this knowledge can be extracted in order to define what work that goes into each element and how much of it is needed. In order to utilize and map quantity take-off from the BIM model to these activities, they need to be defined in the database according to how much of each activity is needed per unit of measurement for each element. Next up is the sequencing which describes in what order the activities should be performed. This information can also be derived from the building system but could also be adapted in a separate process where the sequencing is further standardized to suit this type of automated approach. In order to create a mapping for a specific element in this database and the corresponding elements in the BIM model, classification codes from the classification system is used to label the elements within the database. The result from using this database is a product where each element and their activities can be described and used for scheduling.

- Cost and resource database: Last out in our approach is a database that is used to create cost estimates. From descriptions of detailed construction of each element found in the building system, material and resources requirements can be derived. This information can then be mapped against suppliers, contractors and other sources in order to determine the cost of each element. Similar to how the activity and sequencing database is used, in order to map quantities from the BIM model this also needs to be set up so that the values for each entry is based around what units of measurement is appropriate for the described element. Furthermore, the role of the classification system is the same in this database where classification codes are used on each entry to create mappings between the BIM model and entries in the database. The result of combining quantities from the BIM model, activities from 4D scheduling and this database is a product that contains the building as a set of required materials and resources combined with information on their pricing.

As mentioned above, a classification system is used to map different sets of data from the various sources to each other. This is done on a level that represents each specific type of object, or building element in this case. For example the classification system can contain a code for a load-bearing interior concrete wall with 200 mm thickness. This code is then applied to each of the objects in the BIM-model that corresponds to this specific type and can then be used when retrieving information from the other sources of data where the same code is found. A suitable classification system should be chosen that can be used, or extended, to describe each of the building elements available in the building system.

In what way each of these databases is implemented depends on what software is available, what building system serves as the foundation and how that is structured, how the classification system is built and what level of detail is desired. In our case study, an example of these implementations will be further described.

4 Case study

As a part of the development of our proposed workflow, a case study was conducted at one of Scandinavia's largest construction and property development companies. The case company has used various software and methods in order to create the BIM-model, cost estimation and scheduling including Revit, ArchiCAD, Plancon and Vico Office. At the chosen company they have developed and implemented use of a building system that is standardized on structural solutions with tested production methods. Data collection from models and interviews were made to validate and describe the method of using automated planning for building systems in industrialized house-building. Lastly the building system together with knowledge from three of the case company's projects was combined to observe a scenario where our proposed approach is used.

First up is an investigation in what activities and activity sequencing that has been used in three projects (see Figure 2) where they have used their building system. This information is used to see if there are any noticeable patterns in how the planning of the projects is made. Also the way that

locations, e.g. how multiple buildings and floors are planned, was investigated by looking at the Location Breakdown Structure (LBS).

Figure 2 Three projects from the case company where they have used their building system.

Overall information on the projects and the LBS used can be seen in Table 1. What the investigation of the LBS showed was that in the first of these projects, only a breakdown including each floor was used. The other two projects used breakdowns including both buildings and individual floors in order to accommodate scheduling for the individual buildings. The difference in LBS mainly is derived from each projects unique specification. If a project consists of multiple buildings, then the company usually implements LBS with respect to both buildings and floors. Otherwise when a project only consists of one building, a LBS with respect to floors is usually sufficient.

Table 1 Description of the three projects from the case company.

Project	Type	Apartments	Total gross area	LBS
Hildedal	Residential	45	3,489 m^2	Floor
Traversen	Residential	230	20,500 m^2	Building and floor
Kvarnbergsplan	Residential and preschool	171	10,500 m^2	Building and floor

Going further, results from the study of activities and activity sequencing can be seen in Table 2. Activities that are present for structural framing in the projects vary slightly depending on each unique building as each might be designed to use different parts of the building system. For example some projects use an access balcony and some do not. The sequence of activities also varies from project to project, even though the same activities may be present. One explanation for this is that different project managers were involved in each project, meaning that differences in experience and opinions on the sequence varied. Another cause stems from the placement of the installation module within the apartments where certain positions mean that it needs to be placed before other elements in order to lift it into place. In some cases there is also a desire to mount the exterior walls early on in order to mitigate the need for protective railing in various locations.

Table 2 Activity sequencing for the three validation projects from the case company. Act = Activity, (I) = Installation module, (YV) = Exterior wall, (IV) = Interior wall, (BJK) = Floor slab, (TRP) = Stairs, (BLK) = Balcony slab, (LG) = Access balcony, (LG-P) = Access balcony columns, (LG-B) = Access balcony slab.

Project	Act. 1	Act. 2	Act. 3	Act. 4	Act. 5	Act. 6	Act. 7	Act. 8
Hildedal	(I)	(YV)	(IV)	(BJK)	(TRP)	(BLK)		
Traversen	(I)	(IV)	(YV)	(BJK)	(BLK)	(TRP)	(LG)	
Kvarnbergsplan	(YV)	(I)	(IV)	(LG-P)	(TRP)	(BJK)	(LG-B)	(BLK)

The last study against the case company was made to observe how the suggested approach using their building system would interact. In this study Revit was used as the tool for creating the BIM models and Vico Office was used for the 5D workflow. In this study the three databases were first developed corresponding to our suggested approach:

- BIM manual: A manual for giving building elements labels based on a classification system in a BIM environment was already in use at the case company. It contains a description of how the classification system is used together with a list of classification codes for each of the elements available in the building system. The classification system used is based around BSAB, commonly used in Sweden, but is extended with company specific codes in order to create codes for specific elements as seen in Table 3. Descriptions of how to add classification codes to elements in both Revit and ArchiCAD is also present in this manual.

Table 3 Extract of classification codes from the BIM manual used by the case company.

BSAB code	Specific code	Combined	Description
27.C/31	380-A	27.C/31-380-A	Prefabricated load-bearing exterior wall 380 mm thickness used in architectural model
27.F/31	285-A	27.F/31-285-A	Massive floor slab 230 mm thickness with 40 mm topping concrete and 15 mm finishing surface
27.G	T500-A	27.G-T500-A	Tile roof with 500 mm insulation above massive floor slab

- Activity and sequencing database: Entries for activities and their sequencing were created based on the knowledge gathered from the building system and the three projects that was studied. This information was then stored inside an empty reference project within Vico Office in the corresponding views available using the classification system described in the BIM manual to give each entry a corresponding code. Each time a new project is initiated in the 5D approach, the reference project is used as a starting point, thus loading the list of activities and sequencing into a Vico Office project containing the BIM model.
- Cost and resource database: Based on the available elements in the building system a database for cost and resources was developed in Excel. It contains a hierarchical structure based on the WBS found within the classification system as seen in the BIM manual. Each element contains entries that describe what type of material and work is required together with their consumption and price. This database is then loaded into the project in Vico Office where it can interact with quantities from the BIM model.

After these structures were in place, two different BIM models were created, which can be seen in Figure 3 and are described briefly in Table 4, in Revit based on the BIM manual. The purpose of these two BIM models was to implement at least one building element of each category found in the building system and then to observe how the different BIM models interacted with the proposed approach.

Table 4 Description of the two BIM models created for testing our proposed approach.

Model	Number of buildings	Number of floors	Building elements used
11A	1	8	18 + 1 installation module
11B	3	9, 13 and 7	18 + 3 different installation modules
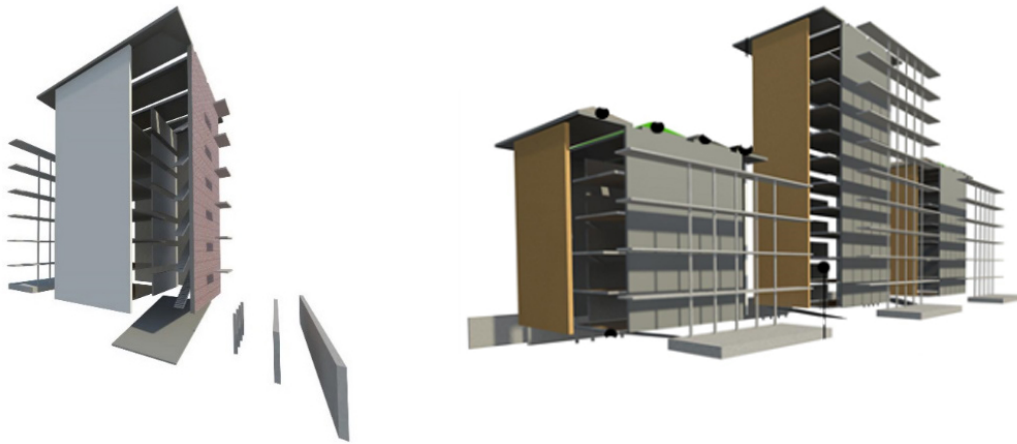
Figure 3 The two BIM models created in Revit based on the case company's building system.

These two models were then tested in Vico Office together with the reference project containing activities and sequencing, and using the cost and resource database created in Excel. By transferring the BIM model from Revit to Vico Office and letting the software perform quantity take-off it produced a list of quantities for each of the types of building elements used. When Vico Office performs the quantity take-off it can automatically link entries in the cost estimation table which has corresponding recipes, in our case done according to the classification system, and give estimations based on the quantities retrieved from the BIM model. From this, observations were made that the automated cost estimation worked well as long as the models were created using proper classification of each element according to the BIM manual. Problems arose though as the automated scheduling was tested. There were requirements on manual input for the location breakdown structure as the second BIM model consisted of multiple buildings and therefore required a breakdown that took the individual buildings into consideration as well. As the reference databases contain several building elements that might not be used in the current BIM model, it resulted in activities that lacked quantities since they were not used. With the way that the software is designed, these empty entries needed to be deleted in order for the scheduling to fully work. The activity sequencing was intact between the different BIM models but needed manual input in order to reapply some of the settings desired, e.g. to create a loop between the different floors. When the necessary manual adjustments were made, exports could be done for both the cost estimation and scheduling in the form of reports and diagrams.

5 Discussion

As one of the pathways to automation is through use of standardization as suggested by Eastman et al (2011), our approach was developed based around this concept. Differing from other presented methods on automation of 4D or 5D that looks into a context where information needs to be searched for or created, e.g. Lee et al (2014) or Zhiliang & Zhehua (2012), our proposed approach encompasses the notion that building elements, their activities and construction methods are known in forehand. Since this information is presumed to be known, our approach is focused on managing information and creating relationships between in order to correctly assemble it into schedules and cost estimations. Through this we rely heavily on a classification system and as pointed out by both Firat et al (2010) and Monterio & Martins (2013), the use of a classification system of some sort is important when looking at approaches using model-based quantity take-off. For our approach it serves as a key factor in order to organize and map information between the different sources.

Similarities to our approach can be found in the approach proposed by Firat et al (2010) where their different project models (BPM, BRCM and BPrM) are being fed information from libraries containing product structures, resources and cost structures, and activity structures. Differences are in the way that we choose not to describe each individual step in the process as different models and that we define the source of information to the libraries or databases as being specifically building systems. We also suggest the use of a classification system within the approach in order to organize and handle the information.

One of the difficult parts of our suggested approach is how to handle activities and their sequencing as seen in observations made within the case study. Since each project consists of a variety of unique requirements and solutions it can be difficult to find a generalization of activities and in what order they should be placed within the scheduling. Another caveat is when dealing with projects that have multiple buildings which in some cases mean that the location breakdown structure also needs to be adapted which can be seen in our case study. These types of project unique solutions can be difficult to implement into an approach that relies heavily on standardization and requires either the approach to be adapted in order to become more dynamic and flexible or the building system and associated processes to become more standardized.

The observations made in relation to how automation of cost estimation panned out showed that the process can be a lot more linear than scheduling as long as a project follows the guidelines given by the building system in conjunction with the BIM manual. However, project unique solutions are still common where they deviate from the building system and implement solutions that impose a problem on an automated approach that depends on standardized solutions.

Observations of our approach also showed that there are both strengths and weaknesses in the used software. At one hand, the cost estimation proved to work well with our approach using the built-in functionality of recipes but the scheduling on the other hand resulted in some issues where manual input was necessary.

6 Conclusion

As the conclusion of this study, four principles have been identified which needs to be fulfilled if automation of planning for industrialized house-building using 5D-BIM with our suggested approach is to be implemented: (1) each element in the BIM model needs to have the correct classification code; (2) no unique building elements can be present, all building elements need to be known forehand; (3) each building element needs to have entries in the databases for cost, activities and activity sequencing; (4) a predetermined process for the construction of the buildings needs to be known. These principles are in line with our core for the approach which is based around standardized solutions and processes that can be provided from a building system. Our study show that automation of the process using our approach is partially possible which can be time-saving in scenarios where changes are frequent; however there are still hurdles to overcome in order to make it fully automated.

Seen as our approach relies on standardized solutions, and as with automation in general, it can be of debate on how wide the solution scope should be within the system. A too wide range of solutions can impose difficulties and a too narrow range might make automation excessive in some cases. Our approach benefits from narrower solution scopes as it usually means that standardization is more accessible but further research is needed for what extent it should be reasonable to implement. Further research is also needed to test other building systems with the approach and to identify possible solutions to the challenges of scheduling.

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