

BIM Application for Integrated Design and Engineering in Small-Scale Housing Development: A Pilot Project in The Netherlands

Rizal Sebastian¹, Willem Haak², Eric Vos³

ABSTRACT

On average, by the time when 1% of the project costs are spent in the design phase, roughly 70% of the life-cycle cost of the building has been committed. Therefore, it is essential to integrate the multidisciplinary knowledge over the life-cycle of the building into design. Building Information Modelling (BIM) is one of the most important supporting factors for a successful integrated design. BIM makes it possible to integrate information from the project participants of different disciplines which traditionally work in different phases of the building process. The application of BIM has been seen in a number of large-scale construction projects, such as in commercial and industrial real estate and infrastructure sectors. The projects in the housing sector, however, are predominantly rather small-scaled and carried out by small and medium enterprises (SMEs). These SMEs have a need to innovate and are looking for practical and affordable BIM solutions.

This paper reports the knowledge dissemination activities through a pilot project of small-scale housing development in the province of Zeeland, The Netherlands. The knowledge of integrated design and engineering and BIM derived from European and national research projects is disseminated to the SMEs through a series of experimental working sessions involving SMEs, i.e. project developer, builder, architect, structural engineer, HVAC contractor, electrical contractor, prefabricated concrete manufacturer, prefabricated roof manufacturer, and component supplier. The conceptual knowledge is translated into a working protocol for direct impacts in terms of cost reduction and quality improvement. BIM knowledge is applied without having to radically upgrade the SMEs' ICT systems and organizational capacities.

KEYWORDS

BIM, integrated design and engineering, collaboration, SME, knowledge dissemination

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1. INTRODUCTION

Zeeland is a province located in the south-west of The Netherlands which consists of a number of islands. In this region, most housing developments are rather small-scaled and carried out by small and medium enterprises (SMEs). These developments are based on a traditionally fragmented process (as illustrated in Figure 1) in which the project participants of different disciplines work subsequently in different phases. Based on the practical observation, 10%-25% loss of efficiency occurs in each project due to unplanned redesigns and ad hoc modifications during the construction. This inefficiency results in delays in the delivery, suboptimal end-product quality, a higher price for the client, and lower revenue for the building participants [HZ 2007].

Traditional designproces

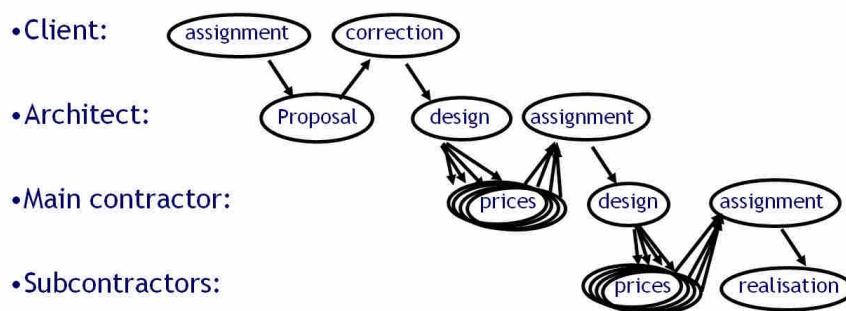


Figure 1: An illustration of traditional building process for housing development

Integrated design has been an important topic in the building industry in The Netherlands for the last two decades [Goossens 2006]. Recently, a number of SMEs from the building industry have decided to learn and adopt integrated design approach in order to solve the fragmentation problem in the traditional building process. However, practical methods and affordable tools to perform integrated design in small-scaled housing developments are still difficult to find.

From the pragmatic viewpoint and within the context of the projects by the SMEs, integrated design is defined as a working method to integrate information from all project participants of different disciplines since the design and engineering phase. By obtaining and integrating information from different disciplines, it is expected that the decisions during the design phase are made with the knowledge of the implications for the constructability, use and maintenance of the building in its life-cycle. For instance, as contractors and component manufacturers are involved during the design phase to contribute their knowledge of the construction and production techniques, the architect's design should be fully feasible to construct, so that redesigns and modifications during the construction stage can be prevented.

The growing interest on integrated design cannot be separated from the developments in ICT, among others Building Information Modelling (BIM). All of these developments are targeting at the sharing of coherent design, construction and building information, generated and maintained throughout the life cycle of a building, for time and place independent collaborative working that need to be managed properly [Sebastian *et al.* 2009]. BIM is not the same as the earlier known Computer Aided Design (CAD). BIM goes further than a digital (2D or 3D) drawing or a centralised database [Bratton 2009]. BIM is a computable

representation of all physical and functional characteristics of a building. BIM in its ultimate form provides the potential for a virtual information model to be handed from design team (architects, surveyors, consulting engineers, and others) to contractor and subcontractors and then to the client [ConsensusDOCS 2008]. BIM makes it possible to integrate information from the project participants of different disciplines which traditionally work in different phases within the building life-cycle.

This paper reports the activities and results of a knowledge dissemination project initiated by HZ University of Applied Sciences and TNO –the Dutch organization for applied scientific research. The knowledge dissemination activities were conducted within the grant research projects RAAK-Wooneconomie 2 and TNO-MKB Technologiecluster, in collaboration with 10 SMEs from Zeeland. The main objectives of the project are:

- Clarifying the practical implications of integrated design for SMEs through improved communication and collaboration processes
- Adopting BIM applications and modelling tools to support integrated design. BIM knowledge from European and national research projects is transferred to the SMEs and translate this knowledge into practical collaboration methods for small-scale housing developments. The knowledge dissemination

The project is undertaken according to a pragmatic approach of action learning. Knowledge dissemination takes place through a series of experimental working sessions involving the project developer, builder, architect, structural engineer, HVAC contractor, electrical contractor, prefab concrete manufacturer, prefab roof manufacturer, and component supplier.

The next section describes the conceptual knowledge refer to literature and several European research projects and reviews how this has been translated into relevant knowledge by the SMEs in Zeeland. In the following, the pilot project and the experimental working sessions of integrated design are presented, including the specific problems and achievements of each working session. Finally, conclusions are drawn after comparing the achievements to the project objectives and several recommendations are given on further research and practice.

2. CONCEPTUAL KNOWLEDGE REFER TO LITERATURE AND RECENT RESEARCH PROJECTS

Integrated design is a part of an integrated building process. In FP6 European research project ‘Open Building Manufacturing (ManuBuild)’, a new paradigm for integrated building process is introduced by combining building production based on manufacturing in factories and on construction sites, and open systems for designing products and components. ManuBuild presents a mass customisation approach which allows building designs to be customized to the clients’ and users’ needs while utilizing industrialized building systems. Industrialized building systems are sets of parts and rules to generate different products based on standard components and through similar processes [Kazi *et al.* 2007].

In ManuBuild it is argued that –based on the fact that buildings are site-related and technology is factory-related– industrialized building systems can be put in three categories, namely: site assembled kit-of-parts, factory-made 3D modules, and hybrid [Richard 2007]. In the site-assembled kit-of-parts category, all subsystems including the structure are made at specialized plants and then transported to the site as separate parts. The important jointing operations take place at the building sites. In the factory-made 3D modules category, all spaces and components of the building are entirely made, assembled and finished at the plants.

At the building sites, the 3D modules only require simple connections to the foundations, between themselves and to the main service conduits. The hybrid category is aiming at the best of worlds, site and factory. Manufacturing of the complex parts takes place at the factory. The size of the modules is kept relative small for easy transportation to the building sites.

On the practical relevance of this knowledge for small-scale housing developments by SMEs, this paper discusses the strategy for integrated design in each category. In the site-assembled kit-of-parts category, integrated design is initially focused on defining the room for creativity for the architect, or in other words: the possibilities for customization based on the information of standard components and systems from the manufacturers and subcontractors. In a later phase, detailed design for prefabrication is elaborated together with the manufacturer and contractor. The contractor's main task is coordinating the assembly of prefabricated components by different subcontractors at the building site. Herewith, BIM can be used to guide how the prefabricated components should be put together to form a building. In the factory-made 3D modules category, all disciplines should work together using one model (BIM). The finished model represents the completed building. BIM is used to produce and assemble the building at the factory; and in some cases, also as an input to operate the manufacturing machines. In the hybrid category, integrated design is crucial for planning and logistics management next to other purposes in the first two categories.

Going further on BIM application to support integrated design, much can be learned from FP6 European research project 'Open Information Environment for Knowledge-Based Collaborative Processes throughout the Lifecycle of a Building (InPro)'. On average, by the time when 1% of the project costs are spent, roughly 70% of the life-cycle cost of the building has been committed. Therefore, InPro develops a conceptual framework for collaborative decision making by the clients and project participants based on open information environment during the early design phase. The use of BIM offers the opportunity to carry out a performance-based design through which information on the future building performance is considered in design decision making [InPro 2009a]. As illustrated in Figure 2, in the InPro project BIM consists of three main aspects, namely: 3D visualisation, specifications, and cost estimates. Each decision is taken after verifying the design based on the requirements and performance analysis. In the decision making process, ideas are translated into concepts, then elaborated in proposals, then approved as results.

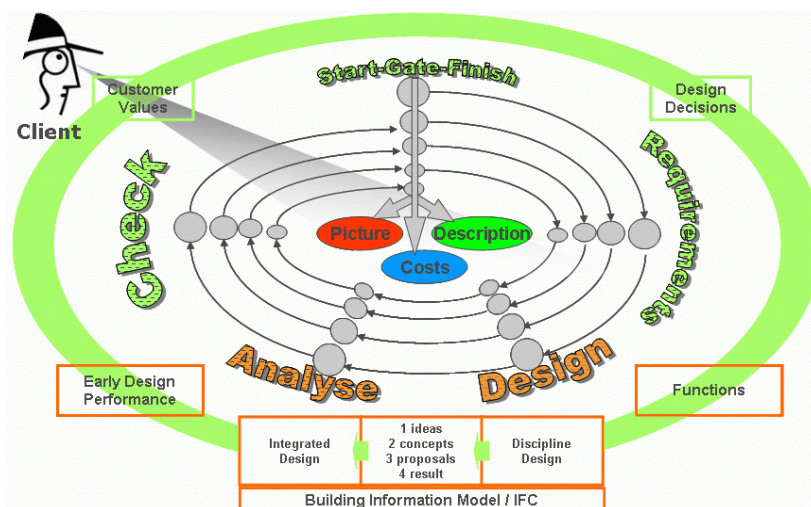


Figure 2: Integrated design with BIM application (source: unpublished presentation by F. Verhofstad et al. in the InPro EU FP6 research project)

On the practical relevance of this knowledge for small-scale housing developments by SMEs, this paper discusses the intermediate steps for the transition from the traditional building process towards integrated design with BIM application. In the current situation, the project participants use individual information storage and different drawing software applications. For performing integrated design using a centralized model, an international open standard, such as Industry Foundation Classes (IFC), are needed. IFC is a software-independent format for exchange and integration of building information. Although the IFC standard is generally agreed to be of high quality and widely implemented in software, the certification process allows poor quality implementations and renders the certified software useless for practical usage with IFC [Kiviniemi *et al.* 2008]. While progressing with the open standard in accordance to the further technological development at international level, SMEs in Zeeland can already begin by adopting a partly-open standard approach. The traditional process of bilateral information exchanges can be replaced by centrally storing important information using the agreed format. This information should be interactively linked to a central model of the building which is regularly updated and made accessible to the project participants. The client (or project developer) can act as the manager of the model and facilitator of the communication process. Such partly-open standard approach can be used before a fully integrated and automated process with IFC open standard is applied.

Since recently, the SMEs can make use of a free-of-charge open source BIM server for organizing central information storage, building model and applications. The open source BIM server has been jointly developed by TNO and Eindhoven University of Technology. It is an application which enables an IT server to operate as a BIM server. Its core is based on the IFC open standard, and therefore, it can handle IFC files. The BIM server uses the reference for implementing Building Information Exchange Protocol, which is a new standard developed by the Open Source BIM foundation. It is published with the GNU GPLv3 licence, which is free to use (www.bimserver.org).

The existing conceptual knowledge referring to literature and recent research projects can provide an adequate basis for the SMEs to perform integrated design. However, there are certain knowledge gaps which can only be filled-in through practical experience. The technology-readiness level for prefabrication may have been sufficient, but there is lack of experience of working in a co-makers consortium to achieve the optimal result of integrated design and open manufacturing as suggested in ManuBuild research project. If the framework for collaborative decision making as proposed in InPro research project is to be implemented, the project participants should be able to communicate design alternatives for verification using a multidisciplinary viewpoint. Before either an open standard approach or partly-open standard approach can be performed, each project participant should comprehend the broader functionalities of their software and share this knowledge with the others. These knowledge gaps were addressed in the pilot project and experimental working sessions, which are described in the next section.

3. PILOT PROJECT AND EXPERIMENTAL WORKING SESSIONS OF INTEGRATED DESIGN WITH BIM APPLICATION

The pilot project in Zeeland, The Netherlands comprises 4 houses as a part of a small-scale complex of residential estate consisting 9 stand-alone family houses in the village of Koudekerke (see Figure 3). This project is similar to a recently finished project. The previous

project was carried out through a traditional design and construction processes (e.g. relying on 2D drawings). Using the current project as a pilot for integrated design with BIM, the participants expect to discover the benefits of integrated design through a direct comparison with the previous project.

This pilot project is an example of a typical housing development in Zeeland with the following development process. A project developer initiates the project by purchasing a building site and preparing it for the realisation of a small-scale housing estate. The project developer is in fact the client that contracted the other building participants, namely: architect, structural engineer, installation companies, etc. The client develops this project based on its marketing strategy, and manages the design, construction and delivery processes. Once the project is finished, the houses will be sold to the consumers/end-users.



Figure 3: A 3D model and a picture of the pilot project of small-scale housing development in Zeeland, The Netherlands, with integrated design and BIM application

The learning aim through the pilot project is to introduce an integrated working method to reduce the loss of efficiency in collaborative processes with the building participants, and to increase consumer's satisfaction by communicating the design ideas through 3D visualisation which can be better understood by the consumer/end-user. By this, redesigns and changes during the construction due to errors and additional consumer's requirements can be significantly reduced. The pilot project is expected to yield direct impacts in terms of cost reduction and quality improvement, without having to radically upgrade their ICT systems and organizational capacities of the building participants.

The methodology for knowledge dissemination and the learning process can be described as follows. Within the knowledge dissemination projects RAAK-Wooneconomie 2 and TNO-MKB Technologiecluster, the abovementioned aim is addressed through a series of experimental working sessions with 10 SMEs. Nine of the ten SMEs are directly involved in the roles of client and building participants in the pilot project. These companies are selected based on their interest and motivation to innovate their products and processes. These companies represent the entire building supply-chain: client, architect, main-contractor, structural engineer, HVAC contractor, plumbing contractor, electrical contractor, prefabricated concrete manufacturer, prefabricated roof manufacturer, and component supplier (kitchen and bathroom furniture).

Each experimental working session is hosted by one of the SME participants. This SME initiator nominates its most important problem (comparable to a research / learning question) in the design process. Other building participants that work directly with this company in practice are invited to join in. The programme of activities is as follows. Each experiment is conducted on one day. The SME initiator introduces the problem and explained their role in the design process. The problem is then discussed as a case in direct relation to the pilot project. All participants work together to solve the problem / the case using the method of integrated design and BIM. When needed, an external advisor or a specialist is asked to guide the experiment. The results of the experiment are evaluated at the end of the day and the applicable lessons for the SME initiator and other participants are formulated for further implementation.

In each experiment, a problem observed at the pilot project is highlighted as a case. For instance, during the experiment at the HVAC contractor, the 3D model derived from BIM of the pilot project was able to detect clash problems, among which between a ventilation duct and a sewer water pipe in the semi-prefab floor (Figure 4). During the experiment, the participants were engaged in communicating the problem with the architect, installation contractors, floor manufacturer, and bathroom furniture supplier. Through collaborative design and engineering they managed to find an integrated solution in a new layout of the bathroom and installations.

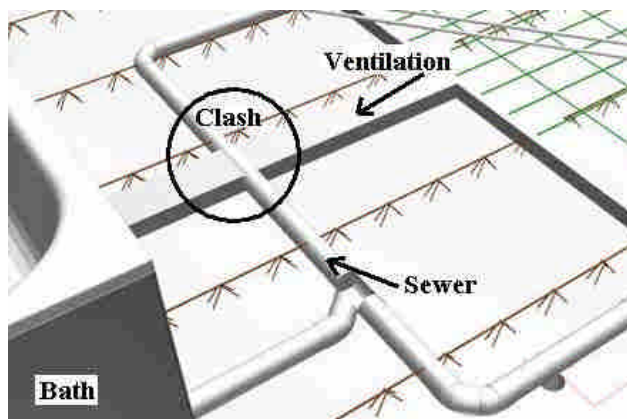


Figure 4: A 3D image of the bathroom of the pilot project detecting a clash problem between a ventilation duct and a sewer water pipe in the semi-prefab floor

Regarding the communication, the experimental working sessions focuses on the exchange and integration of information between different disciplines with their software applications, e.g. Nemetschek AllPlan, AutoCAD, Arkey, StabiCAD, StruCAD, SaniNet, Simar. The 3D model/BIM of the pilot project is developed using AllPlan. During the experiments, different possibilities have been researched, ranging from open standard with IFC, exchange and integration of 3D models through AutoCAD and 3D-Studio format, to a basic information exchange in 2D format. It appears that not all software applications used by the building participants can handle open standards. Despite the fact that an open standard, such as IFC, is not applied in the experiment, the exchange of information is successful to a certain extent due to the agreements on the format of drawings and specifications made between the building participants.

The subjects of the experimental working sessions, the relations between them, and the results are presented in Table 1.

Table 1. Summary of the problems and main results of the experimental working sessions

<i>No</i>	<i>SME initiator</i>	<i>Problem / learning question</i>	<i>Result</i>
1	Client (project developer and main contractor)	How to set up BIM and associate the 3D model to cost calculation application	A prototype of BIM linked with the currently used cost calculation application
2	Architect	How to get an immediate insight in the cost implications of the design alternatives	A method to get an immediate and more accurate cost estimate during modification of the building model
3	Prefab concrete manufacturer	How to accelerate the design process of prefab concrete floors through effective communication	A protocol for integrated decision-making by all disciplines using the support of 3D model
4	Prefab roof manufacturer	How to agree on the accountability of the structural design between the engineer and manufacturer when a prefab solution is used	A 3D model integrating the prefab solution to the main building model, and indicating the limit of the accountability of each party
5	Electrical contractor	How to agree on the format of drawings for information exchange between main contractor and electrical subcontractor	An agreement on an efficient layer structure to accommodate the integration of 2D electrical elements within the 3D building model
6	Plumbing contractor	How to import and export 3D information between StabiCAD and AllPlan	Several techniques to utilize 3D import and export functions in StabiCAD and AllPlan
7	HVAC contractor	How to detect the possible clashes of HVAC installations using 3D visualizations	The discovery of 5 clashes in the pilot project which were then solved during the experiment
8	Structural engineer	How to use BIM resulted from the design stage to check and approve the quality of the structural elements during the construction stage	A technique to obtain visual information from the building site to compare as-built elements with the structural design in 3D, e.g. the position of reinforcement in concrete
9	Component supplier (kitchen and bathroom furniture)	How to improve the communication and decision-making processes in case of modifications of building elements and installations based on the customer's requirements	A proposal containing new functional requirements for ICT infrastructure within the international holding of building component supplier to solve the current limitations

In the analysis of the achievement of the experimental working sessions with all participants, the added value of integrated design and engineering becomes evident as many interface problems can be solved before the construction begins. This saves much time and cost for redesign and repairs. Another proven added value is the earlier involvement of the contractors, subcontractors and suppliers during the design process which makes it possible to get a better insight in the consequences of the design decisions for the construction and delivery. Refer to the main objectives of the knowledge dissemination project as described in the introduction section of this paper, the analysis focuses on which technological innovations are the most relevant for the SMEs and which process and organisational changes are needed to apply integrated design and engineering.

For the SMEs, the most relevant technological innovation is the 3D visualisation which enhances multidisciplinary communication. Most of the SMEs are still in the stage of transition from 2D drawing to 3D CAD. The transition from 3D CAD to a full-performing BIM still needs to take place. Although the SMEs did some experiments with clash detection, planning, and costing tools, as well as open source data sharing, they are not yet ready to use these tools at the full extend due to the limitations of the existing ICT infrastructure. In the future, the SMEs in Zeeland aim at integrated design using BIM which comprises 3D visualisations, material specifications and cost estimates.

On the process and organisational side, some concrete steps have been taken, such as: the establishment of a list of agreements for a more effective communication and data exchange between different disciplines, e.g. data format, layer structure, drawing / document requirements, and schedule. Since the management of the SMEs are involved in this knowledge dissemination project, the decision to adopt the approach of integrated design and engineering can be taken shortly. The intention to achieve an effective multidisciplinary collaboration is positively supported by the fact that most of the SMEs involved have already possessed some experience of working together in previous projects. These SMEs are also willing to research the advantages of the integrated procurement methods (e.g. design-and-build) and the possibility to form a multidisciplinary project consortium to undertake such tender in the future.

4. CONCLUSIONS AND RECOMMENDATIONS

Having analysed the main results, it can be concluded that the knowledge dissemination project with the SMEs in Zeeland is successful due to the following factors. First, the combination between the transfer of conceptual knowledge derived from literature and other research projects with the pragmatic approach of action learning has been proven very effective. Second, the use of a pilot project as an actual case study is very helpful. Since almost all participants are professionally involved in the pilot project, they recognize the real problems in the traditional building process and they can experience the improvements through integrated design with BIM. Third, modelling the building project in BIM represents the progress of knowledge development. The model has been gradually enriched by participants from various disciplines throughout the series of experimental working sessions, starting with a 3D building representation and adding detailed objects and information. Last but not least, each experimental working session is organized at the premise and facility of the SME involved. This offers the SME a direct opportunity to share and implement the new experience in its company.

Next to these achievements, the following limitations have not been solved in the projects. The exchange and integration of information using BIM is still limited to the form of the objects (3D visualisation). The specifications are added manually, while the ‘intelligence’ of the model (e.g. automated jointing solutions) is left behind as a model is transferred from one software application to another through an AutoCAD format instead of an open standard. Furthermore, while the SMEs are seriously motivated to perform integrated design, they are still to engage with transformation of internal organizational strategy and external business strategy to establish sustainable collaboration within projects and in the supply chain.

Nevertheless, the projects can yield a broader impact in the building sector in The Netherlands. At present, integrated design using BIM has been implemented for large-scale projects, such as commercial and industrial real estate and infrastructure projects [CPI 2008]. RAAK-Wooneconomie 2 and TNO-MKB Technologiecluster projects have shown that SMEs engaged in small-scale projects can adopt relatively simple working methods with a basic BIM for direct impacts without having to radically upgrade their ICT systems and organizational capacities at a high stake. The direct impacts have been experienced in terms of a better quality of the end product (i.e. interface design errors were visible and solved using BIM), reduced costs (i.e. on-site modifications were prevented), reduced time (i.e. less steps needed for decision making), and a higher employee motivation and human resource effectiveness due to exposure to new possibilities through new knowledge.

For the SMEs, in order to progress with integrated design and engineering using BIM in the future, the following recommendations are relevant. The client and project participants should establish a sustainable strategy to manage the process by optimizing the benefit of integrated design. This should be followed by an integrated procurement strategy which facilitates a transparent and productive collaboration. For instance, if the project participants are asked to contribute to improve the design and eliminate the design errors by using BIM, they should be entitled to a fair distribution of the additional profit from a successful project delivery with a higher quality and shorter time. Such agreement should be formalized in the division of tasks and responsibilities in the project organization. Moreover, an open protocol comprising a collaborative working method and a template to develop BIM and object libraries in housing projects is needed. This will save time and effort to establish management and ICT protocols at the initiation of each new project. Finally, coordinated actions with the local authorities and professional associations are important, so that integrated design can be supported by an efficient building permit procedure and its method and organization can be included in professional standards, such as by the American Institute of Architects [AIA 2007].

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