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BIM application

D4.3

Development and advanced prefabrication of innovative, multifunctional building envelope elements for **MO**dular **RE**trofitting and **CONNECT**ions (MORE-CONNECT)

H2020-EE-2014-1-PPP (EE-01-2014)

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2 Introduction

The main objective of work package 4 is the development and demonstration of new automated production lines for multifunctional modular renovation elements. This concerns product lines for mass customization, applied in an extreme automated line-production in a ‘series of 1’ supporting production facility. These automated production lines support a line production that is effective on series-1 as well as large series and seamlessly combine into mass customization principles; aimed at supporting prefabrication for extreme retrofitting of homes. The extreme automation makes it possible to produce end-user-defined (by choice) integral products efficient in small (1) as well as large series.

Machine instructions then need to come from automated computerized numeric control instruction generation based on BIM and in-situ measurements. Plant management is organized in software solutions that support line-balancing as well as JIT (just in time) and flow. Line design needs to support scalability in product complexity, support of more than one product-market combination and output.

The work in this work package has the following phases:

- A preparation phase in which the technologies to be used in the production lines will be investigated how to implement in the process (geomatics, BIM, decision and configuration tool);
- First adoption of the production line to produce the selected concept renovation modules following from work package 3;
- Implementation of a quality control process in the production lines;
- Final adoption of the product lines to a fully automated process;

D4.3 is based on outputs form D4.2. The D4.2 results are used for input for a BIM system. The Building Information Model is used to steer and to control the production line.

Task 4.3 focuses on:

- Seamless integration of BIM with integral computerized numeric control production;
- What BIM is aimed at construction, not at production/fabrication;

Task 4.3 provides detailed description of data transfer from 3D scanning to .IFC format.

3 Terms and Definitions

3D is Three-dimensional geometry.

4D is Construction sequencing information in BIM context.

5D is Cost information in BIM context.

6D is Project lifecycle management information in BIM context.

3D modelling is the process of developing a mathematical representation of any 3D surface or solid of an object using specialized software.

3D laser scanner is a terrestrial, mobile, or aerial 3D range imaging device that analyses a real-world object or environment to collect data on its shape and possibly its appearance (e.g. colour). This device uses a laser (light) to measure distance via time-of-flight, phase-based, or light-based detection. The collected data can then be used to construct digital 3D models.

AEC/CAD/CAM/CAE is an abbreviation used to describe wide areas in industry dealing with Architecture, Engineering and Construction (AEC), Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), and Computer Aided Engineering (CAE).

aecXML is a specific XML mark-up language which uses Industry Foundation Classes to create a vendor-neutral means to access data generated by BIM for all the non-graphic data involved in the construction industries. It is being developed for use in the architecture, engineering, construction and facility management industries, in conjunction with BIM software, and is trademarked by the buildingSMART (the former International Alliance for Interoperability), a council of the National Institute of Building Sciences.

AllPlan is BIM/CAD software developed by the company Allplan GmbH, a subsidiary of Nemetschek AG, for architects, engineers and building contractors, which is available since 1984 and supports the planning and construction of buildings with regard to quality, costs and time.

ArchiCAD is architectural BIM CAD software for Macintosh and Windows platforms developed by the Hungarian company Graphisoft and are available since 1982 as a desktop. ArchiCAD offers computer aided solutions for handling all common aspects of aesthetics and engineering during the whole design process of the built environment — buildings, interiors, urban areas, etc.

AutoCAD is a commercial software application for 2D and 3D Computer Aided Design (CAD) and Drafting (CADD) which is available since 1982 as a desktop. AutoCAD is used across a wide range of industries, by architects, project managers, engineers, graphic designers, and other professionals.

Bentley Building Design Suite (Architecture/Mechanical/Electrical/Structure) integrates multiple disciplines – from architects to electrical, mechanical, and structural engineers – to successfully design, analyse, construct, and manage buildings of all types and scales. Effectively communicate design intent with information-rich deliverables and increase productivity by bridging barriers between teams. AECOsim software allows to deliver sustainable, high-performance buildings faster and with ease.

BIM Deliverables is information (a package of data or models in numerous formats) to be provided to another party in connection with a BIM-related service over the facility's life-cycle.

BIM Maturity Levels characterize a complexity and collaboration that Building Information Modelling (BIM) can take.

Building Information Modelling (BIM) is a complex process of managing not only design documentation in 3D form but it also includes all the consecutive stages of the design analysis, followed by construction management, and including facility management after the site completion.

Building Information Models (BIMs) are files (often but not always in proprietary formats and containing proprietary data) which can be exchanged or networked to support decision-making about a place. Current BIM software is used by individuals, businesses and government agencies who plan, design, construct, operate and maintain diverse physical infrastructures, such as water, wastewater, electricity, gas, refuse and communication utilities, roads, bridges and ports, houses, apartments, schools and shops, offices, factories, warehouses and prisons.

buildingSMART International ™ (bSi) is a neutral, international and unique not for profit organization supporting open BIM through the life cycle. bSi™ is the umbrella organization for over 30 chapters, including buildingSMART alliance®. The mission (Interoperability) is to accelerate the exchange of accurate, useful information on the built environment among all members of the building community throughout the life-cycle of a facility. In 2013 bSi is developing standards under ISO and following two Road Maps (A Strategic 2020 Roadmap and a BIM INFRA Roadmap 2016). Coordination of issues between bSi projects and buildingSMART alliance® projects may be documented on relevant websites.

Building Life Cycle refers to the view of a building over the course of its entire life – in other words, viewing it not just as an operational building, but also taking into account the design, construction, operation, demolition and waste treatment. It is useful to use this view when attempting to improve an operational feature of a building that is related to how a building was designed.

Construction Operations Building Information Exchange (COBie) is a non-proprietary data format for the publication of a subset of Building Information Models (BIM) focused on delivering asset data rather that geometric information. It is formally defined as a subset of the Industry Foundation Classes (IFC), but can also be conveyed using worksheets or relational databases.

Computer Aided Design (**CAD**) is the use of computer systems to aid in the creation, modification, analysis, or optimization of a design. CAD software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing. CAD output is often in the form of electronic files for print, machining, or other manufacturing operations.

Computer Numerical Control (CNC) is a process used in the manufacturing sector that involves the use of computers to control machine tools. Tools that can be controlled in this manner include lathes, mills, routers and grinders. Computer converts the design data produced by CAD software, into numbers. The numbers can be considered to be the coordinates of a graph and they control the movement of the cutter. In this way the computer controls the cutting and shaping of the material.

DWG (from *drawing*) is a proprietary binary file format used for storing two- and three-dimensional design data and metadata. It is the native format for several CAD packages including DraftSight, AutoCAD, IntelliCAD (and its variants), Caddie and Open Design Alliance compliant applications. In addition, DWG is supported non-natively by many other CAD applications. AutoCAD DWG is a proprietary binary file format used for storing two- and three- dimensional design data and metadata.

Geospatial Information Systems (GIS) is a system that captures, stores, analyzes and manages data and associated attributes which are spatially referenced to the Earth. In the strictest sense an information system capable of integrating, storing, editing, analyzing, sharing and displaying geographically-referenced information. A building and each of its elements has GIS references – in 3 planes.

Green Building XML (gbXML) is an XML schema developed by Green Building Studio, Inc. to facilitate the transfer of building information stored in CAD building information models, enabling integrated interoperability between building design models and a wide variety of energy analysis tools.

HVAC stands for Heating, Ventilation, and Air Conditioning and is the technology of indoor and vehicular environmental comfort. Its goal is to provide thermal comfort and acceptable indoor air quality. HVAC system design is a sub discipline of mechanical engineering, based on the principles of thermodynamics, fluid mechanics, and heat transfer.

Industry Foundation Class (IFC) is a neutral and open specification for object-based data models developed by buildingSMART to facilitate interoperability in the building industry. Version 2x3 is in common use for exchange of BIM information by many BIM applications. Version 4 was released for implementation in 2013.

IFCxml is an XML schema which has been developed to map to the IFC data model.

Integrated Project Delivery (IPD) is a collaborative project delivery approach that utilizes the talents and insights of all project participants through all phases of design and construction.

Interoperability is the ability of diverse systems and organizations to work together (inter-operate). The term is often used in a technical systems engineering sense, or alternatively in a broad sense, taking into account social, political, and organizational factors that impact system to system performance.

Level 0 BIM is an unmanaged Computer Aided Design (CAD) including 2D drawings, and text with paper-based or electronic exchange of information but without common standards and processes.

Level 1 BIM is managed by CAD, with the increasing introduction of spatial coordination, standardized structures and formats as it moves towards Level 2 BIM.

Level 2 BIM is managed 3D environment with data attached, but created in separate discipline-based models.

Level 3 BIM is a single collaborative, online, project model with construction sequencing (4D), cost (5D) and project lifecycle information (6D). This is sometimes referred to as 'iBIM' (integrated BIM).

Level of Development is the degree to which the element's geometry and attached information have been thought through – the degree to which project team members may rely on the information when using the model.

Mechanical, Electrical, and Plumbing (MEP) services are significant components of the construction supply chain. MEP design is critical for design decision-making, accurate documentation, performance and cost-estimating, construction planning, managing and operating the resulting facility.

OpenBIM is defined as a universal approach to the collaborative design, realization and operation of buildings based on open standards and workflows. It allows project team members to participate in Building Information Modelling (BIM) regardless of the software tools they use. It promotes a transparent and collaborative open workflow, creates a common language for widely referenced processes, and provides enduring project data for use throughout the asset life-cycle.

Parametric design is the generation of a building model based on a series of pre-programmed rules or algorithms. When components of a building are designed parametrically, they are assigned parameters which have limits or boundaries. When these boundaries change (elements within a repeated component in the model, for example), the parameters assigned to adjacent elements allows them to be automatically adjusted and changed.

Point cloud is a set of data points in some coordinate system. In a three-dimensional coordinate system, these points are usually defined by X, Y, and Z coordinates, and often are intended to represent the external surface of an object.

Revit (Architecture/Structure/MEP) is Building Information Modelling software for architects, structural engineers, MEP engineers, designers and contractors is available since 2000. In 2002 it was purchased by Autodesk and develop further to allow users to design a building and structure and its components in 3D, annotate the model with 2D drafting elements, and access building information from the building model's database.

Story is an enclosed horizontal division of a building characterized by structural surface capable of supporting loads imposed upon it by occupants. It is sometimes referred to as a "floor".

Vectorworks is a global design software developer serving the architecture, landscape and entertainment industries produces the Vectorworks family of software which includes Vectorworks Designer, Architect, Landmark, Spotlight, Fundamentals, and Renderworks. These programs are designed with the intent to help designers communicate effectively and bring their visions to life while keeping Building Information Modelling (BIM) at the heart of the design process.

xBIM (eXtensible Building Information Modelling) toolkit is a free software development tool that allows users to read, create and view building information models (BIM) in the Industry Foundation Classes (IFC) format. It can be used to create BIM middleware for IFC-based applications.

XML is Extensible Mark-up Language, for encoding data in a format that is human-readable and machine-readable.

4 BIM Use in Building Industry

Building Information Modelling (BIM) is a complex process of managing not only design documentation in 3D form but it also includes all the consecutive stages of the design analysis, followed by construction management, and including facility management after the site completion. The success in the collaboration to unite common efforts of architects, constructors and HVAC engineers would make the work of all involved stakeholders more productive because the existing information technologies provide this option already for a long time. The training for effective use of this relatively new and very complex approach from the very beginning of the building lifecycle in the construction industry is even a more complex task.

4.1 BIM Definition

There are many definitions of what BIM is and in many ways it depends on the point of view of what is being sought to be gained from the approach. There are two common definitions. In the UK, the Construction Project Information Committee (CPIC) has defined BIM as "... a digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it forming a reliable basis for decisions during its life cycle, from earliest conception to demolition" (RIBA).

In the USA, the National BIM Standard has even more refined definition. According to the version 3, published in 2015, BIM is a term which represents three separate but linked functions:

1) BIM is a BUSINESS PROCESS for generating and leveraging building data to design, construct and operate the building during its lifecycle. BIM allows all stakeholders to have access to the same information at the same time through interoperability between technology platforms.
2) BIM is the DIGITAL REPRESENTATION of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life cycle from inception onwards.
3) BIM is the ORGANIZATION & CONTROL of the business process by utilizing the information in the digital prototype to effect the sharing of information over the entire lifecycle of an asset. The benefits include centralized and visual communication, early exploration of options, sustainability, efficient design, integration of disciplines, site control, as built documentation, etc.– effectively developing an asset lifecycle process and model from conception to final retirement (National BIM Standard).

A Figure 1 demonstrates the interaction between all stakeholders involved in the building project and shows how the information advances during design, construction and operation stages.

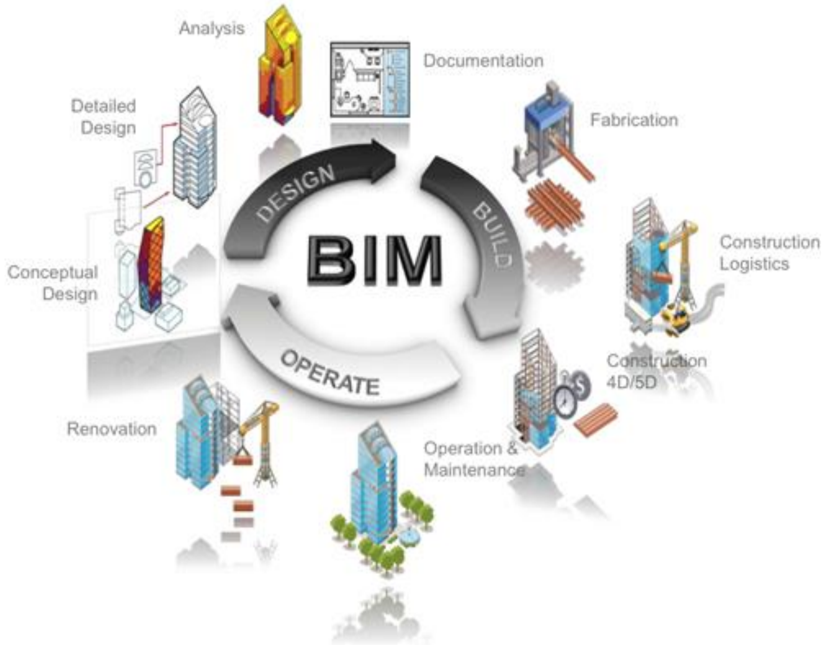


Fig. 1. Information exchange and project data advancement in Building Information Modelling process.

Building Information Modelling covers geometry, spatial relationships, light analysis, geographic information, quantities and properties of building components (for example manufacturers' details). BIM can be used to demonstrate the entire building life cycle, including the processes of construction and facility operation. Quantities and shared properties of materials can be extracted easily. Scopes of work can be isolated and defined. Systems, assemblies and sequences can be shown in a relative scale with the entire facility or group of facilities. Dynamic information of the building, such as sensor measurements and control signals from the building systems, can also be incorporated within BIM to support analysis of building operation and maintenance.

4.2 BIM Development

It is assumed that the first trace of BIM concept originates from the projects of Professor Charles Eastman at the Georgia Tech School of Architecture. Abbreviation BIM stands for Building Information Modelling (or Model) in early 1970s. The developed Building Description System (BDS) was the first software which manipulated with individual library elements from the database in the model on PDP computers. This idea was developed a long time before the victorious march of personal computers and therefore could not get a wide popularity because not many architects had a chance to get grips on it. Later several similar systems (GDS, EdCAAD, Cedar, RUCAPS, Sonata and Reflex) were developed and tested on practical projects in United Kingdom in 1980s (Bergin M. 2012). A wider application of this concept into practice became possible only with the development of personal computers, when the ArchiCAD software from Graphisoft Company appeared on the scene, which incorporated the idea of Virtual Building rather than drawing from the very first of its versions - Radar CH (ArchiCAD 1.0) in 1984. The power of software was amplified by flexible built-in programming environment for its parametric library components using GDL (Geometric Description Language).

The Virtual Building concept, realized by Graphisoft in its software ArchiCAD v. 2.0, which debuted in 1982, could be considered as the first broader application of BIM in practice. The representation tool BIM starts as a three-dimensional model tied to a database of project information, with this current support tool being the most powerful for Integrated Project Delivery (IPD) projects (Becerik-Gerber B. et al. 2010; Wright J. A. 2012). This is because BIM integrates the design, fabrication, assembly instructions, logistics and project management into a database, also providing a platform for collaboration for all the IPD members. This is a tool, not a method; a tool that still is not frequently used in the sector; but it may end up enabling the efficient development in very complicated projects, or projects that are easily understood by all the agents. The project team reaches an understanding regarding how the model will be developed, introduced and used. In order to carry out the introduction of this information modelling, a series of usage protocols must be established in the conceptualization phase within the IPD model by the different agents.

The next step was when Irwin Jungreis and Leonid Raiz split from Parametric Technology Corporation (PTC) and started their own software company called Charles River Software in Cambridge, MA. They were equipped with the knowledge of working on Pro/ENGINEER software (released 1988) development for mechanical CAD that utilizes a constraint based parametric modelling engine (Bergin M. 2012). The two wanted to create an architectural version of the software that could handle more complex projects than ArchiCAD. A trained architect David Conan joined the project and designed the initial user interface which lasted for nine releases. By 2000 the company had developed software called Revit, which was written in C++ and utilized a parametric change engine, made possible through object oriented programming.

In 2002 the power and promising future of Revit was noticed by Autodesk which purchased the company and began to heavily promote the software in competition with its own object-based software Architectural Desktop (ADT). This provided a transitional approach to BIM, as an intermediate step from CAD (Howell I. & Batcheler B. 2005). At that time ADT created its building model as a loosely coupled collection of drawings, each representing a portion of the complete BIM.

Approximately at the same time period the concept of BIM was adopted by another two software developers Bentley and Nemetschek in their further products. Bentley Systems interpreted BIM differently as an integrated project model which comprises a family of application modules that include Bentley Architecture (internationally known also under Microstation Triforma name), Bentley Structures, Bentley HVAC, etc. Nemetschek provided a fourth alternative with its BIM platform approach. The AllPlan database was “wrapped” by the Nemetschek Object Interface (NOI) layer to allow third-party design and analysis applications to interface with the building objects in the model (Howell I. & Batcheler B. 2005).

Over the past decade the emerging benefits of BIM application have been recognized by many governments worldwide. The UK Government has mandated that all public building projects will have to be using BIM design processes at 'level 2', fully collaborative 3D BIM, or higher by 2016 (McGough D. et al. 2013). The 'level 2' is defined as file-based collaboration and library management. However, in majority of countries the BIM implementation in practice has caused considerable resistance from many stakeholders, involved because of its complexity. There are several reasons for this, but the most important one is the misunderstanding about what the BIM process is in general.

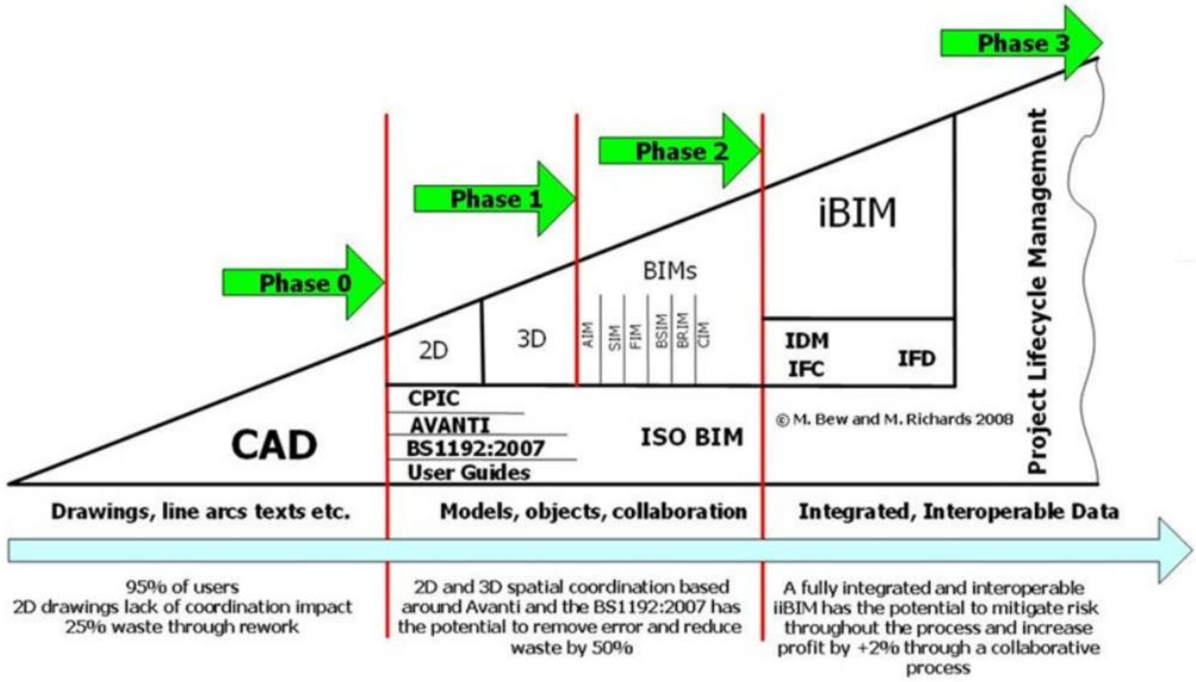


Figure 2. BIM maturity model for UK (Bew, Richards, 2008/2010).

Some will compare the BIM with just the 3D modelling and visualization tools, followed by structural analysis at best. The first two options nowadays are integrated into numerous CAD software packages. The teaching of the use of different CAD software in the university courses over the past three decades has gone through the ever-changing issues due to enormous increase in both the PC hardware performance and the software potentials. It all started with computer aided drafting software like AutoCAD when the former classic manual engineering graphics drafting skills had to be reoriented towards PC usage, which was problematic issue especially for elderly specialists. In some cases the CAD software teaching turned into specific keystroke training. As a result, the instruction was mainly focused on training the particular special courses with the support of computer aided solutions if at all, but in many cases these courses remained isolated on their own, rather than coordinated between each other. The BIM involves much greater challenges than the pure computer aided drafting and therefore the main concept of BIM is the whole building information coordination and sharing. Without these aspects there will hardly be any effect in the use of the most powerful hardware and the most expensive software. The problem of cooperation between parties involved exists almost at the same scale both in industry while implementing this concept and in education while training effectively and preparing the future users of this technology.

4.3 A Multiple Dimensions of BIM

BIM concept uses parametric object-oriented three dimensional or 3D data in virtual models in contrary to the conventional 2D drawings, a long time used so far by engineers and designers. Instead of drawing just a filled rectangular in a plan view which represents a wall of a building in section, in BIM concept supporting software the model is built virtually in 3D space. The relative location of all neighbouring elements is precisely determined and easily observable from arbitrary viewpoint for visualization purposes. The model includes not only the geometric relationships between all building elements, but these elements carry information on many real attributes associated with them, like material, paint, class of fire safety, cost, etc. The drawings – plans, elevations, and sections – are obtained automatically from the unique virtual building model, along with the bills of materials and are updated immediately after any changes are performed in the original building model. Amount of wall material in specifications (schedules) is updated as soon as real virtual building elements like windows and doors are placed in the model. This method highly eliminates the human errors while producing drawing documents, which cannot be avoided using the conventional 2D drafting technique. The synchronization between views, elevations and sections in the manually produced drawing documents is the responsibility of all parties involved, which in the case of large projects and many stakeholders involved could be a serious problem.

Designers and subcontractors create digital, 3D models of their respective scope of work based on their design documents. These models can be uploaded to a common server which then integrates the design, discipline and trade specific models into a consolidated 3D-model, and from this integrated model, creates Clash Reports. The model and the Clash Reports in coordination meetings with the designers and subcontractors are reviewed and solutions to the identified problems are discussed. Based on these discussed solutions, the designers and subcontractors revise their designs and 3D-models and re-submit the 3D-models for the next iteration. This process is repeated until all involved parties have confidence in the constructability of the coordinated design.

The concept of BIM besides the conventional three dimensions of the model and real attributes attached to these elements includes the fourth dimension – time. The so called 4D design approach allows the coordination between parties involved not only during the building construction phase but also during exploitation, reconstruction and finally even utilization. The information is maintained and updated in the common database from the initial stage of the design through the whole lifecycle of the building.

The fifth dimension incorporated in the BIM concept is “money”. One of the most important attributes for elements and processes of the real building included in the virtual model is a cost. In this case the process is described as 5D design approach. The databases may include building elements with their attributes from many vendors and the designers could easily simulate several variants of the design. Numerous design scenarios “what if” could be played to find out the most effective solution.

Besides the five more or less known dimensions the current BIM concept supports also the sixth dimension which are facility management applications like CAFM (Computer-Aided Facility Management) and the seventh dimension with procurement solutions e. g. contracts, purchasing, suppliers, and environmental standards.

In order to support all these dimensions of the BIM concept in the numerous software and applications, it is evident that a common standard has to be used to share the information between so many different “players on the field”. There are many problems which have to be solved before this undoubtedly effective BIM process can be widely used in practice (Eastman C. et al. 2011). Therefore the core technological and modelling principles of BIM were defined and the IFC (Industry Foundation Classes) and aecXML standards are used. These standards define the data structures for representing the information which is used in BIM. There are a few other data structures developed by commercial vendors in the BIM domain besides the two mentioned.

Wikipedia describes the technology adoption lifecycle model as the adoption or acceptance of a new product or innovation, according to the demographic and psychological characteristics of defined adopter groups. The process of adoption over time is typically illustrated as a classical normal distribution or “bell curve”. The model indicates that the first group of people to use a new product is called “innovators”, “followed by early adopters”. Next come the early and late majority, and the last group to eventually adopt a product are called “laggards”.

Since these BIM tools and techniques have become increasingly complex, architectural and civil engineering schools have been faced with a great challenge not to lie behind and not to become laggards. To train specific software requires first of all mastering itself provided there is a financing for it. In general, industry lies behind and picks up the innovations slowly. A student with knowledge of only one type of software may well be trained to design according to the biases of the programs that they are using to represent their ideas (Bergin M. 2012). In the case of BIM tools, the building is represented as parametric components including walls, roofs, floors, windows, columns, etc. These components have pre-defined properties, rules or constraints which help them perform collaborative tasks thanks to shared project model data.

In a blog by Shilovitsky O. in 2008 the BIM is characterized as the process of generation and management of the “building data” during its lifecycle. BIM is accepted by major vendors in architecture, engineering and construction industry and is widely used in all building types – from simple warehouses to many of most complex new buildings. BIM covers multiple domains – geometry, spatial relationships, geographical information, quantities and properties of building components. It helps manage a wide scope of works, system assemblies and other related processes. BIM provides potential future as a virtual information model to be handled from design teams to contractors and subcontractors, and then to owners, each adding their own additional discipline-specific knowledge and tracking of changes to the single model.

BIM uses 3D, real-time, dynamic building modelling software to increase productivity both in design and construction. This process successfully coordinates products, project and process information throughout new product introduction, production, service and retirement among the various players, internal and external, who must collaborate to bring the concept to life. OpenBIM is a universal approach to the collaborative design, realization and operation of buildings based on open standards and workflows and it is an initiative of buildingSMART and several leading software vendors using the open buildingSMART data model. Educators have to seek contacts/relationships with a view of developing joint actions with industry and enterprises. Particular attention should be paid to small and medium sized enterprises as they account for an enormous part of economic growth and could be the places where the innovations could be introduced much easier. There is an evident role for universities to play in lifelong learning and continuing education thought them to offer possibilities of companies to increase competitiveness, productivity and efficiency, total costs estimation, and to become concurrent also on the global rather than the local market.

4.4 Problems in Industry

Contemporary hardware and software provides enormous potentials for the nowadays designers. How come that these potentials are not introduced in everyday practice and are not used in full scale? The two main factors that affect this are the expenses and training. The BIM's learning curve could be one of the top barriers of implementation in construction. There is an opinion that wide use of BIM concept mainly fails because of another two much more important factors – people factor and change factor (Shilovitsky O. 2012). BIM implementation is not really about the software, but it is about organizational change. The experiences of clients have demonstrated that people and processes are far more important than technology.

BIM is an absolutely wonderful tool, and it has great potential to streamline costs and processes, to help different disciplines communicate effectively and to ensure little confusion on a job site. But to get to that promised land of benefits, you have to pass through the wilderness of adoption, which always seems to hinge on organizational change, not technology. This is the inconvenient truth.

People's factor has been acknowledged by many AEC/CAD/CAM analysts (Barison M. B. & Santos E. T. 2011; Shilovitsky O. 2012). The influence of people is significant factor in software product implementation that requires from people to re-think the way they are doing their business. BIM software can eliminate some roles in organizations and change business processes between organizations. It makes the process of software adoption long and complicated. This is a place where failure comes very often.

Changes are another aspect, which very often comes together with data and object and/or process oriented software like BIM and PLM (Product Lifecycle Management). The specific character of almost every enterprise-level data and process management software is to focus on how to change the organization – improve processes, re-organize business relationships, change tools, etc. It is extremely hard to people, since the change is hard, it consequently leads to failures (Shilovitsky O. 2012).

During all phases of a construction project, the involved parties have an increasing need to define more precisely what is being modelled and how the modelling is done. In Finland as a response to the rapidly growing use of BIM in the construction industry the set of documents "Common BIM Requirements 2012" or COBIM were published in 14 Series (BIM Guide, 2012). COBIM is based on the previous instructions of the owner organizations and the user experiences derived from them, along with the thorough experience the writers of the instructions possess with model-based operations. The project was properly funded by Senate Properties in addition to several other real estate owners and developers, construction companies and software vendors. BuildingSMART Finland also participated in the financing of several projects.

A vague attempt has been initiated by a group of enthusiasts from private companies to embrace similar documents for local industry in Latvia. No support or any funding has been provided from the governmental agencies side. This initiative has resulted in some documents being translated also in Latvian – BIM Handbook (BIM Rokasgrāmata 2013) and first two COBIM series (COBIM v. 1.0a 2013; COBIM v. 1.0b 2013) with adjustments for the peculiarities of local industry. Local BIM compatible software distributors are active promoters of this initiative as well. They actively organize information seminars on BIM issues.

4.5 Design Automation in Building Industry

Current trends in building design and construction industry feature the switch from conventional sequential engineering to more advanced concurrent engineering approach (Justifying… 2004). Timber frame wood building segment in this area is not an exception. Many design institutions now are considering an option to implement new 3D design and CNC based production methods based on modern IT advancements. Another option is to stay with the conventional CAD based 2D drafting design. Companies with well-organized business very often do not see a necessity to decline from proved and familiar methods. Any serious IT based improvements require new investments in many aspects – hardware, software, and what is the most important – personnel training.

The switch from conventional drafting boards to 2D CAD systems in a wide range of engineering bureaus started about two decades ago. Qualified persons with CAD systems could perform their tasks much faster and in much better quality. For the beginners the work not always was faster, because generally the training of the personnel to use new technology was not provided by the employer.

The new CAD systems had numerous advantages. Just to mention a few of them – it was much easier to fix the mistakes and issue new versions of drawing documents; the drawings were more accurate; it was possible to re-use and modify preliminary issued documents. However, for some people and businesses CAD seemed too difficult, expensive and unnecessary because old methods allowed reaching goal with the same success, less effort, and expenses. Conservative persons just slightly delayed these innovations in their businesses, because now the questions about 2D pencil drafting or 2D CAD is not anymore on agenda. Nowadays we can hardly find few companies, which do not use the CAD software.

The next step in the IT progress for designers was CAD approach. The original product idea is instantly implemented into 3D concept model which is further developed and refined through the interaction of all associated parties. Contemporary design today is already performed in IT media rather than with IT tools like 3D CAD systems. Even modern 3D software applications nowadays are just simple IT tools.

All this has influenced the way of interaction between product designer and developer. One of the greatest challenges for the building developers is to find less labour intensive ways of converting the designs submitted by architects into a format that can be easily read by the software that operates in CNC sawmill. Many software suppliers have been developing solutions to help meet this specific demand from the timber frame industry.

Advanced options of hardware and software provide to the users' incredible potentials in their application. Is there a next step in further progress? The correct answer is "Yes, there is". In architecture and civil engineering nowadays we face with a new design concept BIM – Building Information Modelling. This concept actually is not a new one because it has been circling around for some time and several software developers already have been using and developing it for almost two decades. It provides and option to include in the design all the required information from the initial idea, through the building construction, along with facility management after it is built and even final utilization of the building when its lifecycle expires. Effective teamwork resources are provided in these design systems for all interacting co-workers like lighting, electric, HVAC, fire protection, cost estimation, construction management, and safety, etc. specialists to share and exchange the information.

4.6 Case study: Timber Frame Construction Design Automation

Despite that AutoCAD provides 3D design option, generally it still is being used as simple 2D drawing board. SEMA (The Innovation… 2015) instead is specialized timber construction design software which models 3D timber design objects and automatically generates the required drawing documentation according to specified industry standards. SEMA provides the next step in the automation of timber construction design and production allowing transferring the information directly from the designer's computer to CNC sawmills facilities. SEMA is just one of the numerous existing software solutions in this field and the alternatives are not a topic of this paper.

The origins of SEMA software which now is specialized in timber design in wood building industry date back to 1984. In Latvia for the first time this technology was implemented in 2002 with version 9.0 in Zemgales Tehnoloģijas centrs, SIA. Before that all the design documentation was prepared using standard AutoCAD. To judge about these two different design approaches the prepared design documentation for typical private house was prepared using both alternatives and will be compared.

4.7 Benefits in the Private House Design

The drawings of timber frame building elements are prepared in AutoCAD and they are used in production process to prefabricate the elements at the factory to assemble them later at the building site. All the information in the drawings is two dimensional and represents building elements in plans/elevations, sections, etc. The real object exists only in the designer’s mind and object representation in the drawings is only interpretation of this object according to his/her expertise level and the industry standards’ requirements. It is very time consuming process and it is subject to human error if the right software is not used.

The required construction documentation for a typical private house (full area 150 sq. meters) design prepared back in 2004 using AutoCAD consisted from 152 pages (Design Project… 2004). The time for the preparation of this documentation for the designer with proper AutoCAD skills was 4 months.

In AutoCAD the whole house design initially is prepared as plan drawings. After that object is separated into several elements and joints are designed in a similar way providing document drawings. Later the timber frame and frame borders (Fig. 3) are designed likewise. To provide complete information about this element it is still required further information about corresponding sections. In addition to geometric information the material description of elements is compulsory.

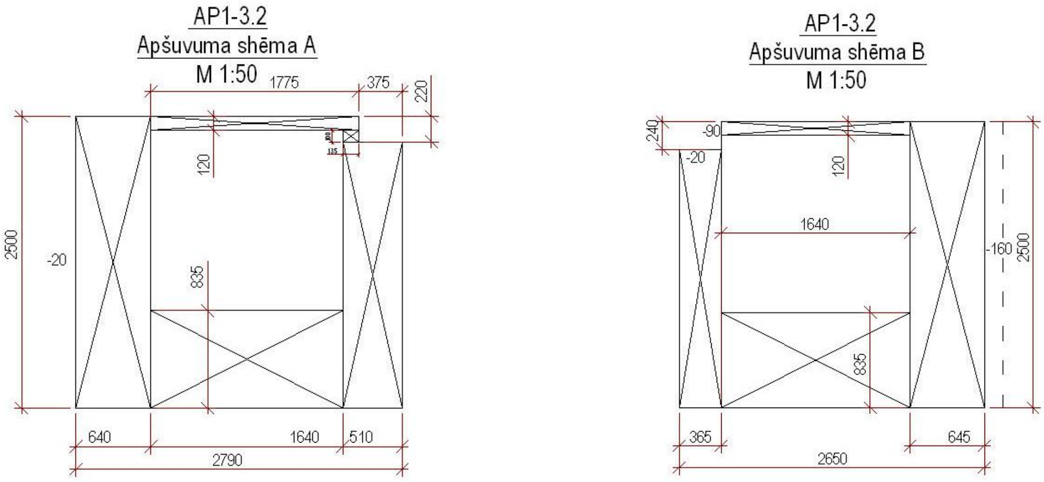


Fig. 3. Wood frame drawing of the designed wall.

There are 70 to 100 similar elements in one 150 m^2 building which have to be designed and interpreted separately. The general process of the design is much more complicate and will not be discussed in more details. If the geometry of the whole building is simple, the wood frame wall connections are easy to represent in plans and sections. When the rooms in the buildings are more complicate in form, additional information is required in different additional elevations. In this case a potential risk of errors caused by human factor is inevitable. Three months were spent purely for the design process and documentation preparation using this approach. Additional time was spent for structural analysis and general project management.

In a medium size and not very modern timber frame house factory it is possible to prefabricate elements for about 50 buildings (~150 m^2) each year. If the design of each building will last for minimum 4 months, it will be required at least 20 engineers only for the design documentation preparation. This is serious consideration to take into account in this situation. The question is about moving further in the development or waiting somebody else to take over using the provided IT potentials.

Few years later when SEMA software was implemented in the office, exactly the same typical private house was re-designed using SEMA (ver. 10.1) software (Design Project… 2007). In this case all the required blueprint documentation consisted from only 16 pages. The preparation of the documentation with SEMA took only three weeks and was performed by the designer with advanced skills in the use of software.

The design sequence with SEMA software is as follows. First of all the required materials are selected. The immersions of the building size, elevations and other data are input into software. The required wall functions are defined. Then the building wall size, their location and ceiling information or building envelop is defined. Then SEMA software will automatically take over to frame the walls, roofs and floors based on user definable parameters and settings, such as the quantity and dimensions of cripple studs, top and bottom plates, and default opening behaviour, default headers, trimmer and studs.

The software provides accurate shop drawings for either individual panel and/or for each wall/roof plane. All the special design elements enable useful and fast combinations of 2D and 3D data to create dimensioned floor plans, sections, elevations and detail drawings. All the details can be automatically numbered and dimensioned automatically (Fig. 4). Modifications in any detail or element are automatically updated into the whole database. All details can be listed in the parts list, where information about their size, material and number is presented. The end result includes all the finer construction details including all the studs and sheeting as well as electrical elements and entire roof details, allowing every single cut to be prefabricated in the factory.

Software will automatically visualize the object (Fig. 5) allowing the information representation in a structured way. Thus the design can be observed from any point of view in space. In these visualizations it is possible to choose any projection method – parallel or perspective, obtain information about any elevation/section, and even visualize the section with predetermined field of depth.

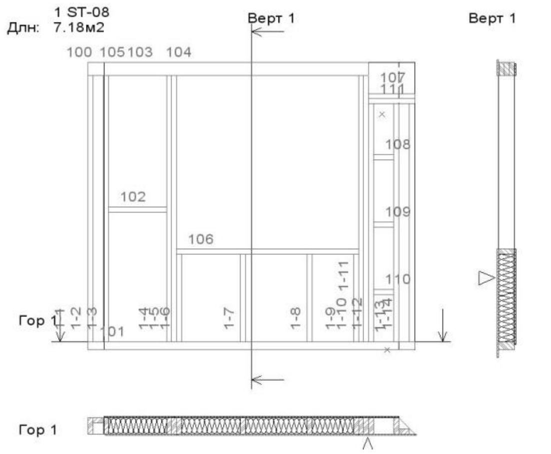


Fig. 4. The numbering of the wall elements.

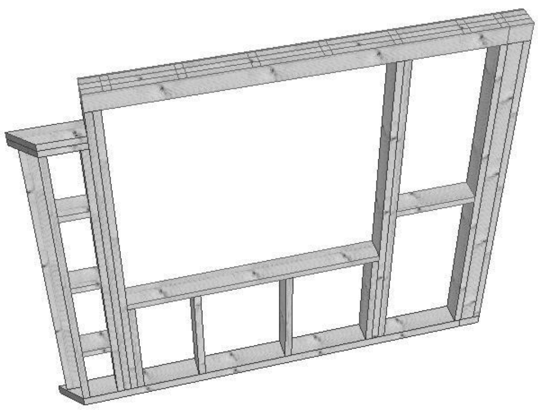


Fig. 5. The visualization of wood frame.

SEMA software has modular structure. It is possible to integrate separate module for static calculations, which provides an option to perform structural analysis. Another module is for modern stairs design with different materials used. Automatic production of stair element detail drawing is another time saving option in the whole design process.

As a result, the same building design project was geared up in three weeks. To prepare the design documentation for 50 buildings each year using SEMA software only four engineers are required instead of 20 before.

SEMA expanded its development capacities to meet the increasingly higher demands of CNC-control in timber construction. The software can easily communicate directly with CNC machinery such as the Hundeggar, Weinmann, and many others. The CNC file is generated from the 3D model and no additional translations are necessary. The control of the finger router of the modern Hundegger machines of the K series has been modified in such a way that all kinds of contours now can be defined in the timber design software and are then automatically transferred to the CNC machines.

The use of 3D design software SEMA allowed to reduce the time required for documentation preparation from 4 months to 3 weeks. The change in the basic philosophy determines that we must move from minimizing the costs to maximizing the added value first of all in the design and construction phase. The transition from 2D design to 3D design approach is not only motivated, but even necessary in all industries, which need fast and effective product development.

SEMA software facilitates the translation of architect’s design ideas directly to timber frame manufacture. The application of specialized software reduces the risk of human factor avoiding serious mistakes. Detailed return of investments has not been analysed in this study and requires further research. However, it is evident already now that it will be cost-effective in any case and will pay off sooner or later.

5 BIM for Architects, Constructors, and Coordinators

5.1 Visualization

One of the major advantages of BIM software is the ability to provide great visualization outcomes for the design. Visualization tools provide a wide range of virtual representations, like photo rendered images, animation movies, 360 degree panoramas, augmented reality solutions, and interactive virtual walk-through of the building from the very early stages of idea development. This can be very helpful during the bidding phase of the project when the developer and construction manager can easily share the BIM concept in 3D with wide range of involved persons.

Visualization provides a better understanding of what the final product may look like. It can replace the traditional physical mock-ups with the virtual ones which can be produced much faster. This would help to visualize and make the decisions on the aesthetics and the functionality of the space. The virtual mock-ups help to communicate and collaborate among the project stakeholders. Virtual mock-ups could become a good standard practice to precede the physical mock-up process.

When the end deliverable of the visualization of a scanned environment is animated in a fly through, a HD quality movie files are easy available along with planned design features added. Using high definition point clouds detailed 2D elevation drawings may be extracted that are delivered in *.dwg or *.dxf format of the cleaned scan data. Fully rendered visualizations may be performed from the 3D laser scan data to demonstrate existing structures or environments and optionally incorporate design elements. The results of infrared thermography measurement may be superimposed on the visualizations of the scanned data ().

5.2 Coordination

Collaboration of the construction team with the architect, engineer and the owner is preferred to be started on early stages of the design phase when BIM should be implemented. If the architect is only providing 2D drawings, then the construction manager should convert the 2D drawings to 3D intelligent models. When the specialty contractors, especially the MEP contractors and the steel fabricators are involved, they need to spatially coordinate their work. The 3D coordination can be started right after the model is created to ensure that any element interference, clash or clearance conflicts are resolved. The coordination efforts of construction manager and specialty contractors in advance of construction help to reduce design errors tremendously and to better understand ahead of time the work to be done.

5.3 Prefabrication

Prefabrication of elements in the factory in the contrary to the on-site fabrication reduces field labour cost and time and increases accuracy in a good quality construction. There are more tools and options readily available in a controlled environment of the jobsite to perform work more precisely, and less costly in a shorter period of time. Prefabrication requires design and field accuracy. BIM can provide this level accuracy by including the specifications, sequence, finishes, and the 3D visualization for each component. However, the construction team must make sure that the BIM is interoperable with the software used by fabricators. This way the contractors can use the BIM and generate details for the product in their fabrication software. Once the details are approved, the products can be fabricated using Computer Numerical Control (CNC) machines. Furthermore, the construction managers must administer the procurement schedule of the products. Overall, the prefabricated products must be delivered to the installation site on time.

A few beam penetrations may become inevitable for complex project. A good coordination of these penetrations with BIM technology advocates determining the beam penetration locations and prefabricate offsite. Prefabricated beam penetrations would save tremendous time, money and effort in comparison to onsite beam penetrations. Moreover, roof penetrations for concrete rooftops should be sleeved prior to concrete pour at the roof level. Supplemental steel for each penetration may be required. These penetrations can be coordinated with BIM when the specialty contractors are on board (Hergunsel M. F. 2011).

Curtain wall systems whether panelised or stick system, can be used with BIM to prefabricate parts and components. Panelised curtain wall systems may be considered for the schedule purposes. Stick systems require the use of assembly of each one of components onsite whereas the panelised systems already come prefabricated with all the components which includes, insulation, glazing, stone, framing, etc.

Walls, rooms, and houses can be virtually designed and constructed with Building Information Model. These walls, rooms and houses can be prefabricated with roughed mechanical, electrical, plumbing (MEP) components. Final MEP connections can be made once the prefabricated components are assembled onsite.

In healthcare and biotechnology projects, various equipment such as Biosafety Cabinets (BSCs), fume hoods, autoclaves, cage washes, and MRIs, etc. may be required. This equipment may require some type of coordination with MEP contractors. For instance, fume hoods may come with prefabricated piping for vacuum, gas, or nitrogen lines at laboratories. BIM can be used to determine the exact location of the fume hood and more importantly, the drop in location to the prefabricated piping at the fume hood. This enables the in-wall roughing and plumbing drops of the piping work before the fume hoods come to the site. Moreover, the electrician can pull cables to junction box to later tie into the circuits for lights, outlets, and fan. Lastly, the ductwork contractor can use the 17information from the BIM to drop its branch duct so the fume hood can later be tied in. Overall, Building Information Modelling can help achieve the implementation of the MEP roughing work by promoting collaboration of information exchange between the subcontractors.

BIM can help to coordinate between casework installers and MEP contractors. For example, island benches (cores) are prefabricated with electric outlets, and gas turrets. BIM can be used to determine the roughing locations. Then, the electrical circuits of the island benches can be roughed to a junction box. The plumbing pipes can be fed to the horizontal branches above the ceiling. Overall, the roughing can be completed successfully with the use of BIM process.

Pipe manufacturer could use BIM to gather coordinated piping locations, lengths and sizes for its fabrication software as long as the interoperability is possible. This allows in-wall drops including hot, cold, drain/vent, vacuum, etc. to be prefabricated. The drops typically stick out a foot from the wall to provide connection to the horizontal branches above the ceiling. Furthermore, if pipes need to be weld, they must come at manageable sections. Pipes typically come to jobsite 5 to 10 feet sections. Welding small sections of black iron pipe with four inches or bigger diameter would be feasible to weld offsite whereas two 10 foot sections welded offsite would not be manageable. Also, offsets and joints would prefer to be prefabricated. Overall, it is ideal to prefabricate all the small pieces in a controlled environment with readily available equipment which would yield more efficient, higher quality, and less costly products (Hergunsel M. F. 2011).

BIM can be used to enhance the information exchange of the products between participations. Furthermore, it is used to virtually coordinate the location and routing of the products. Based on this information, the products can be detailed using the fabrication software. Once the material is prefabricated and arrives on site, the foreman of the 18 specialty trade coordinates with the general superintendent to ensure that he is making the virtual design and construction a reality.

5.4 The Matrix of BIM Tools

The list of BIM authoring and analysis software tools that integrate with gbXML is shown in Table 1. Click the vendor name hyperlink in any row to view more information about the vendor and the software that they offer. (Also, please note the "Not Yet" label located under the "gbXML Verified" column means that the software has not undergone the verification process which is still a work-in-progress on our part. The fact that the software is listed here means that it does successfully import or export gbXML.).

Table 1. BIM Authoring and CAD software vendors and tools

Vendor	Tool
Artifice	Design Workshop
Autodesk	AutoCAD Architecture
Autodesk	AutoCAD MEP
Autodesk	AutoCAD Revit Architecture & Autodesk Revit MEP
Bentley	Bentley AECOsim Building Designer
Bentley	Bentley Architecture
Bentley	Bentley Building Mechanical Systems
Bentley	Bentley speedikon Architectural

Vendor	Tool
Cadsoft	Envisioneer
Digital Alchemy	Simergy/ Building Model Creator™
Graphisoft	ArchiCAD
Nemetschek Vectorworks	Vectorworks Architect
Onuma	Onuma BIMStorm
Rhinoceros 3D	Rhino 3D and Grasshopper
Trimble	Skechup

5.5 Energy Analysis Software or Add-ons

There is a wide variety of BIM compatible analysis software. In this study only the energy analysis will be discussed. The Green Building XML schema (gbXML) is an open schema developed to facilitate transfer of building data stored in BIM to engineering analysis tools. gbXML is being integrated into a range of software CAD and engineering tools and supported by leading 3D BIM vendors. gbXML is streamlined to transfer building properties to and from engineering analysis tools to reduce the interoperability issues and eliminate plan take-off time. gbXML is the underlying architecture of Autodesk's Green Building Studio commercial on-line energy analysis product, and is the main export option for energy analysis from their modelling products. Disciplinary solutions for Building Energy Modelling analysis are provided by huge number of developers (Table 2).

Table 2. Software vendors and building analysis tools that integrate with gbXML

Vendor	Tool
Arup	EnergySave
Autodesk	Green Building Studio (GBS)
Bentley	Bentley-AECOsim
Bentley	Bentley-Hevacomp
blueCape	BlueCFD-AIR
CADLine	Cymap
Carrier	HAP (Hourly Analysis Program)
CYPE	CYPETHERM Loads, HVAC. EPlus, and CYPELUX
DesignBuilder Software Ltd	DesignBuilder Energy Assessor
DIALux	DIALux
Digital Alchemy	Simergy
E4Tech	E4Tech
Elite Software	Chvac - Commercial HVAC Load Calculations
EnergySoft, LLC	EnergyPro
Environmental Design Solutions Limited	Tas Engineering
EQUA Simulation AB	IDA Indoor Climate and Energy
Granlund	RIUSKA
Graphisoft	EcoDesigner STAR
greenspace Live	greenspace Live Energy Design and Analysis Tools
HVAC Solution	HVAC Solution
IES Limited	Virtual Environment (VE)
mh-software GmbH	RaumGEO
National Renewable Energy Laboratory	Open Studio
National University of Ireland, Cork	Cylon Controls Ltd. & Ace Controls ltd.
Passive House Institute	PHPP – Passive House Planning Package
Relux Informatik AG	ReluxSuite
Software fur Haustechniker	Win_Ht
Solar-Computer	Green-Building-Information-System (GBIS)

Vendor	Tool
StruSoft AB	VIP-Energy
Trane	Trace 700

A Table 3 lists some of the Autodesk tools for energy analyses which are geared towards architectural discipline.

Table 3. Autodesk energy analysis tools

Use with Revit	Name	Characteristic
Externally	Insight 360 (new tool announced by Autodesk at Greenbuild 2015)	New cloud-based tool enabling a new way to experience building energy and environmental performance and the collective actions that lead to better outcomes throughout all stages of the building lifecycle.
	Green Building Studio (GBS)	Standalone cloud-based whole building performance analysis using the DOE2 simulation engine.
	FormIt 360 Pro	Cloud-based concept modeling tool with energy and solar analysis tools built in.
Internally	Energy Analysis	Analyse a design's expected energy use based on geometry and location on earth
	Solar Analysis (now part of the Insight 360 add-in for Revit)	Visualize and quantify the distribution of solar radiation on various surfaces
	Light Analysis (now part of the Insight 360 add-in for Revit)	Analysis for illuminance and validation for LEED v3 IEQc8.1 and LEED v4 IEQ Daylight Credit, Option 2
	Generate Insight (part of the Insight 360 add-in for Revit)	Automatically varies building design inputs resulting in high and low possible annual energy costs with approximately +/- 10% accuracy. Inputs can then be adjusted, e.g., glazing properties, to see instant feedback on performance impacts.

5.6 As-built 3D BIM Model

Modelling as-built model is a process of creation of BIM objects that represent building components, including both geometric and non-geometric attributes and relationships. If BIM is modelled on the basis of previously captured building information, the preceding data capture, processing and recognition methods influence data quality through the deployed technique and the provided level of detail. To compare different approaches and their modelling capacities, created models might be assessed e.g. with respect to modelling accuracy or level of detail (Tang P. et al. 2010; NIBS, buildingSMART alliance 2007). Yet, no standard BIM assessment method has been established to compare model qualities.

In practice, "as-built" BIM modelling very often is done interactively in a time consuming and error-prone process (Eastman C. et al. 2011; Arayici Y. 2008; Tang P. et al. 2010; Remondino F. et al. 2006), e.g. with the most familiar BIM compatible software of the few major vendors Autodesk Revit, Bentley AECOsim, Graphisoft ArchiCAD, Tekla or Nemetschek Allplan. The latest versions of this software provide powerful features for reverse engineering tasks and processing of captured point clouds. Although some allow the rapid generation of building floor plans or offer BIM integration, the depicted software solutions are far from automated or semi-automated BIM modelling of existing buildings.

Automated BIM modelling or transformations of surface models into volumetric, semantically rich entities are in its infancy (Arayici Y. 2008). Many reviewed publications cope with (semi-) automated modelling of building surfaces or components with respect to their geometrical representations. However, they do not regard component properties or semantic information yet (Xiong X. 2013, Klein L. et al. 2012; Adan A. et al. 2011; Barazetti L. et al. 2010; Frahm J. et al. 2010; Furukawa Y. et al. 2009; Kim S.-A. et al. 2009; Ordóñez C. et al. 2010; Styliadis A. et al. 2011). If non-geometric attributes like functional, relational, economical or semantic information of existing buildings are integrated into BIM, it is done interactively or semi-automated (Adan A. et al. 2011; Donath D. et al. 2010; Hajian H. et al. 2010; Xiong X. et al. 2013). Due to an effortful BIM creation process, model creation of existing buildings either focuses on coarse building components or is not applied yet. Besides, the high Level of Detail (LoD), e.g. required for specific maintenance or deconstruction considerations is not compatible with current time and cost restrictions in the AEC/FM/D sector.

Furthermore, our review reveals that object attributes and relations relevant for maintenance and deconstruction functionalities are not widespread modelled yet, partly due to undefined properties, unavailable object libraries containing older building components or unspecified LoD. As skilled personnel and high efforts are necessary to model BIM of existing buildings, further research in automated capturing, processing and modelling could reduce building auditing cost and increase productivity in BIM-based maintenance and deconstruction processes.

6 BIM in Building Renovation

Most of the time, the measurements are taken on site, then the materials are cut on demand directly on the building site in order to fit. The frames (windows, doors, solar modules, etc.) are adjusted on site with waste of materials. Finally, cladding is attached according to the architect expectations. Most of these activities are achieved on the building site with a very low degree of anticipation. As a result, the effectiveness of the working site is low, the energy efficiency of the renovation is questionable and renovation costs tend to increase.

An assessment of the situation in France revealed that from about 20 million apartments, half of which were built before first energy regulation was issued in 1975, there are around 400 000 energy-inefficient buildings to renovate. It is obvious that the building renovation process cannot remain at the craftsman stage and needs to be considered as an industrial activity. The main idea behind this industrialization is to distinguish: the existing building analysis, the renovation design, and the components production, from the renovation assembly on the building site. This allows to design, to prepare and to produce all the renovation components in factories with some anticipation allowing waste reduction and some optimization concerns. Then, all components are moved towards the building site for renovation assembly with a minimum of adjustments or fitting (Aldanondo M. et al 2014).

The industrialization need of this reconstruction may be satisfied by chaining of stakeholders including renovation owners, renovation designers, architects, modular component suppliers, and on the building site installation teams in the streamlined digital engineering processes that are supported through BIM media (Juan Y.K. et al. 2010).

Reconstruction typically begins with existing conditions modelling when a project team develops a 3D model of the existing conditions for facilities on a site. This model can be developed in multiple ways: including laser scanning and conventional surveying techniques, depending on what is desired and what is most efficient. Once the model is constructed different modernization alternatives may be analysed digitally.

The main techniques for capturing 3D data about the built environment from terrestrial platforms are through laser scanning or total station measurements. The latter being the predominant method for building surveys where a predetermined set of point measurements are taken of features from which 2D CAD plans are produced. Terrestrial laser scanning has been the technology of choice for the 3D capture of complex structures that are not easily measured with the sparse but targeted point collection from a total station since the technology was commercialized around 2000. This includes architectural façades with very detailed elements and refineries or plant rooms where the nature of the environment to be measured makes traditional workflows inefficient.

BIM is a digital data flow surrounding the lifecycle of an asset or element of the built environment, intended to provide better information management to aid with decision making. As a process, BIM has been gaining global acceptance across the Architecture, Engineering, Construction, and Operations (AECO) community for improving information sharing about built assets. A key component of this is a data-rich object-based 3D parametric model that holds both geometric and semantic information. By creating a single accessible repository of data, then other tools can be utilized to extract useful information about the asset for various purposes (Thomson C. & Boehm J. 2015.).

7 Capturing of Building Information

In small scale projects in practice much of the data is still obtained by hand, using tape measurements, and documentation by recording information in a notebook. A little more advanced approach uses a method of photogrammetry, which requires dedicated camera, software and skills of application. These traditional methods sometimes are still used for small scale and little budget solutions. The most well-known drawback in these methods is that too much personal work is involved in the on-site data acquisition procedure, which is time consuming, not accurate enough, sometimes difficult and can be even dangerous. In addition, the method of data recording and storing cannot make full use of modern IT and computer technology to speed up the data processing, and then provide the input data in a required format for further analysis and design.

It has been recently realized that applying some more advanced methods for on-site 3D data acquisition is the key point in solving the bottleneck problem for improving mapping data, in terms of both quality and quantity. Especially with the development of IT technology, the digital data must be used as the input for computer-aided work. Therefore, the interest in the new methods for acquisition of digital data has greatly increased in recent years especially when these methods had become much cheaper and more widely available for practical application.

A proposed general WP4 process workflow may be split into several steps (Fig. 6).

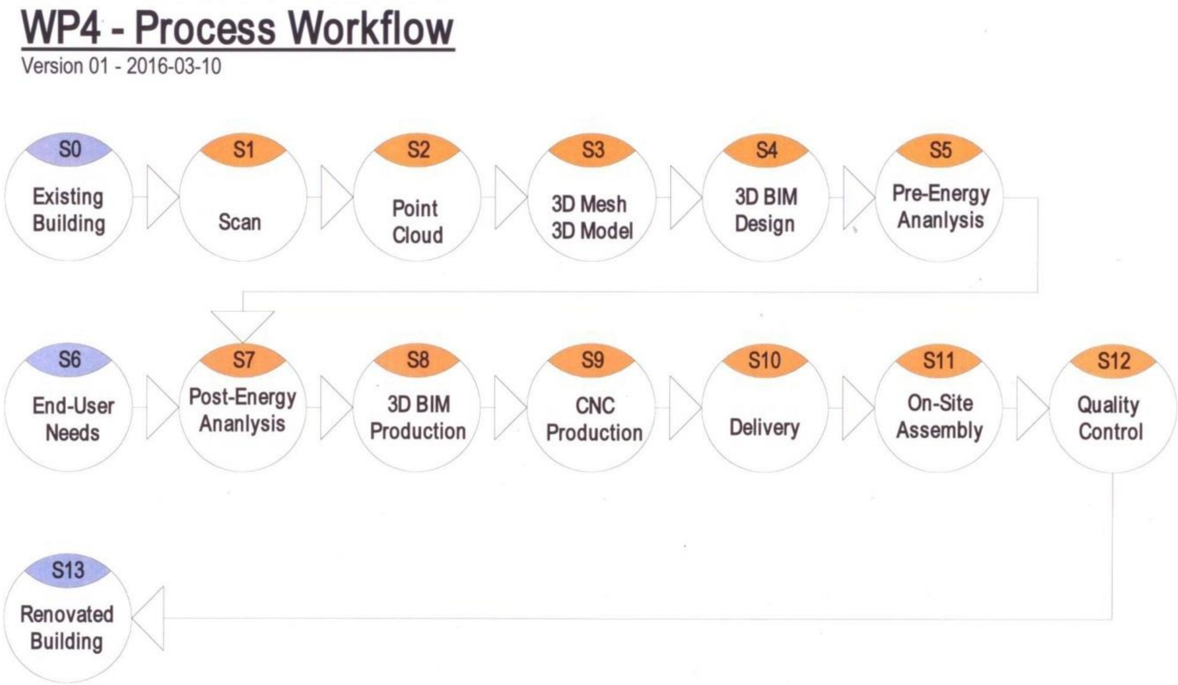


Fig. 6. WP4 Process Workflow.

7.1 3D Scanning

3D laser scanning techniques have been developed since the end of 1990s for 3D digital measurement, documentation and visualization in many fields including geospatial and survey industries, architecture, processing and mining industries, building infrastructure, archaeology, and etc. (Feng Q. & Röshoff K. 2015). Recent advances in hardware technology and building information modelling (BIM) are helping to overpass to a new level of scanning application for the building construction industry. Scanning for building construction is being applied most often to existing structures, but is also seeing an advent of applications relating to new construction work. Scanning technology is becoming a critical function necessary to complete the integrated BIM cycle and provides a clear value-add for the integrated BIM workflow. Nowadays a 3D laser scanning is the fastest and most convenient method of data capture compared to the traditional geometry documentation methods used before.

This approach requires contemporary resources like conventional surveying equipment, 3D laser scanner, laser scanning point cloud manipulation software and BIM supported software. In addition, the users must have a wide range of competencies like:

- Knowledge of conventional surveying tools and equipment;
- Knowledge of 3D laser scanning tools;
- Ability to filter through large amount of data generated by a 3D laser scan;
- Ability to determine what level of detail will be required to speed up the to the project;
- Knowledge of BIM authoring tools;
- Ability to manipulate, navigate, and review a 3D model;
- Ability to generate BIM from 3D laser scan and/or conventional survey data

The purpose of the present study is to assess the laser scanning method for the capture of geometric form and size of facade elements of building, determine an optimal workflow for this procedure and prepare recommendations regarding fluent streamlining of the stored data for the design of product which will be manufactured on a CNC production line.

Laser scanning, sometimes referred to as LiDAR (Light Detection And Ranging), is a new technique to obtain the digital data of an object by capturing millions of measurements by rotating mirrors. The 3D scanner is a type of a device that records the as-built situation with the data on its shape and its appearance (i.e. intensity or colour) by emitting light and detecting the reflection of the light in order to accurately determine the distance to the reflected object. There are different scanning systems used for capturing various sizes of objects (i.e. from a small tool to a large building), within a wide range of scale (i.e. from few millimetres up to tens of hundreds of meters), and so can be divided into different scanning systems according to the range (Fig. 7, Böhler W. et al. 2001):

- Airborne Laser Scanning (ALS)
- Terrestrial Laser Scanning (TLS)
- Micro Laser scanning (MicroLS)

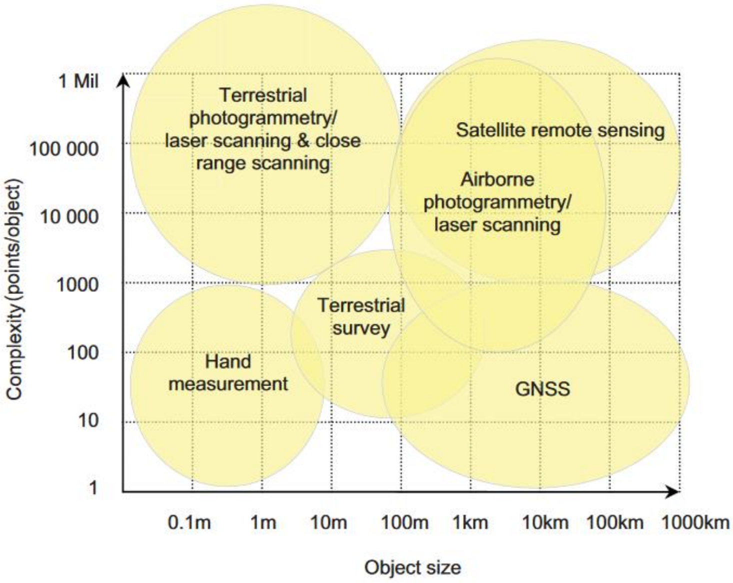


Fig. 7. 3D survey techniques characterized by scale and object size (Böhler W. et al. 2001)

Terrestrial 3D laser scanner is a contemporary instrument for capturing a geomatic data. It offers numerous measurement benefits including 3D data capture, remote and noncontact operation, a permanent visual record and dense data point acquisition. 3D laser scanners are currently being used in a variety of applications for documentation. The 3D laser scanners with respect to the price may be divided into low, middle and high cost range. For example, 3D laser scanners with accuracy 2-3 mm to 10 mm are the middle cost scanners, but with accuracy 0.7-1 mm are high cost scanners. For objects where the accuracy of the surface geometry needs to be within 5-10 mm range, the most effective scanners from economical point of view are the ones from middle-range cost. A scanning time for these scanners in the field from one position requires about 15 minutes.

The operation of each different scanning system is different, because it depends upon the requirements of the particular scanning software and reference surveying. Basic parameters which must be considered and correctly selected for different applications are as follows:

- Scanning resolution;
- Scanning range;
- Position of each scanning;
- Number and location of reference targets.

In addition, some scanning systems are also sensitive to the environment, such as temperature, moisture, density of particles in the air, and even the reflectivity of the object. These parameters and factors must be carefully considered in order to obtain good quality scanned data.

7.2 Data Processing Software

Software for terrestrial laser scanning actually comprises several software modules of different types. Considering the whole procedure of a scanning project from data collection to the final model, a rough division may be as follows (Feng Q. & Röshoff K. 2015):

- Software for scanning control;
- Software for registration of individual scans together or into the global co-ordinate system;
- Software for point cloud treatment;
- Software for CAD modelling;
- Software for texture and image mapping;
- Software for data and project management;
- Software to integrate scanning data to another existing program, e.g. GIS and CAD systems.

The software described above generally serves for scanning and simple modelling. Sometimes more specific software is required:

- Software for converting between scanning data and CAD or BIM software, and
- Software for special applications, i.e. architecture documentation, rock surface mapping, documentation in mining and archaeology, etc.

The development of the software is advancing rapidly, and becoming more and more studied by the users because the quality of these software modules has a considerable influence on the quality of the final modelling results, and also on the time needed to achieve the results. Thus, a smoothly performing software product is the basic requirement for the acceptance of 3D laser scanning techniques.

7.3 Prep-processing Software

For laser scanning data, the most important software is the one for point cloud processing. Most of the scanner manufacturers have developed their own point cloud processing software. Exporting the point cloud data from any scanner in a xyz file format allows further process with any software package. Most popular point cloud processing software includes:

- Cyclone and Cyclone Cloudworx (Leica)
- Polyworks (Innovmetric)
- Riscan Pro (Riegl)
- Isite Studio (Isite)
- LFM Software (Zoller+Fröhlich)
- Luposcan (Lupos3D)
- Split FX (Split Engineering)
- RealWorks Survey (Trimble)
- Pointools (Pointools)

There are also numerous third party developers offering specific point cloud processing software which is tuned for specific tasks. For example, a Scan to BIM software add-in for Revit from a company IMAGINiT considerably eases the process of getting 3D laser scanning data into a high-quality as built BIM compatible model (IMAGINiT 2016). The use of this add-in makes the scan to model process much easier and provides tools to automatically create geometry such as walls, pipes or ducts, analyse the deviation between what is modelled and the point cloud, check interferences, as well as a variety of other productivity tools. (Fig. 8).

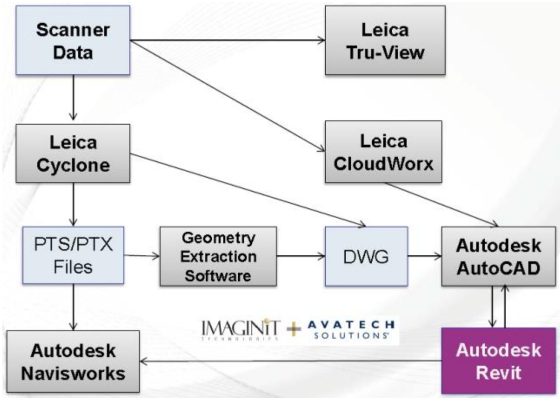


Fig. 8. 3D scan data workflow to Autodesk Revit and Autodesk Navisworks (IMAGINiT 2016)

Furthermore, much research work has been focused on the development and improvement of the algorithms in order to provide good quality software, including:

- Error analysis and control of the whole scanning procedure from scanner calibration to modelling; and
- Matching and segmentation of 3D point clouds in order to make the modelling more effective and automatic.

A documentation of civil engineering buildings objects is rather complex process. One of the main tasks in the documentation is a capture of the geometry of the building – a collection and storage of the form and size of numeral geometric elements of the façade and sometimes also interior.

7.4 Benefits of Laser Scanning

Compared to the traditional methods, laser scanning techniques have some advantages for on-site documentation, as follows.

1) Integration of both visualization and position.

Laser scanning data consists of both position information with the coordinates for each point and the visual information with the laser image or intensity image. An object in the laser scanning intensity image cannot only be visualized but also measured in 3D. This is a unique feature compared to the photos from a still camera or film from a video camera.

2) Provide relational information.

The on-site documentation by traditional methods, e.g. written notes and pictures from a camera, has no exact positional information, so it is difficult to interrelate the data. By laser scanning, the scanning data can be registered into the same coordinate system, so the laser scanning image has the exact location, and any objects shown on the image can be positioned in space, and the relationship between them can be obtained.

3) Generate different types of ways for visualization from the same data resources.

The recommendation precision of the scan works for getting the geometry of the surface is 5 mm. The accuracy of the scan works must be 2-4 mm of the scan point. The accuracy of the scan points depended from type of the scanners, distance from scanner to surface, surface quality, material of the surface and point foot size. Very important is point foot size. The big foot size gives the divergence of the point on the corner of surface.

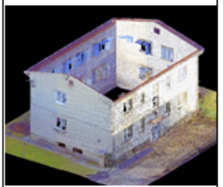
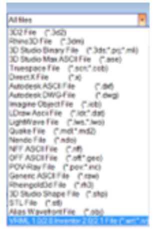
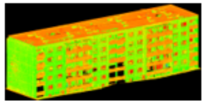
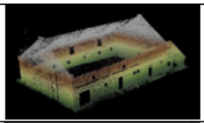
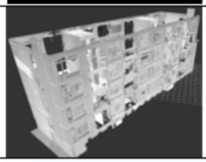
4) Point cloud data processing integrated into specialized software.

Nowadays the end users of CAD and BIM software can exchange the laser scanning data much easier because of developed special purpose built-in modules.

5) A high resolution intensity image can be recorded by scanning without illumination.

The best resolution of a high speed scanning can now be up to less than 1 mm with the intensity image. In addition, as the scanner utilizes an infrared laser, so illumination is not necessary, which means a high resolution digital image can be quickly captured in the dark, so it is especially useful for underground rock engineering projects.

8 File Formats Used by Industrial Partners

Project location, Provide two letter country code	Sample of the building's point cloud representation Please, insert one illustrative picture of scanned building (other please put in the attachment)	Total net area of the building, m^2	Equipment used for 3D scanning and software	Number of scan stations	Total onsite scan time, hours	Point cloud size, format and size	Software used to transfer point cloud into 3D building model ArchiCAD, REVIT, other – what?; native format of resulting model, size	Creation of 3D BIM model: Automatic, Semi-automatic or Manual	Creation of 3D BIM model: Name of add-on or plug-in if used Provide short description of the procedure	Creation of 3D BIM model: Total time spent on model creation, hours	Creation of 3D BIM model: Internal energy evaluation module	Creation of 3D BIM model: Export file format used	External energy evaluation software: Name	Potential software to be used for machinery/production (CNC): Name	Potential software to be used for machinery/production (CNC): Acceptable import formats
LV	 original scanned file used *.pts, ~3.9 GB	559	Scaner FARO 3D 120 ; Software Faro Scene and Leica Cyclone	9	6	*.e57, ~682 MB	ArchiCAD, *.pln, ~10 MB	Manual	Manual tracing with point cloud in background	~16, depends on experience and building complexity	EcoDesigner STAR	*.ifc	IDA ICE (currently not all informatio n correctly imported from original file)	SEMA (dot no accept data import from *ifc file)	 IFC
						*.rcs, ~1 GB	Revit, *.rvt, ~4 MB no windows recognized by external sowtware	Manual	Manual tracing with point cloud in background	~16? Depends on experience and building complexity	MagicCad and RIUSKA ** extra cost*				
EE		773	Leica ScanStation C10; Software Leic Cyclone	10	6	*pts ~900MB	Revit *.rvt	Manual	Manual tracing	The model was based on drawings	MagicCad and RIUSKA ** extra cost*	*.ifc	IDA ICE (currently not all informatio n correctly imported from original file)	AutoCad plugin software "Seina Paneel" And/or HsbCad	
CZ		576	Surphaser 25HSX; Geomagic Studio	9	6	*.las, ~190MB	Autodesk Recap360, Autodesk Revit	Manual	Manual tracking	~10	Autodesk Insight360	*.ifc	Autodesk Green Building Studio	CadWork	Btl dxf ifc
NL		24 * 85	Laser Scanner FARO 3D	10	6	Appr. 1 Gb	Autodesk Revit	Manual	Manual tracking	>40	Not done by Webo/BJW	*.ifc	PHPP	Vertex (export from Revit to Vertex)	Btl Ifc dxf
PT		345	Topographic survey digital with gps	4	6	~30 Mb	Trimble	Semi-Automatic	Semi-Automatic	8	Tekla	*.dxf	Tekla	Tekla	*dxf

8.1 A Pilot Study for Residential Building

A two-story residential building of approximately 300 sq. meters was selected in a pilot study. Residential house with four apartments was designed in early 1960s and built in 1967 when there were no regulations regarding energy saving policy at all. A practical reconstruction of a BIM compatible 3D building model from 3D laser scanner data included the following steps.

8.1.1 Laser scanning and data pre-processing

The building is located in a suburb territory of a small town and there were no concerns about how to eliminate pedestrian "noise" from the scan data. The building plot is single rectangle with rather simple facades having no tiny de-tails. Therefore, the number of scan station lo-cations was basically determined only by the amount of adjacent greenery and interfering objects like cables, and etc. The laser scanning of the building was performed from nine positions (Fig. 9) with phase shift technology scanner FARO 3D 120. The scanning work was carried out during on-site visit on a well-lit day without precipitations.

Altogether 18 registration marks or spherical reference targets were used. The average distances between scan points on the walls were 5 mm. The scanning time in each scanner position took about 7 minutes. The actual time spent on-site for the equipment setup, calibration and data acquisition from the arrival until the departure in this study was about 6 hours. Information about geo-referencing (orientation, location and elevation) of the site along with the neighbourhood characteristic (soil type, trees, nearby buildings, etc.) required for further energy analyses was documented during the same day visit. All the procedures were performed by two persons.

Some of the metadata may be stored directly in the point cloud file format, or may be linked to the point cloud for later use in BIM models. The existing plan views and sections for the building were collected in an analogue format (blueprints) from the available inventory documentation and then digitalized.

The data sets with about 400 million points from all scanning positions were downloaded from the scanner. Pre-processed raw scan data as point clouds were positioned and oriented in their own coordinate systems. Merging or stitching together all the point clouds in a single coordinate system was performed by Faro Scene software on a network.

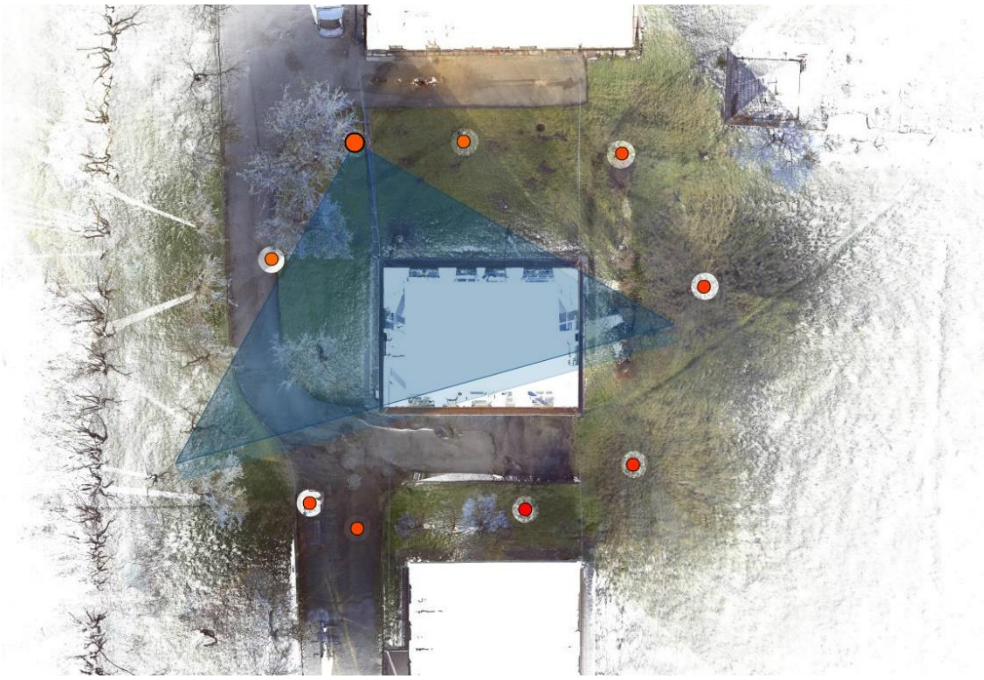


Fig. 9. Nine scanner positions for two-story residential house in Cēsis, Latvia.

Not all the scan points in the data set may be used because of some always existing noise accidentally captured. The noise points need to be filtered out or cleaned from the raw data. For data cleaning and deleting of duplicates Faro Scene and Leica Cyclone software were used. This process took about 4 hours and included the following steps:

- Deleting outliers;
- Unifying the scan points to delete double points, unify the space between the points;
- Cleaning off the noise of neighbouring objects like trees, bushes, cables, etc.

All these adjustments in a post processing or registration stage resulted in 3 mm accuracy with respect to the station. It took another 4 hours to perform the following procedures:

- Checking the convergence between the scan positions;
- Checking the conformity of the reference dimensions for e.g. windows, doors or corners with different survey methods (total station, tape measure or laser distance measuring tool). In the present study the checked dimensions are between 5-10 mm.

Since various raw data formats are used for scanners, sometimes it is necessary to convert the scanning data into another format, depending upon which modelling software is used for the post-processing. In this study *.pts and *.e57 scan data formats were required.

Raw data obtained by laser scanning are referred as point cloud, which is a set of vertices in a 3D coordinate system. These vertices de-fine or digitally represent xyz coordinates of the points of the external surface of the building. For most of the phase-based scanners, the raw scanning data are combined as both point and intensity, so the corresponding intensity image in both 2D and 3D can be obtained, which is useful for more detailed documentation and identification of objects. Data are stored in *.pts or *.e57 formats and examples of the representation of building details are shown in Fig. 10 and Fig. 11.

For the purpose of visualization of the point clouds and collaboration between all stake-holders a free online viewing and mark-up tool Faro WebShare was used (Fig. 12). Data were shared in the cloud to make them available for inspection with conventional browser. Data may be also embedded into a client's website. This allows all participants to observe the original site in real situation later at any time during any stage of the collaboration process. Any further measurements between elements may be performed directly in the visualized point cloud media by means of web browser without installing any additional software. As an alternative online data viewer a Leica Truview browser may be used.

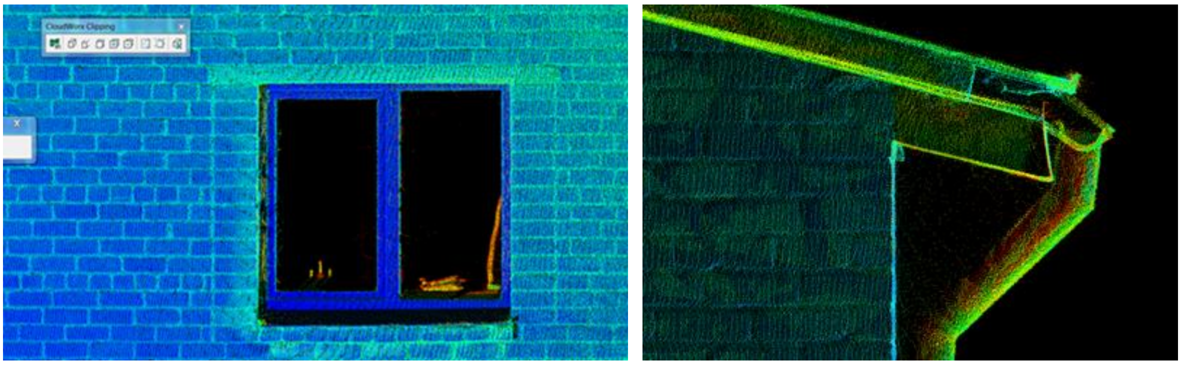


Fig. 10. Details of the building elements in point cloud visualization mode in *.pts format.

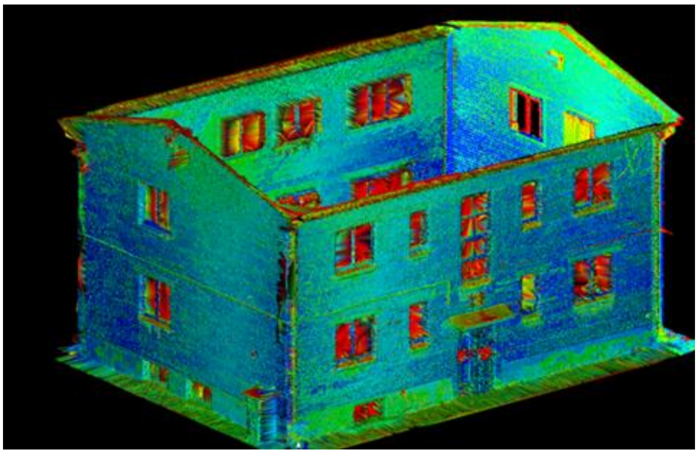


Fig. 11. Surface model of a two-story apartment building visualized with Leica Cy-clone software.

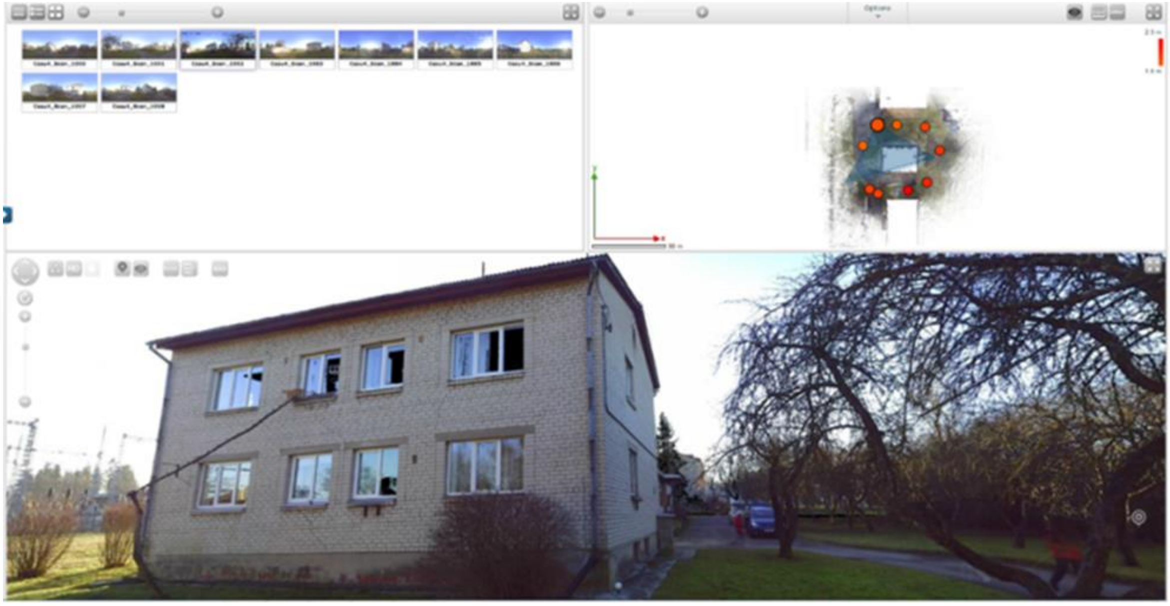
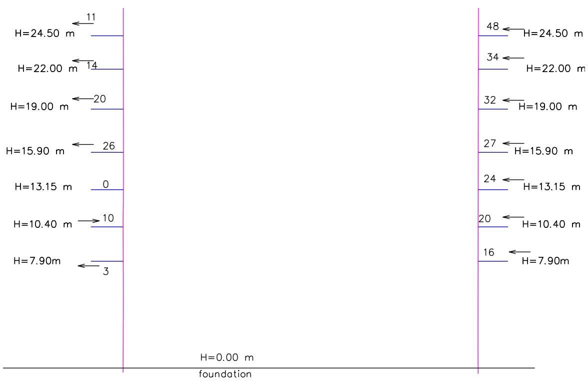


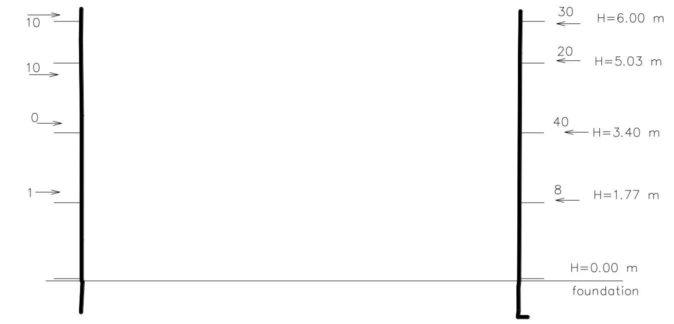
Fig. 12. Interface of the web share of a two-story apartment house in Cēsis, Latvia.

3D point clouds are available in a variety of industry standard formats including *.las, *.pts, *.ptx, *.pcg, *.pod, *.txt etc. which are registered and optionally coordinated to fit all the most popular practically used systems.

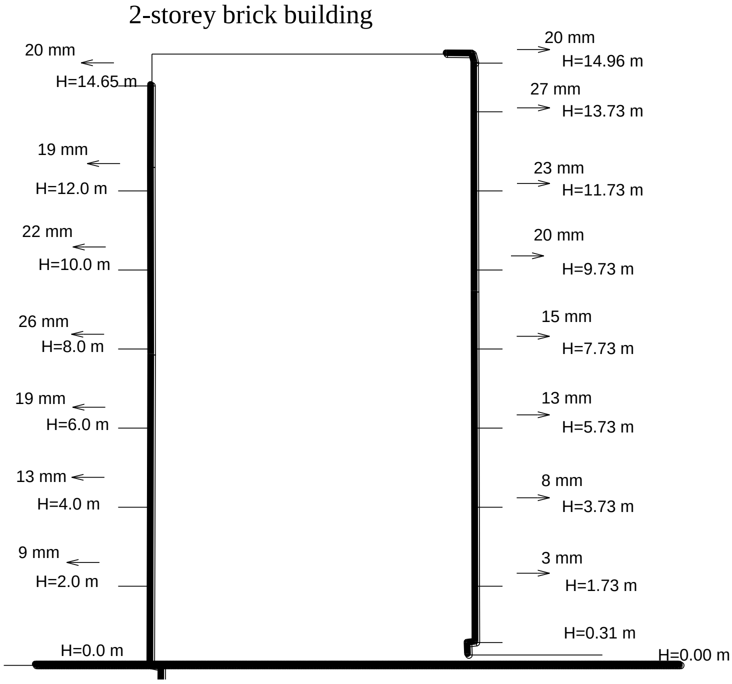
Three different apartment buildings were analysis in order to estimate post-World War II buildings' facades vertical displacement. This survey was performer for 2-storey brick building, 5-storey panel/brick building and 9-storey panel building. The Figure 4 shows facades with most critical vertical deviations.



9-storety panel building



2-storey brick building



5-storey brick building

Vertical deviations of measured 2, 5 and 9 story buildings

The survey of three different buildings showed that the vertical displacement is 40mm from foundation to top of roof for 2-storey brick building, 48 mm for 9-storey building and 20 mm for 5-storey building. The maximal difference between equal levels is 32 mm. The more precise analysis of vertical deviations is shown in Annex 1.

8.1.2 Data post-processing

The post-processing using software may be performed in two different ways as follows:

- With specially developed or dedicated software, or
- Importing directly into existing specialized end user software.

Specially developed software that is dedicated for particular tasks can process large amounts of scanning data, and create different results, including support for a CAD model, mesh-model, cross-section, etc. The results later can be exported into other systems, such as CAD, GIS, BIM or other user-familiar systems for different applications.

A surface modelling of the building included the following steps:

- Creation of mesh,
- Creation of path surface (B-spline surface),
- Creation of SmartSurface.

The most popular surface generation method is a triangulation. For this purpose different type of software may be used: post-processing (Farro Scene, Leica Cyclone, etc.), CAD soft-ware (Autodesk, Bentley, etc.) or specialized for surface generation (MeshLab, Geomagic Studio, 3DReshaper, etc.). Fig. 13 shows the SmartSurface model of the building generated with Bentley, but Fig. 14 – the triangulated with 3DReshaper the surface model of the corner walls of the building with interfering neighbouring object.

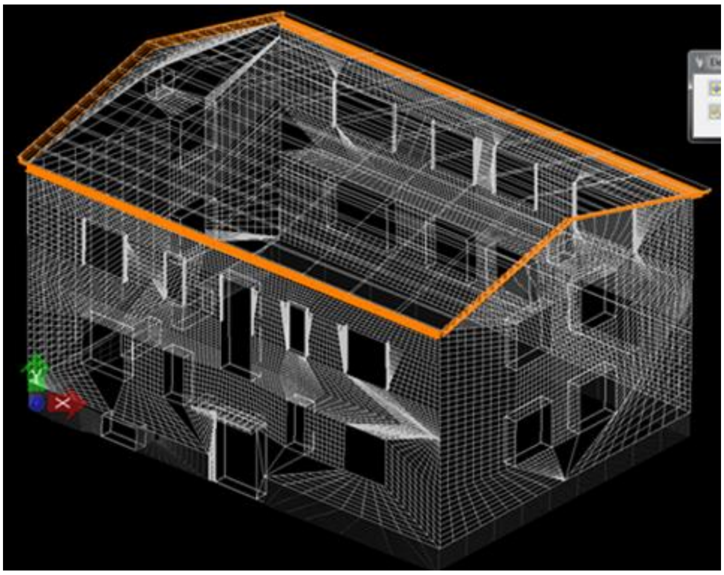


Fig. 13. The SmartSurface model of the building generated with Bentley software.

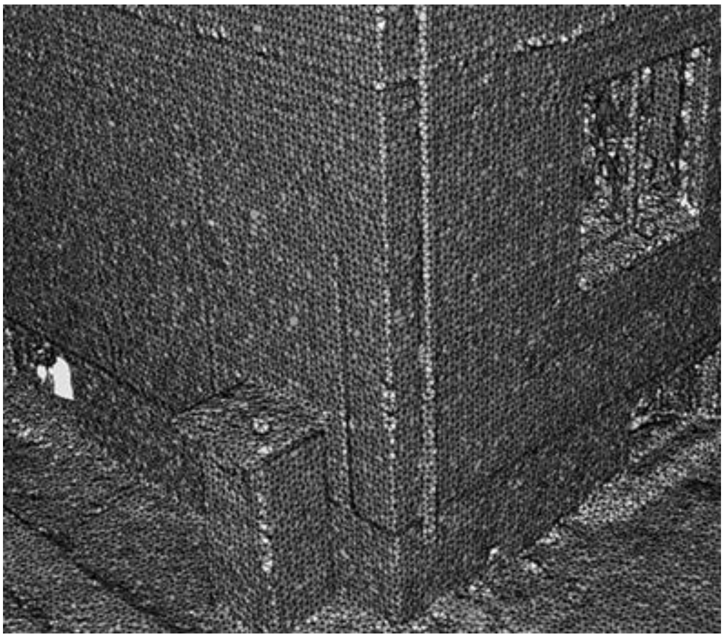


Fig. 14. The triangulated surface of the corner of building walls generated with 3DReshaper software.

Triangulated surface mesh is quite complex and problematic for the further use in most popular CAD formats. The mesh model size for the surfaces of all walls exceeded 100 MB. It was decided to use additional software and convert the mesh surface model into patch model (Geomagic Studio) or SmartSurface model (Bentley). The software uses other sur-face interpolation algorithms and after trans-formation the obtained surface models are much simpler and smaller, and easier for analysing the deviations from the exact geometry.

The existing information captured as point cloud data usually has a higher accuracy than the existing pre-construction drawings in blue-print format. Therefore, the created 3D surface meshes can be used to create deliverables in the form of 2D drawings which may be imported into wide range of CAD or BIM applications. 3D model deliverables should be created using standard formats, such as

*.ifc, or common ex-change formats like *.dxf to allow clients to retain as much data intelligence as possible. However, mesh models capture only the geo-metric properties of the building and are not suitable for direct use as BIM models.

Traditional 2D deliverables (plans, sections, elevations, details, etc.) can be generated directly from the point cloud data by taking virtual sections through the point cloud and generating drawings in conventional *.dwg or *.dxf format. The surface accuracy of point clouds is high, making this a superior method for reproducing existing conditions in comparison to manual measurements.

When the end deliverable of the visualization of the scanned environment is animated in fly-through mode, a HD quality movie files are easy available along with planned design features added. Using high definition point clouds the detailed 2D elevation drawings may be extracted that are delivered in *.dwg or *.dxf format or alternatively scaled ortho photograph elevations of the cleaned scan data. From the 3D laser scan data fully rendered visualizations can be pictured from any viewpoint to provide detailed graphics of existing structures or environments and optionally incorporated design elements. The results of thermographic measurement can be superimposed on the visualizations of the scanned building (Wang C. & Cho Y.K. 2015).

8.1.3 The capture of BIM model

The building elements in a BIM model which are of particular interest in the present study are those which exchange energy with the environment, namely, walls, slabs, foundation, roofs, windows, doors, and the soil of the terrain which is in contact with building foundation elements. None of the deliverables available in the 3D scan workflow described above provide a model in a BIM compatible format which is required for further energy analysis.

Manual, semi-automatic or automatic processes for BIM model creation may be distinguished when capturing the external and/or internal elements of the building (Wang C. & Cho Y.K. 2015). Some third party application designers have developed tools which are usable in Revit, ArchiCAD or AECOsim, and etc. software for automation of conversion process. However, according to (Tang P. et al. 2010) in practice a 3D model generation from point cloud data and setup for energy analysis so far is a time-consuming and labour intensive manual process subjected to numerous errors.

BIM models in this study were produced directly from the point cloud data. Autodesk Re-Cap freeware was used to cope with different scan data file formats (*.rcp, *.rcs, *.e57) to share the data with Revit or ArchiCAD soft-ware if the scan data did not meet the requirements. The imported point cloud was adjusted to the zero level of the ground floor location and the slab height was referenced with respect to the window sill and corresponding room height dimensions which were retrieved and documented during the on-site visit (Fig. 15).

An approach of manual BIM model production proved to be the most efficient and fastest workflow as compared to conventional on-site measurements. This method also minimizes efforts and time spent and cost of post-work when finding and fixing errors after automatic BIM model generation process (Cho Y.K. et al. 2015; Xiong X. 2013).

Automatic process of BIM model creation has limited success for old buildings also due to some other practical issues. One is related to the foundation settlement which causes serious problems for the design of prefabricated insulation panels. The foundation settlement of the building in present study was almost 13 cm on the 10 m long base (Fig. 16). The window openings are neither rectangular nor orthogonal to the vertical and horizontal directions.

Another factor preventing automatic recognition is that in practice the external walls very often are neither planar nor strictly vertical.

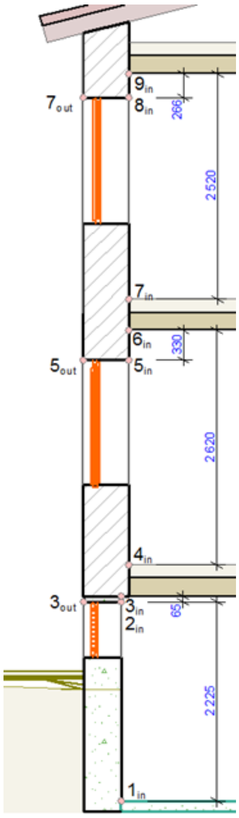


Fig. 15. The on-site reference measurement scheme (points 1 through 9) for zero level and slab location adjustment in the point cloud.

Fig. 16. The height difference between left and the rightest window on the North façade (red line is zero reference on 10 m base line).

Local cross sections in the point cloud were identified at different story heights and used for existing external wall tracing. To create a medium fidelity BIM model, the interior walls were also included in the model. Since the rooms of the residential building are relatively small with a lot of indoor occlusions (furniture) the scan process is not effective. Instead the existing inventory plan drawings were digitally referenced to the BIM model and internal walls were manually traced over.

Definition of structural materials (composites in ArchiCAD) includes a setup of visual representation of structural materials representing existing walls, slabs and roofs was performed before the tracing BIM model from the point cloud. Composites consist from several layers of uniform building materials to which their physical properties are defined. Thus several variants of considered types of composites may be easily defined and used in digital simulations estimating energy consumption and efficiency.

Manually created as-is BIM model provides information at the element level (walls, slabs, roofs, soil, windows and doors). Elements can be summarized by a small number of parameters therefore BIM model has the capability to supplement the 3D data with additional intelligent and semantic attributes before sharing it with other stakeholders for the use in external analysis applications. Since the BIM software provides easy and intuitive interface for visual representation of geometric model and element manipulation, it is very convenient for the definition of physical parameters of the elements considered during analysis either directly in the original media or in the applications of the third party developers.

The prepared BIM model of the building (Fig. 17) consists from parametric building elements with customizable semantic parameters. Model can be exported to different analysis applications in different formats.

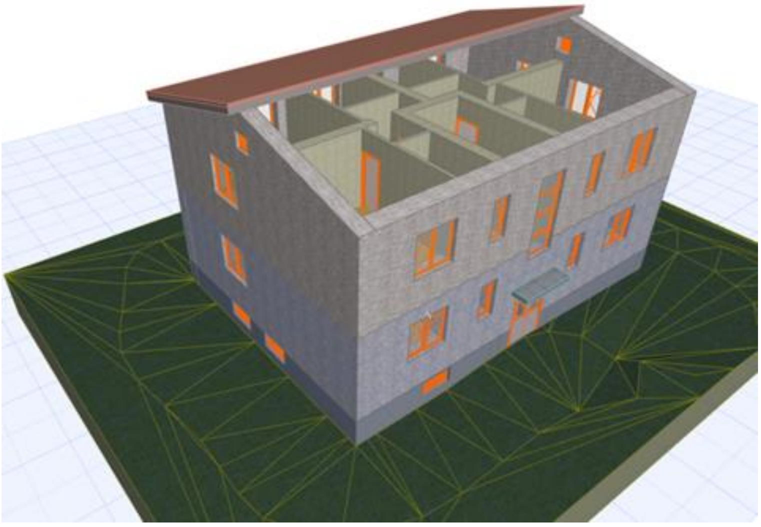


Fig. 17. BIM model of residential building including simple terrain model in ArchiCAD.

Topographic surveys or geographic features surrounding a building are as important as BIM model itself. In the case of evident relief of the terrain it is possible to combine 3D scan data with existing LiDAR and GPS surveys to provide topographical contours or other custom datasets. In this study the terrain was modelled with simple standard tools which are available either in ArchiCAD (Mesh) or Revit (Toposurface). The terrain interfering with the building foundation also carries physical properties.

9 Energy Analysis

Energy analysis of the existing building and renovated can be performed directly with the selected BIM modelling software – internally either in ArchiCAD (used in this study) or in Revit, or in an external energy simulation software.

9.1 Internal Energy Analysis (ArchiCAD)

A preliminary energy analysis of existing and different renovated building variants may be performed internally in the preferred BIM modeller. For this purpose, ArchiCAD modeller is powered with EcoDesigner STAR add on. Within Revit internal energy analysis allows calculation of expected energy use based on the geometry of building and its location on the earth. Simulation is run using Autodesk's Green Building Studio or alternative engine that might require subscription service. Any other alternative software may be used which supports internal energy analysis listed in the Table 1.

The preparation for internal energy analysis includes several procedures:

- Setup of geographical location,
- Definition of physical properties of structural materials,
- Definition of operation profiles,
- Definition of supply building systems (heating, cooling, ventilation),
- Definition of environmental settings,
- Assigning climate date for the location,
- Definition of energy source factors,
- Definition of energy costs,
- Definition of thermal bridges if modelled (not used in this study),
- Setup of other energy simulation options depending on the module performance
- Validation of BIM model.

9.1.1 Setup of geographical location

If all the required data are not provided with the point cloud data file the properties should be stored manually using single and straightforward interface (Fig. 18).

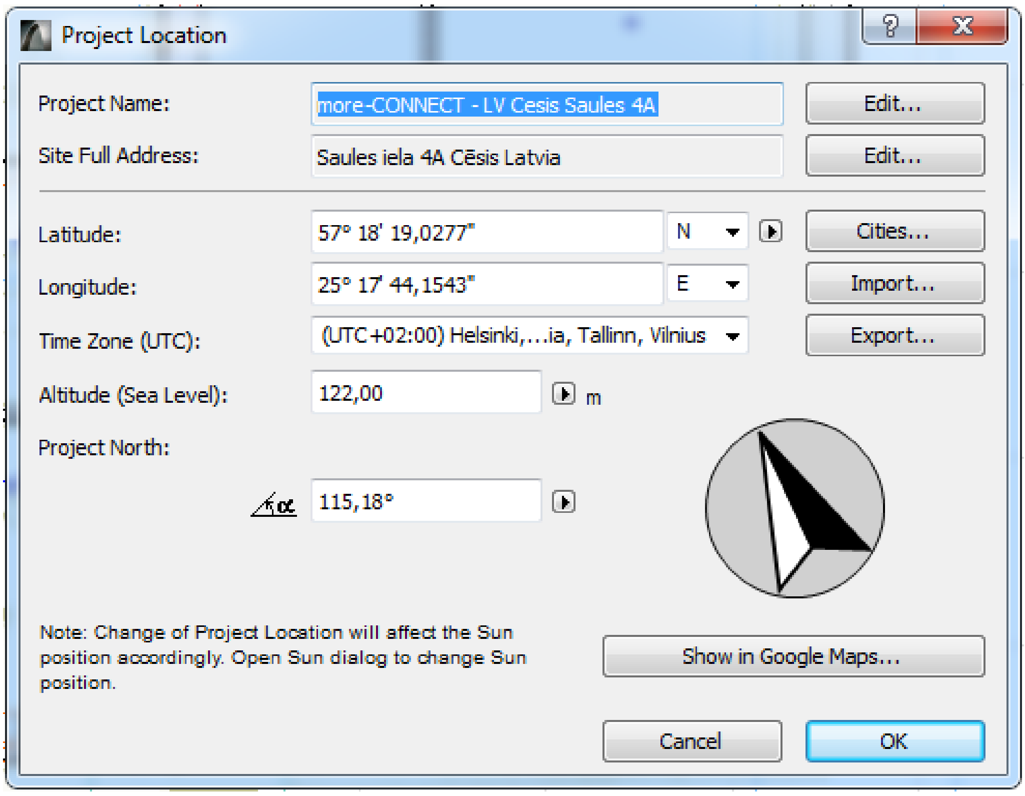


Fig.18. Interface for setup of building geographic location.

9.1.2 Definition of physical properties of building materials

A setup of visual representation of structural materials (composites in ArchiCAD) representing existing walls and slabs was performed before the tracing BIM model from the point cloud. Composites consist from several layers of uniform building materials. Physical properties are assigned to particular building materials (Fig. 19) and stored in the database. Existing and renovated composite wall structures were defined in the pilot project.

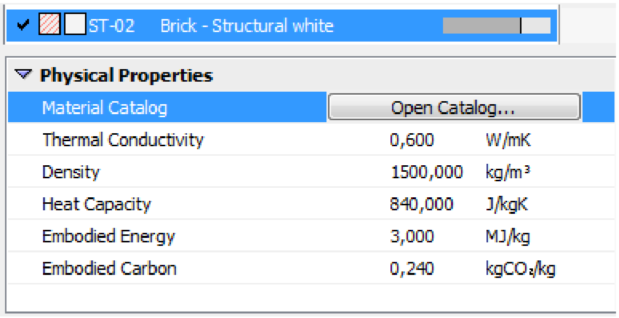


Fig. 19. The interface for the definition of physical properties of the building material for structural white brick wall.

9.1.3 Definition of operation profiles

Residential operation profile with default daily habitation schedule was selected for the existing building (Fig. 20).

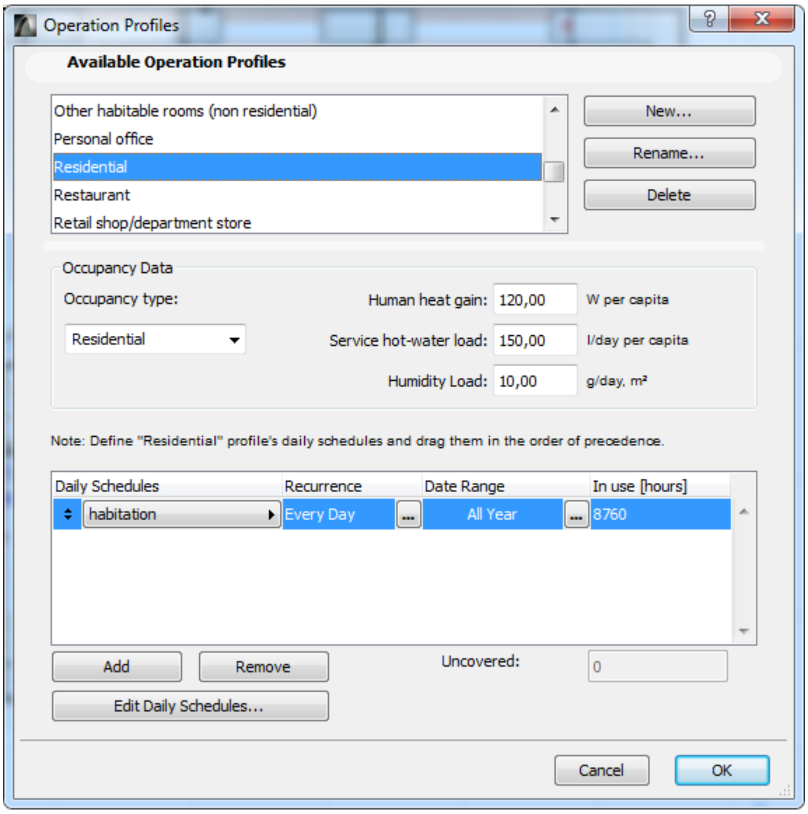


Fig. 20. The interface for the definition of operation profiles.

9.1.4 Definition of supply building systems (heating, cooling, ventilation)

The types of supply building systems can be selected from the existing predefined list of typical systems (Fig. 21). Interface provides an option to visually check the setup and easy redefine at any stage of project. User defined supply building system can be also created and added to the existing list.

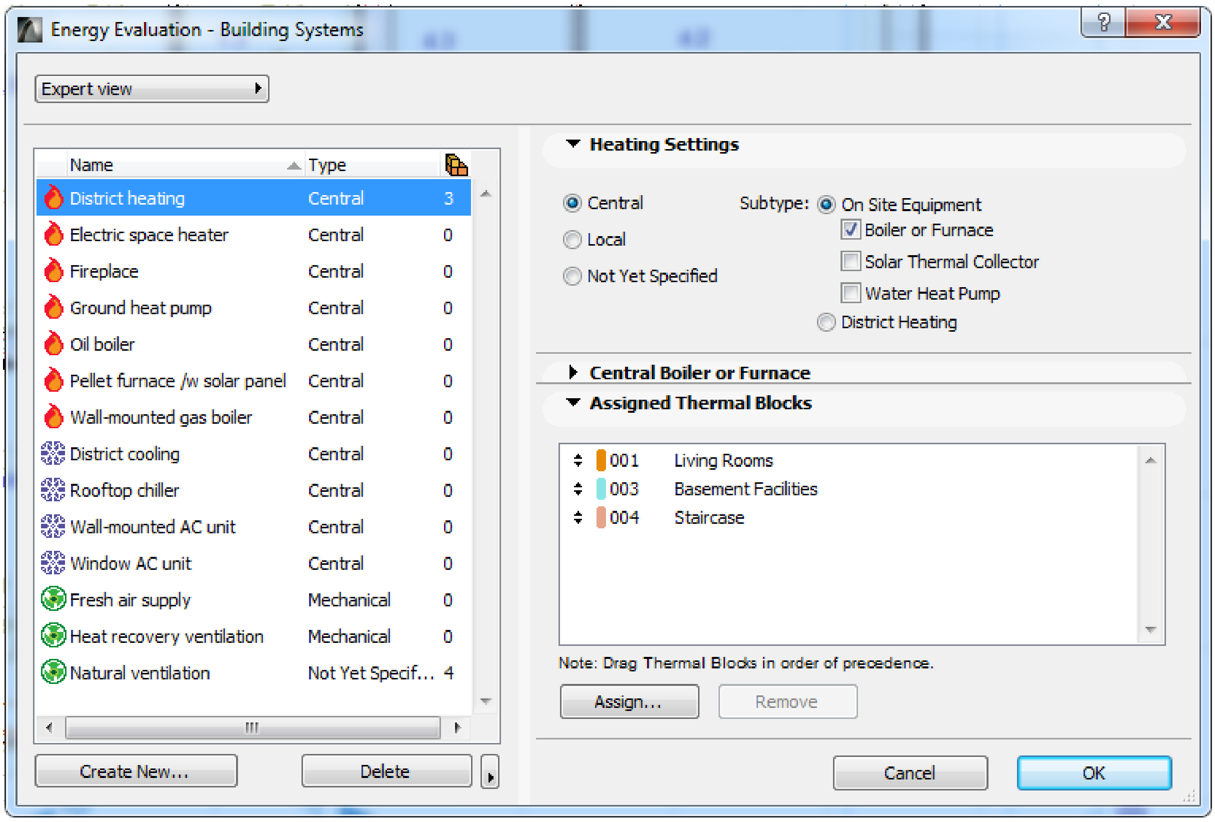


Fig. 21. The interface of selection and definition of supply building systems.

9.1.5 Definition of environmental settings

Environmental settings include geographic location (retrieved from project settings), information about climate data source, climate type (moist, dry, marine), soil type and its physical properties, percentage of ground reflectance, type of surrounding area, wind protection and horizontal shading (Fig. 22). Default settings allow to download climate data from Strusoft Climate Server based on geographic location. Another option is to use the specified ASHRAE IWEC, TMY or WTEC2 file data (Fig. 23).

Besides the geographic location of the building environmental settings include North orientation, elevation, wind protection, horizontal shading, climate data, soil type with physical properties, and etc. All information is stored within the BIM model.

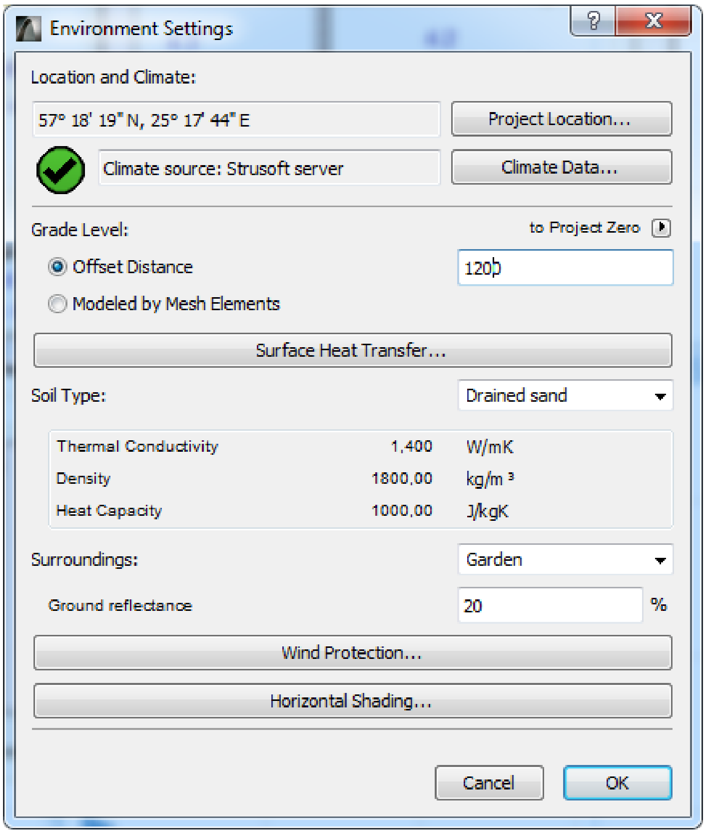


Fig. 22. The interface for the definition of environmental settings.

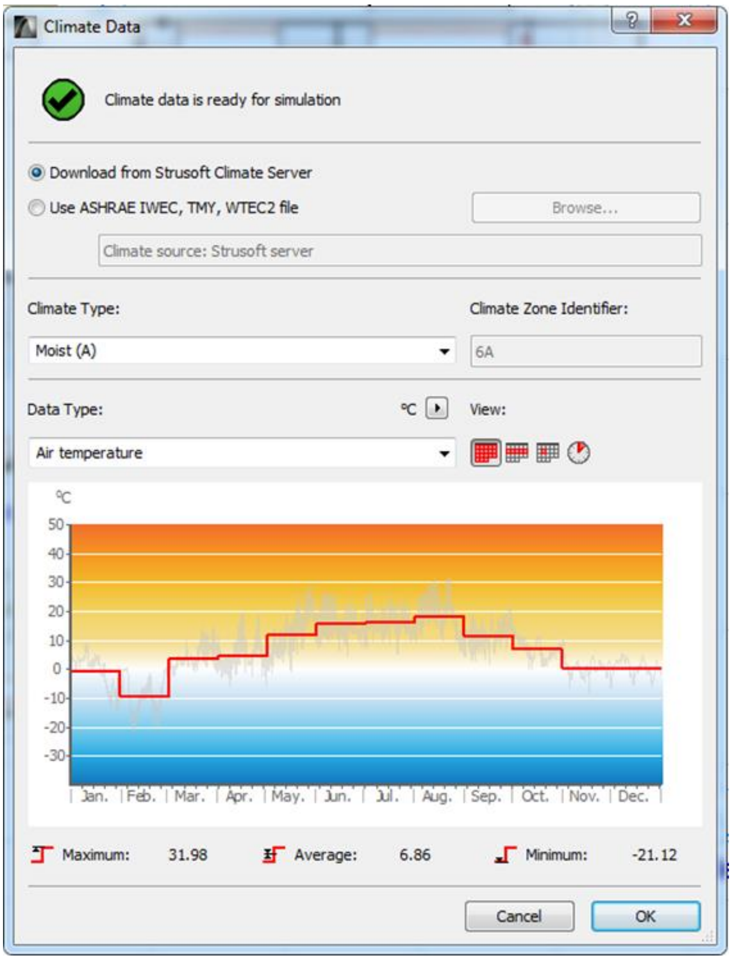


Fig. 23. The interface for the definition of climate data.

Wind protection was assessed during the on-site visit and defined as presented in Fig. 24.

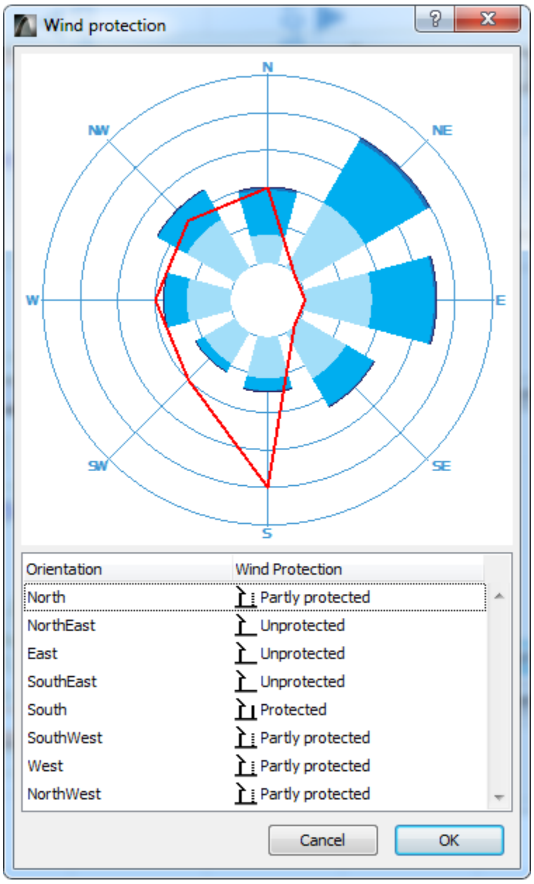


Fig. 24. The interface for the definition of wind protection properties.

Horizontal shading was assessed during the on-site visit and defined as presented in Fig. 25.

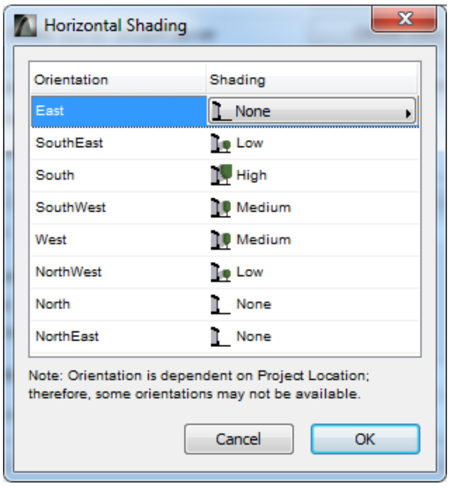


Fig. 25. The interface for the definition properties characterizing horizontal shading.

9.1.6 Definition of energy source factors

A key factor for energy sources is specifying how the electricity is produced. Combined sources may be defined if required (Fig. 26).

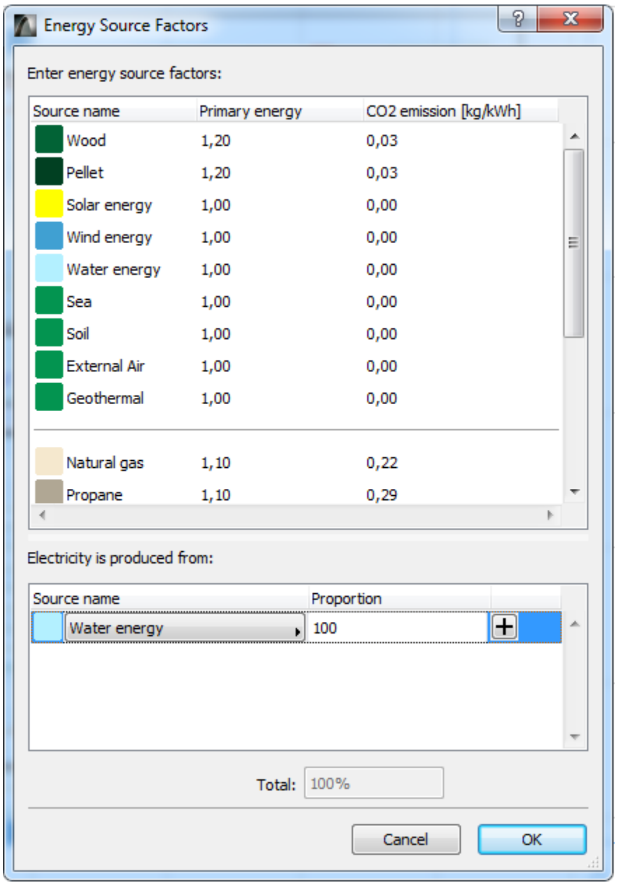


Fig. 26. The interface for the definition of energy source factors.

9.1.7 Definition of energy costs

Local energy costs have to be collected and updated (Fig. 27).

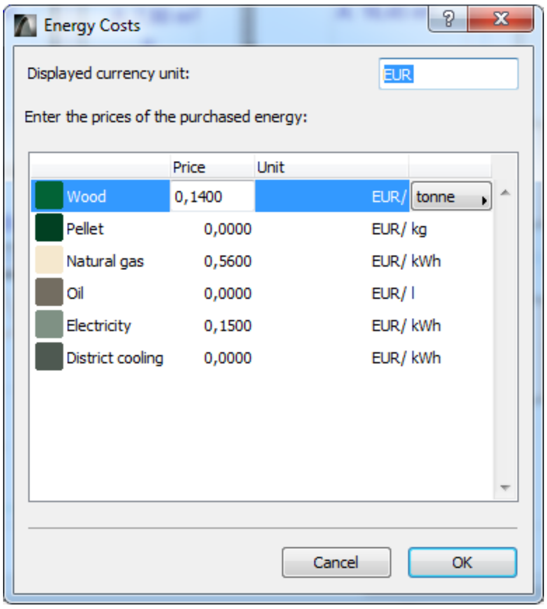


Fig. 27. The interface for the definition of energy costs.

9.1.8 Energy simulation options

Some other energy simulation options may be specified (Fig. 28).

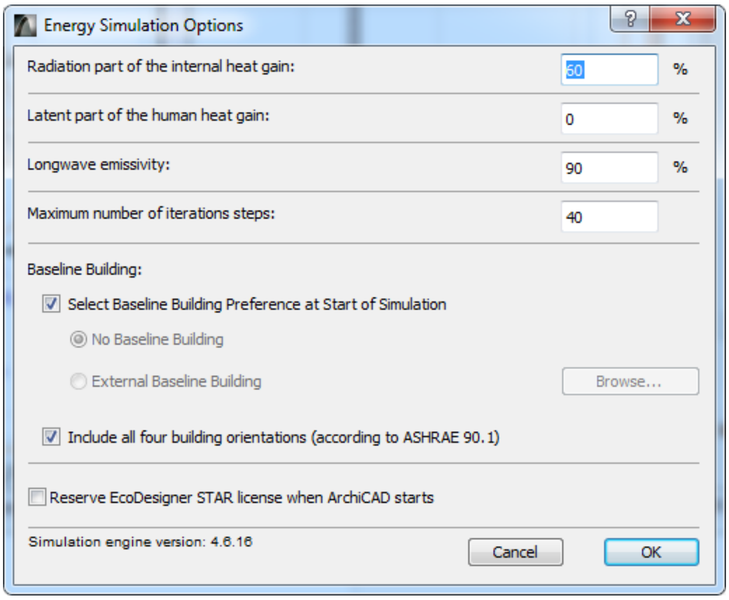


Fig. 28. The interface for the definition of energy simulation options.

A validation of BIM model confirms that the model has no geometric errors and the all the required data are sufficient for analysis.

9.1.9 Definition of thermal blocks

The energy model review palette is located in the main user interface for Energy Evaluation. It contains three tab pages that display input data for the building energy simulation. The tab pages to edit allow to modify the information about thermal blocks, structures and openings.

Thermal blocks in the building have to be defined at first. Thermal blocks are collection of one (in low fidelity model) or more (in medium or high fidelity model) zones or 3D spaces in the building that have similar orientation, operation profile and internal temperature requirements. 3D spaces are separated by building elements with intelligent physical properties and need not be contiguous to be combined within a single thermal block. Spaces in the BIM model are represented by 3D zones with an option to customize not only the height but also change their geometric form. Outer surfaces of the zones adopt the physical properties from the separating building materials.

More freedom to shape the geometric form provides BIM modellers rather than specialized energy analysis software where this could require several complex procedures or even may not be realized at all. Boolean operations performed on building elements in BIM modeller allow defining the natural boundaries between building elements more precisely. Thus thermal blocks may consist from non-cuboid 3D spaces.

Based on the geometry of the model 3D spaces are automatically defined by manual zone identification in each room. Four thermal blocks were defined in the model: 001 Living Rooms; 002 Attic; 003 Basement Facilities; 004 Staircase.

The properties of each thermal block allow to assign an individual supply building system for heating, cooling, and ventilation. In this study for living rooms a residential operation profile was selected with central district heating system which uses on-site equipment (boiler) and natural ventilation. Manual indication of zones added them to the selected thermal block. After regenerating or updating BIM model the 3D zones' boundary structural elements were automatically retrieved from the database including all openings (doors, windows, empty openings). The structural elements were generated in a single form, grouped for each block separately and listed as external and internal structures. Openings were generated in another form, grouped for each block separately and listed as doors and windows.

The interface for energy model review provides convenient visual feedback for checking the physical properties of selected building element and allows to check the consistency of the building energy model before the simulation is run (Fig. 29-30).

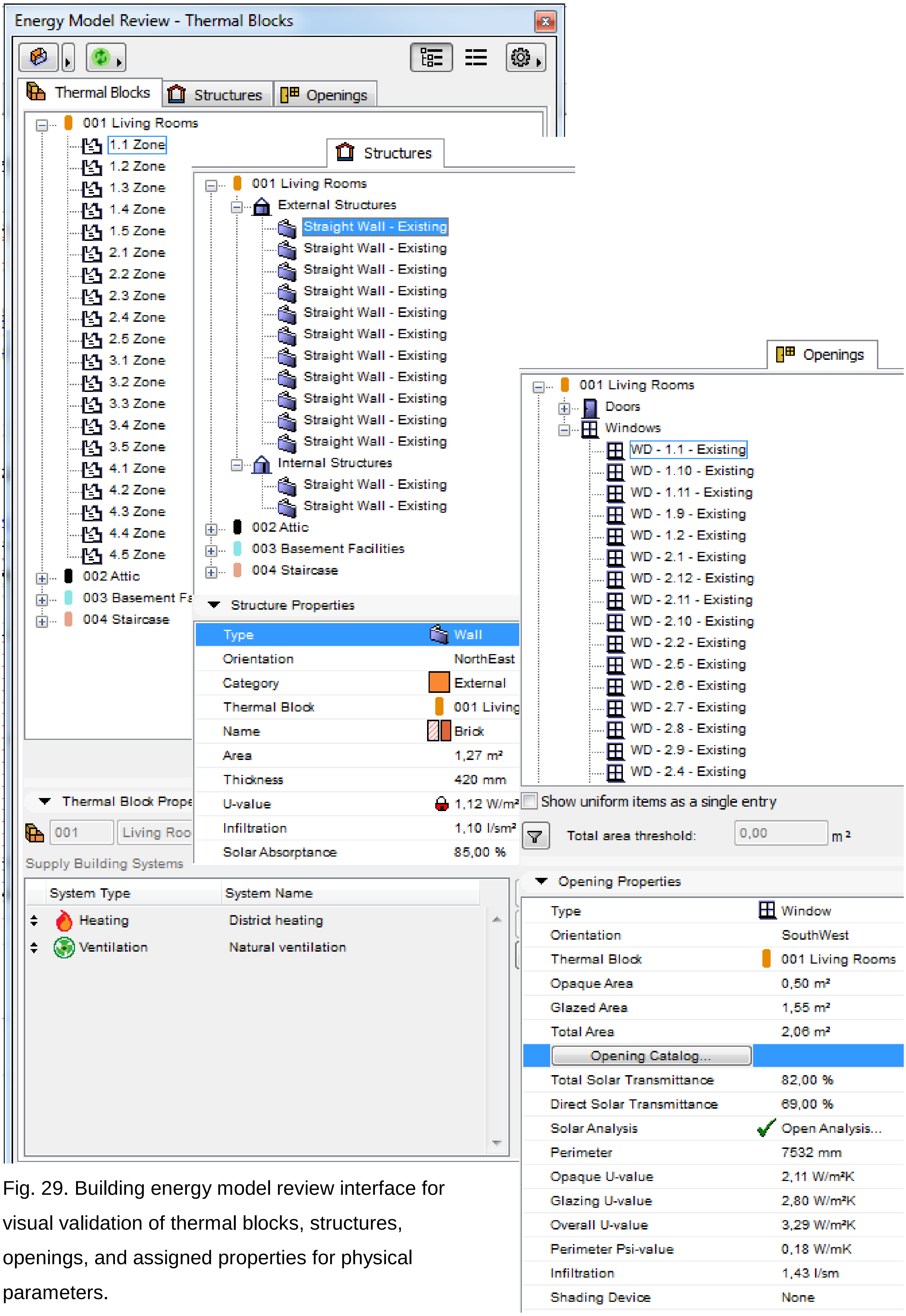


Fig. 29. Building energy model review interface for visual validation of thermal blocks, structures, openings, and assigned properties for physical parameters.

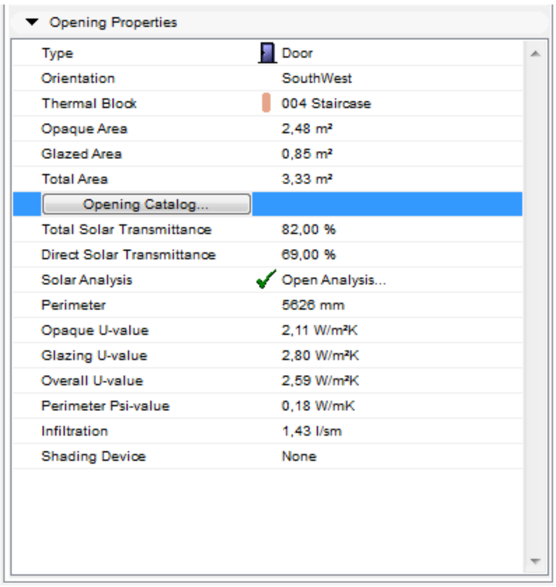


Fig. 30. The interface of properties setup for door openings (similar for windows).

More detailed setup of opening physical properties is shown in Fig. 31.

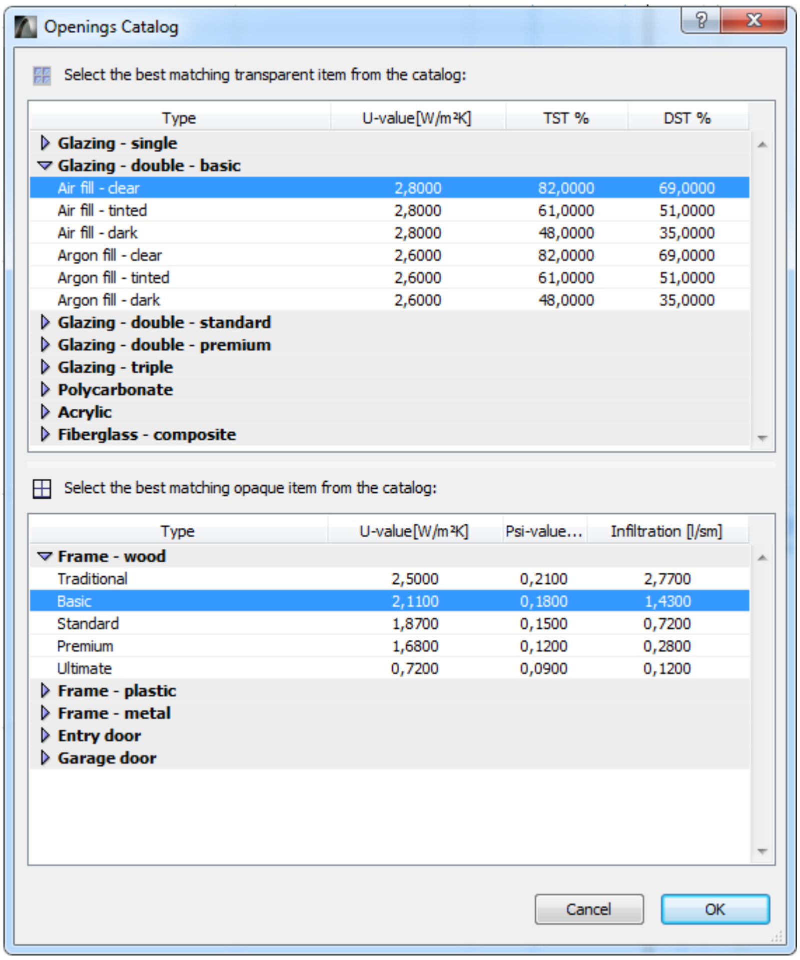


Fig. 31. The interface for physical properties setup of door and window openings from a catalog.

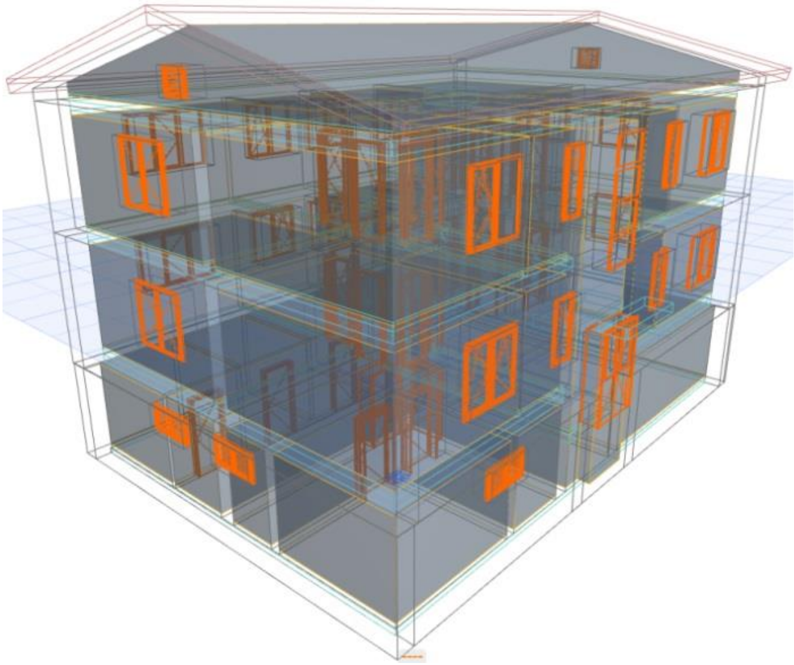


Fig. 32. Visual validation of identified 3D spaces (grey) combined in thermal blocks. Spaces are separated by building elements shown in wireframe mode in ArchiCAD BIM model.

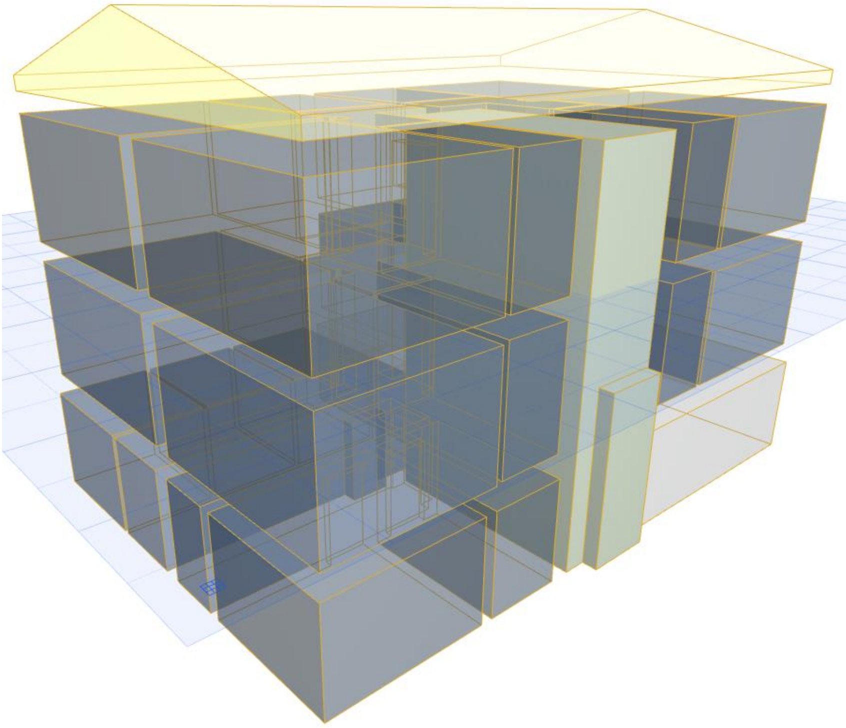


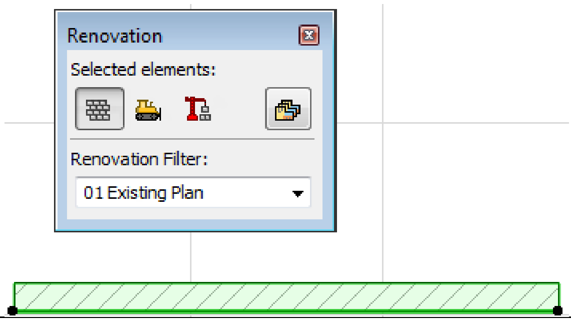
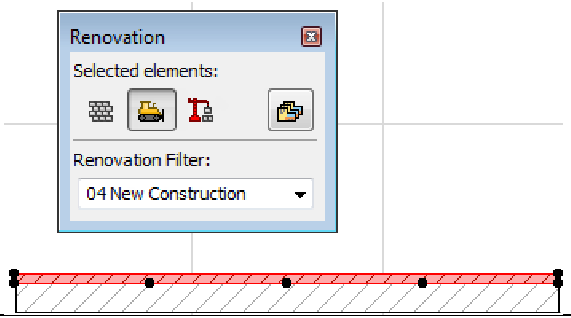
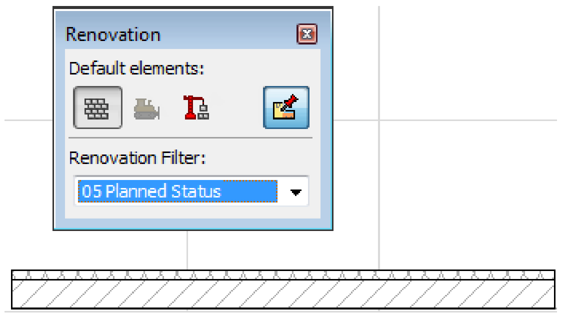
Fig. 33. Different thermal blocks may be marked with diverse colours.

9.1.10 Consideration of different remodelling variants

If a layer of insulation has to be added to the existing wall, simple insulation skins have to be defined to the existing composite wall. However, it is not possible to assign "New" status to just a single component of a wall – only to the wall itself.

An advanced option of renovation filter in the software may be used to distinguish a new insulation panel to be added to the original wall. The recommended workflow in this case is summarized in the Table 4.

Table 4. Suggested workflow for insulation panel model.

1.	Existing Plan View 1. In the Renovation Palette, assign the original wall a status of “Wall Existing Cēsis Saules 4A”.	
2.	New Construction View In this view both the Existing and the New components of the wall can be shown. 2. Alongside Wall 1 another placed wall (Wall 2) represents insulation. Define Wall 2 as “New”. This way, only the new part of the Wall – the insulation part – is displayed as “New” in this view.	
3.	Planned Status View 3. In planed status view both Wall 1 and Wall 2 are shown with their own original attributes.	

However, this approach causes additional work to be performed on the model because the holes for windows and doors are not added automatically and have be defined once again (Fig. 34).

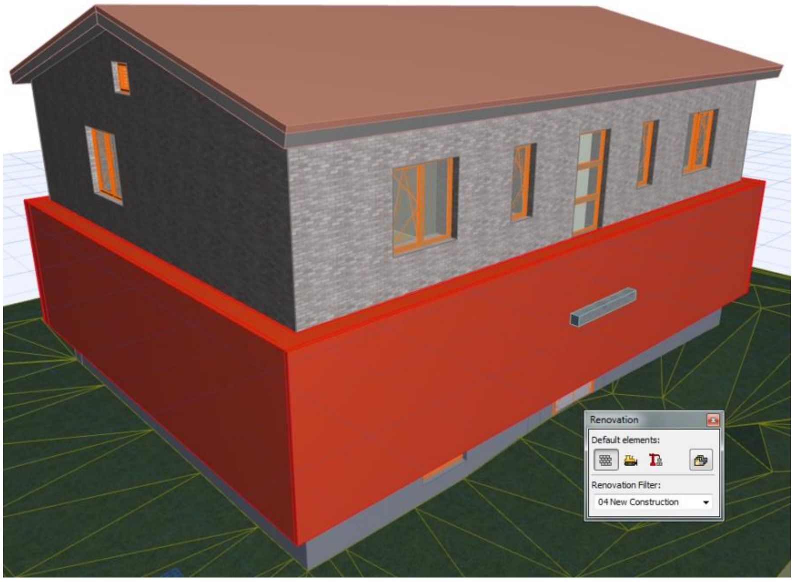


Fig. 34. The modelling approach using renovated visualization option requires extra work for window and door recreation and therefore is not recommended.

Another option does not allow to use the renovation feature for better visual feedback of project, therefore individual files have to be used for each variant of panel. BIM model of the renovated building may be straightforwardly set up by creating in the database another structural element of wall for which both a new geometry of wood panel element/s and new physical properties of the building materials used are added to the existing. Only the external walls in the former model need to be replaced provided the walls' reference lines for both wall elements are consistent. In this case the integrity of the rest of the model is not influenced and model automatically updates accordingly.

If the windows and doors are not replaced in the renovated building most likely their reveal distance to wall core has to be modified to keep consistency with the model of existing building. The software provides very wide range of handy tools for modifying wall reference line and core location. ArchiCAD provides handy visual feedback using renovation feature to assign special status for remodelled elements.

An example of a new composite wall created by adding to the existing wall new layers of wood panel is presented in Fig. 35. For each variant of the panel, a new file has to be saved. The energy analysis might be re-run repeatedly if different wood panel variants are considered.

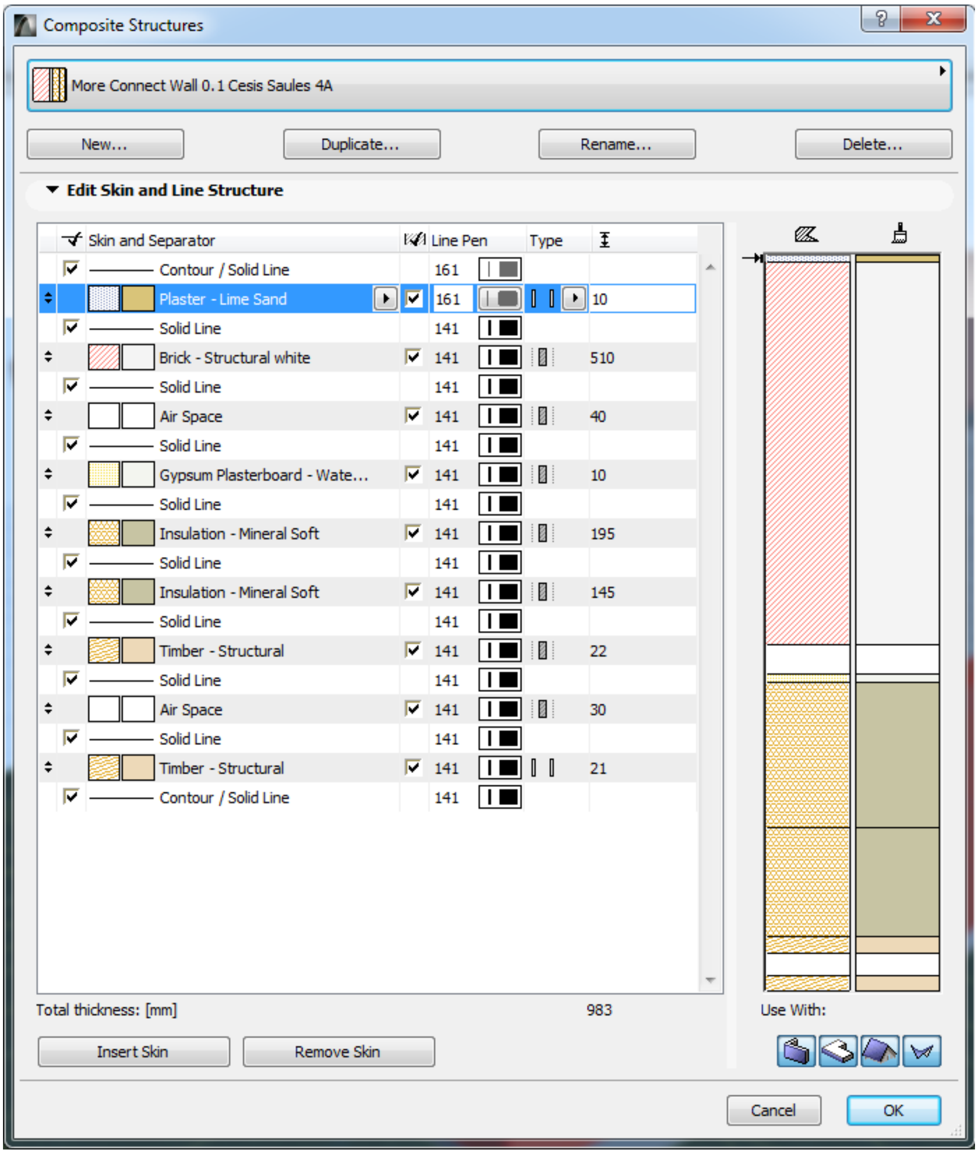


Fig. 35. Dimensions of layers in the composite wall representing the existing wall and the elements of insulation panel.

A daylighting performance highly depends on the design and if the existing windows will not be replaced some impairment of indoor lighting might be noticed as can be noticed in the visualization of the remodelled building (Fig. 36). It is also obvious that the geometry of the existing roof and gutter system will not satisfy the new design.

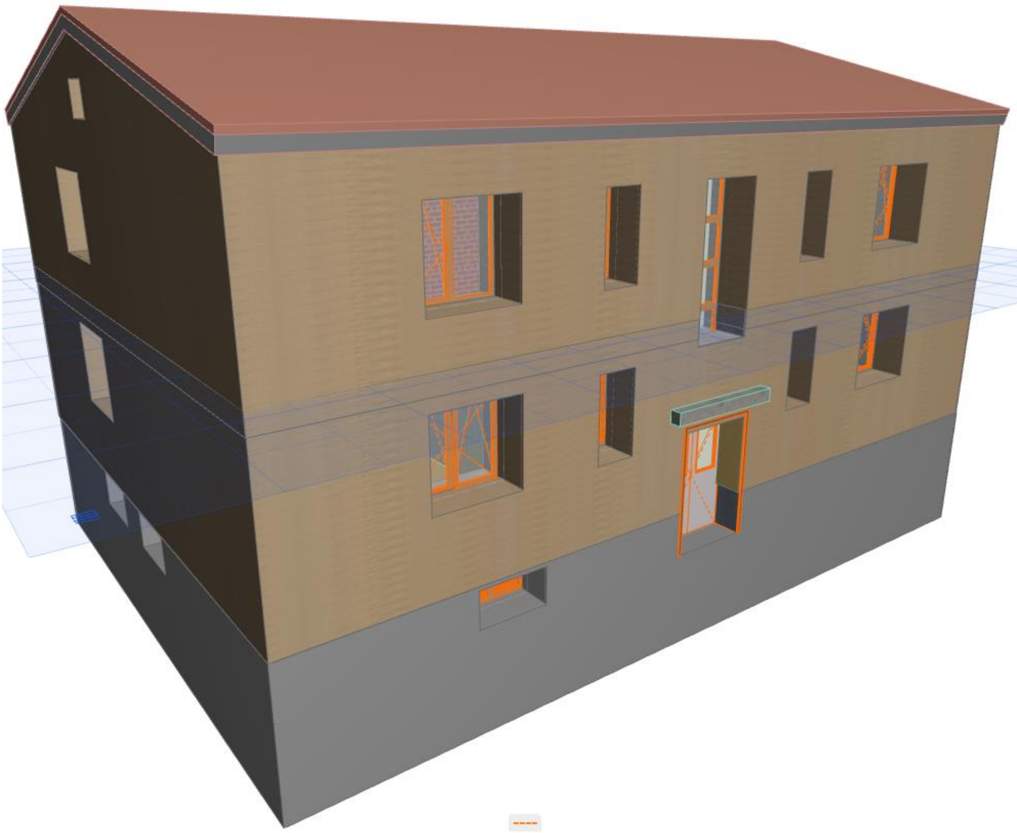


Fig. 36. Visualization of the building insulated with 463 mm thick wood panel including 40 mm air space separating existing wall.

High fidelity level of BIM model requires detailed drawings of the building elements which will allow thermal bridge simulations. For old existing buildings this information might be difficult to obtain and time consuming to consider in the model but it is possible.

9.2 External Energy Analysis

Data exchange formats have to be considered before information sharing and checked for model consistency. Theoretically the *.ifc or *.ifcxml file formats should cope flaw-less data exchange between different BIM applications. However, in practice not always this works fine. The prepared model exported in *.ifc format and imported into external IDA ICE software, which will be used in the future, in this study resulted in some missing elements or elements with corrupted geometry (Fig. 32). This requires extra time and efforts for identifying and fixing errors. Environmental settings does not come through and have to be redefined. None of the environmental settings or even geographic location information is stored in the default *.ifc data exchange filters and therefore this information has to be redefined from the scratch.

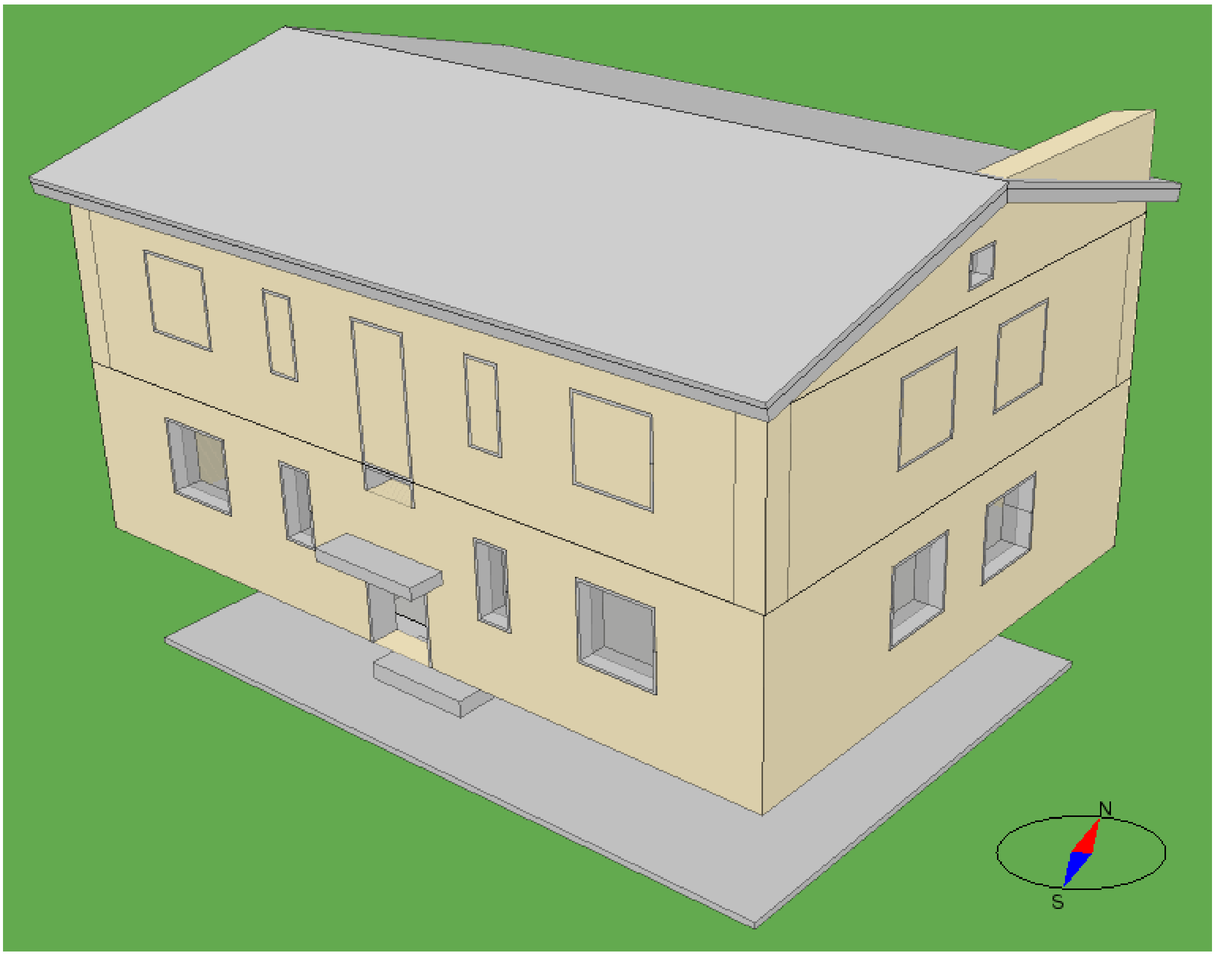


Fig. 34. The imported BIM model file in *.ifc format into IDA ICE (Indoor Climate and Energy) software shows some missing walls (foundation), missing entrance doors and windows, and corrupted geometry (wall not trimmed below roof).

10 Conclusions

Therefore the created 3D surface meshes can be used to create deliverables in the form of 2D drawings which may be imported into wide range of CAD or BIM applications. 3D model deliverables should be created using standard formats, such as *.ifc, or common ex-change formats like *.dxf to allow clients to retain as much data intelligence as possible. However, mesh models capture only the geometric properties of the building and are not suitable for direct use as BIM models.

Raw data obtained by laser scanning are referred as point cloud, which is a set of vertices in a 3D coordinate system. These vertices define or digitally represent xyz coordinates of the points of the external surface of the building. For most of the phase-based scanners, the raw scanning data are combined as both point and intensity, so the corresponding intensity image in both 2D and 3D can be obtained, which is useful for more detailed documentation and identification of objects. Data are stored in *.pts or *.e57 formats

A laser scanning process is the fastest method of 3D data acquisition for the existing buildings. The selection of the scanner type and scanning setup depends on the architecture or geometric complexity of the building elements.

The accuracy of the points in the point cloud and average spacing between points in the processed point cloud is within 3 mm range. The accuracy of the surface model automatically generated from the point cloud with standard algorithms is within 5-10 mm.

The accuracy of a manually traced BIM model of the building highly depends on the accuracy of point cloud and the experience and the skills of the modeller. The tested building example is very simple therefore in the case of realistic and more complex buildings more precise scan data might be required.

3D building model can be created on the basis of point cloud using REVIT or ArchiCAd ArchiCAD software. Building model data can be easily exported into energy simulation modules or separate software. In addition, data can be directly used for design and production of prefabricated thermal insulation panels. The most precise is manual creation of BIM model. However, it’s time consuming process. Full 3D model which takes into account all vertical displacement requires file size up to 10GB. Thus in practice simplified building models without vertical displacements are used.

The survey of three different buildings have shown vertical displacement of extremal wall is up to 40mm from foundation for 2-storey brick building, 48mm for 9-storey building and 20mm for 5-storey building. The maximal difference between different levels is 32mm.

BIM models in this study were produced directly from the point cloud data. Autodesk Re-Cap freeware was used to cope with different scan data file formats (*.rcp, *.rcs, *.e57) to share the data with Revit or ArchiCAD software. The point cloud was adjusted to the zero level of the ground floor and the slab height was referenced with respect to the window sill and corresponding room height dimensions retrieved during the on-site visit.

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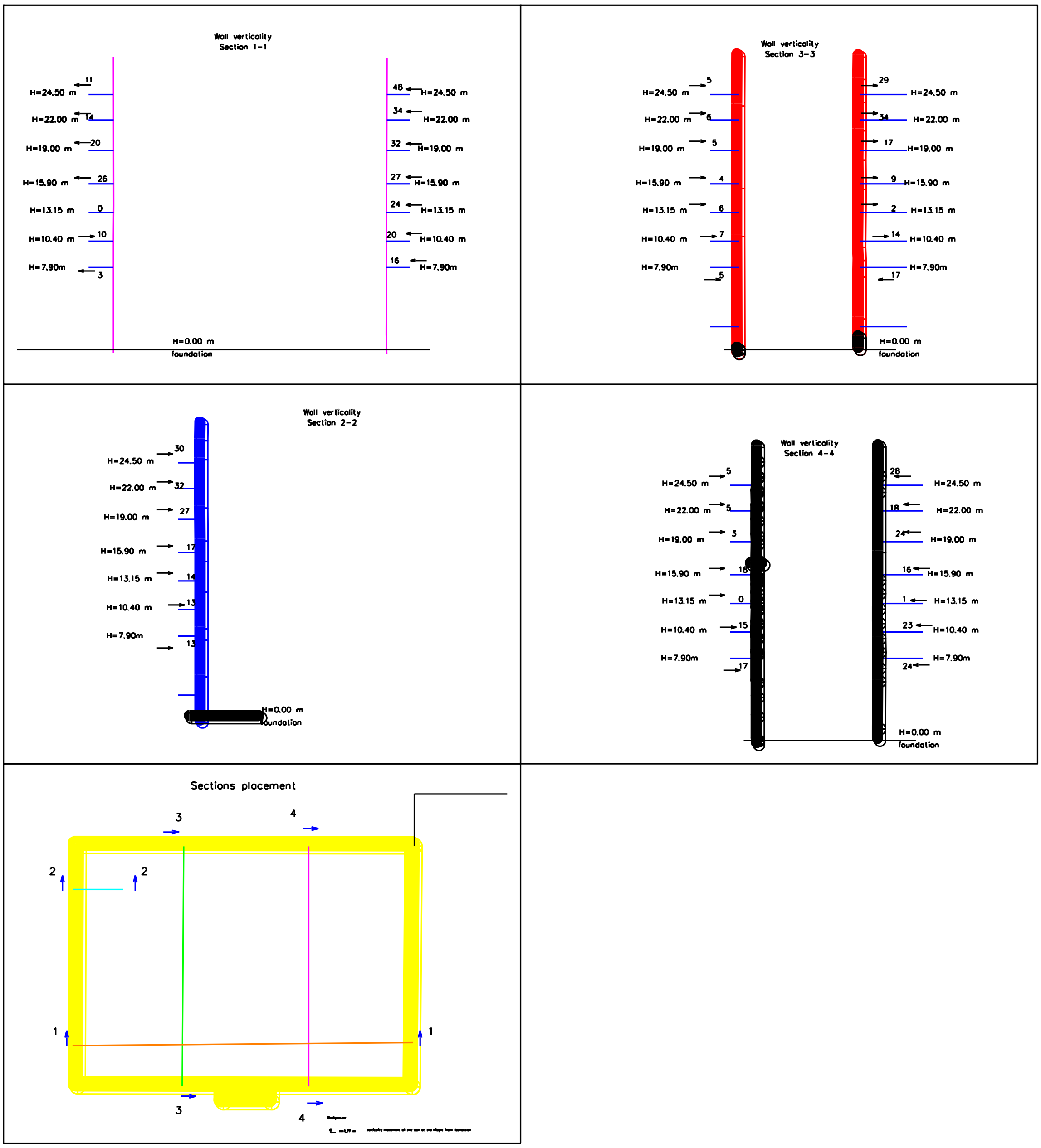
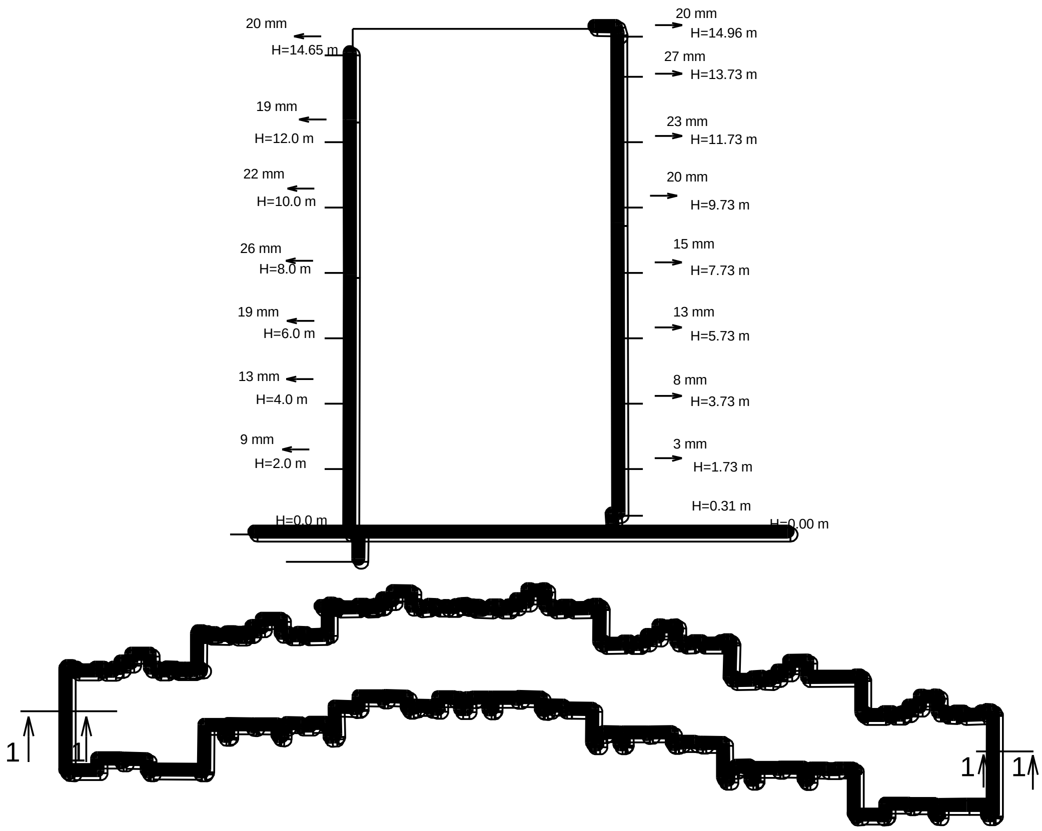
ANNEX 1 Vertical deviation

9 storey apartment building



5 storey panle building



ANNEX 2 Measures and traced surfaces