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BECK

INTEGRATING EDUCATION WITH CONSUMER BEHAVIOUR RELEVANT TO ENERGY EFFICIENCY AND CLIMATE CHANGE AT THE UNIVERSITIES OF RUSSIA, SRI LANKA AND BANGLADESH

WP2 - TEACHING (LEARNING) MATERIALS: SIMULATION OF CONSTRUCTION MANAGEMENT STRATEGIES FOR ENERGY EFFICIENCY

TalTech

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SIMULATION OF CONSTRUCTION MANAGEMENT STRATEGIES FOR ENERGY EFFICIENCY - TEACHING (LEARNING) MATERIALS

Revision of June 14, 2021

Contents

Introduction

The Simulation of Construction Management Strategies for Energy Efficiency module involves a multiple criteria simulation game in which the (BIM) information model of a building is used as the basis for simulating different solutions. Energy efficiency indicators and outcomes determine the value of solutions over the whole building life. The students work in stakeholder-based groups to develop, argue and present solution proposals and work out compromise solutions with a focus on energy efficiency.

The module promotes the development of a green built environment by enabling students:

- To experiment with different solutions and evaluate the effectiveness of alternative options.
- To get insights into the roles and interests of all the construction industry stakeholders including users in construction projects and into how their decisions, actions and behaviours influence the energy efficiency of buildings.
- To develop teamwork skills and abilities for critical discussion and argumentation to optimise solutions and find compromises.

Module details

Programmes in which the module is offered: Construction Management
Structural Engineering
Architecture

Level: MSc / PhD
Module title: Simulation of Construction Management Strategies for Energy Efficiency
Module credits: 6 ECTs
Semester(s) in which to be offered: Autumn
Indicative learning hours: 160 hours (20 hrs lectures; 140 hrs independent / group work)

Aims and intended learning outcomes of the module

Aims of the module

To enable students to understand the roles of different stakeholders, their interests and how each stakeholder influences the overall value of the built environment with regard to energy efficiency and climate change.

Intended Learning outcomes and assessment

Learning Outcomes of the module Students will:	**Methods of studies**	**Assessment methods of student achievements**	**Assessment criteria for students achievements by assessment levels**
O1. Understand the different interests of stakeholders in achieving energy efficient buildings.	Blended learning, integrated affective tutoring and affective computing methods. The Integrated Method include the computer learning systems, big data mining, affective tutoring system, access to e-sources (open-source videos, simulators (calculators and software), case studies from the best universities around the world), self-study in Moodle virtual environment (educational material including Video – audio material, Text material; Interaction in forums for building learning community; Exercises with integrated feedback mechanism); Live events (video conferencing)	☒ Problematic questions ☐ Intelligent tests ☐ Regular tests ☒ Problematic tasks ☒ Projects ☒ Peer evaluation ☐ Automated feedback ☐ Final evaluation ☐ Other	*Threshold achievement level* Knows the concepts, theories and perspectives of different stakeholders with regard to the green built environment, energy efficiency and climate change, but is not able to explain and apply in wider context *Typical achievement level* Able to explain and apply the concepts, theories and perspectives of different stakeholders with regard to the green built environment, energy efficiency and climate change. *Excellent achievement level* Able to explain and apply the concepts, theories and perspectives of different stakeholders with regard to the green built environment, energy efficiency and climate change in wider context
O2. Be able to argue their points of view and justify the decisions made.	Blended learning, integrated affective tutoring and affective computing methods.	☒ Problematic questions ☐ Intelligent tests ☐ Regular tests ☒ Problematic tasks ☒ Projects ☒ Peer evaluation ☐ Automated feedback ☐ Final evaluation ☐ Other:	*Threshold achievement level* Able to research and make decisions in the development of context-relevant solutions for the green built environment in relation to energy efficiency and climate change by using modern ICT technologies at

			a basic level
			Typical achievement level Able to research and make decisions in the development of context-relevant solutions for the green built environment in relation to energy efficiency and climate change by using modern ICT
			Excellent achievement level Able to research and make decisions in the development of context-relevant solutions for the green built environment in relation to energy efficiency and climate change by using modern ICT at an advanced level
O3. Have gained near real-life experience in decision-making, communication and teamworking to achieve energy efficiency in buildings.	Interactive group work in developing context-relevant solutions.	☐ Problematic questions ☐ Intelligent tests ☐ Regular tests ☒ Problematic tasks ☐ Projects ☒ Peer evaluation ☐ Automated feedback ☒ Final evaluation ☐ Other:	*Threshold achievement level* Has basic skills to develop, communicate, manage and negotiate context-relevant solutions for the green built environment in relation to energy efficiency and climate change.
			Typical achievement level Has intermediate skills to develop, communicate, manage and negotiate context-relevant solutions for the green built environment in relation to energy efficiency and climate change.
			Excellent achievement level Has advanced skills to develop, communicate, manage and negotiate context-relevant solutions for the green built environment in relation to energy efficiency and climate change.

Learning and Teaching Strategies

This MOOC contributes to opening access to education for the benefit of both of learners and wider society while reflecting values such as equity, quality and diversity. The course learning strategy features:

- Openness - open entry (no formal pre-requisites), freedom to study at any time and in any place, the course is accessible to the widest diversity of students possible. Course activities, tasks and routes are designed in such way that they can be performed at different levels of difficulty or complexity, to account for a broad spectrum of students' knowledge and skills.
- A learner-centred approach - the course helps students to construct their own learning from a rich environment, and to share and communicate it with others.
- Independent learning - the MOOC enables an independent learner to progress through self-study. The course provides learners with regular feedback through self-assessment activities, tests or peer feedback. The MOOC includes possibilities for students to follow their scores and progression.
- Media-supported interaction - course materials make best use of online affordances (interactivity, communication, collaboration) as well as rich media (video and audio) to engage students with their learning and sufficient interactivity (learner to content, learner to learner and learner to teacher) to encourage active engagement. Feedback of academic tutors is limited and scalable.
- Recognition - successful course completion will be recognised as indicating worthwhile educational achievement and certificated.

The innovative Simulated Big Data Interuniversity Networked Affective Educational Centre (BECK Centre) will enable the delivery of the MOOC within the Moodle learning environment.

The pedagogical model of the course is such that the efforts of all services do not increase significantly as the number of participants increases. All aspects of the course are delivered online. Learning outcomes are assessed using a balance of formative and summative assessment appropriate to the level of certification.

The course teaching strategy is to provide all learning materials in a clearly-structured and easy-to-understand way online. These materials will be available on Moodle and will include:

- Relevant background information.
- Overall objectives and work-flows for the simulation game.
- Stakeholder descriptions detailing their scope of work, work-flows, commercial interests, responsibilities.

In order to apply what they have learned, students are required to develop solutions in groups. These may be virtual (online) groups, colocated groups or mixed groups (incorporating both online and colocated students). However, group members must work concurrently and within a specified time. The solutions developed by student groups will form inputs to other student groups and the effectiveness and quality of each developed solution will be primarily peer assessed by the group receiving the work as an input to their own work.

Module assessment and grades

Assessment components (in chronological order of submission/examination date)				
Type of assessment	Weight %	Duration *(if exam)*	Word count *(if essay or similar):*	Component pass required
Assessment of the participation of the students, their input to group activities and satisfactory group outputs	20%			Yes ☒ No ☐
Individual reflection on learning	10%		500 words	Yes ☒ No ☐
Group peer evaluations	40%			Yes ☒ No ☐
Group presentations	30%	30 minutes		Yes ☒ No ☐
Total:	100%			

Recommended Software

Students are expected to have access to and to use the following software or equivalent. The course does not offer any direct instruction in the use of these software packages - assistance with software use is avaiable from external sources (e.g. YouTube tutorials) as well as from student peers.

No.	**Software, manufacturer**
1.	Autodesk Revit
2.	Autodesk Navisworks Manage
3.	MS Excel
4.	Adobe Acrobat reader

Syllabus outline

#	**Topic**	**Number of hours**
1.	Introduction to the module	5
2.	Building user behaviour modelling for energy efficiency	10
3.	Client's objectives and information requirements	10
4.	Designers' objectives and information requirements	10
5.	Construction objectives and information requirements	10
6.	Facilities management objectives and information requirements	10
7.	Other stakeholders' objectives and information requirements	10
8.	Setting energy efficiency optimization criteria and functions	10
9.	Project simulation	50
10.	Energy optimization	20
11.	Feedback and reporting	15
Total:		**160**

Teaching and Learning Materials for each Topic

1 - Introduction to the Module

Reading: Simulations in Construction Education

Simulation games are widely used in the study process (Sacks et al. 2007, Lam 2018, Nikolic 2011, Lee at al. 2011, Castronovo et al. 2015, González et al. 2015, Construction Simulator Pro 2017). For example, Lam (2018) developed sustainability performance simulation tools for building design. It is a physics-based software for simulating building energy use, taking as inputs the building description including geometry, construction materials, lighting, HVAC, refrigeration, water heating, renewables, and control strategies. Sacks et al. (2007) developed The Technion LEAPCON™ (Technion Lean Apartment Construction) game, which simulates construction of an eight story building with four apartments on each floor. It was initially developed to test the impact of a Lean management model that was proposed in response to the significant waste identified in the conventional approach to scheduling and managing construction of high-rise residential buildings. It was found to be an excellent tool for introducing project managers, site engineers, supervisors, senior management, and students at all levels to some of the basic concepts of lean construction: single-piece vs. batch flow, pull vs. push scheduling and control, and multi-skilling vs. task specialization.

The Simulation of construction management strategies for energy efficiency module is composed of following topics:

- Building user behaviour modelling for energy efficiency
- Clients' objectives and information requirements
- Designers' objectives and information requirements
- Construction objectives and information requirements
- Facilities management objectives and information requirements
- Setting energy efficiency optimization criteria and functions
- Project simulation
- Energy optimization

Aim and key learning outcomes of this topic

The aim of this topic is to ensure students understand the module objectives, scope and protocols, how they can access course content and it serves to manage students' expectations for the module.
On completion of this topic, students will:

- Be able to access all relevant module information and materials;
- Understand the scope of the module;
- Appreciate the relevance of the module to them as construction professionals.

2 - Building user behaviour modelling for energy efficiency

Reading: Building user behaviour modelling for energy efficiency

Simulations games and tools for energy efficient behavior are developed by various researchers (Konstantakopoulos et al. 2014, Mondrup et al. 2014, Fernández-Cerero et al. 2019, Garwood et al. 2018, International Building Physics Toolbox 2019, Mathworks 2019, Alwisy et al. 2018, Mahmud et al. 2018, Ceballos-Fuentealba et al. 2019, Porcar et al. 2018). Konstantakopoulos et al. (2014) developed the social game for building energy efficiency. The purpose is to encourage energy efficient behavior amongst building occupants with the aim of reducing overall energy consumption in the building. Occupants vote for their desired lighting level and win points which are used in a lottery based on how far their vote is from the maximum setting. Mondrup et al. (2014) describe a methodology for adopting Building Performance Simulation (BPS) tools as energy and environmentally conscious decision-making aids. The methodology has been developed to screen buildings for potential improvements and to support the development of retrofit strategies.

Fernández-Cerero et al. (2019) present a new simulation tool for cloud computing, GAME-SCORE, which implements a scheduling model based on the Stackelberg game. This game presents two main players: a) the scheduler and b) the energy-efficiency agent. We used the GAME-SCORE simulator to analyse the efficiency of the proposed game-based scheduling model.

Significant benefit can be gained by utilising simulations in order to predict energy demand allowing companies to make effective retrofit decisions based on energy as well as other metrics such as resource use, throughput and overhead costs (Garwood et al. 2018). International Building Physics Toolbox (IBPT) (International Building Physics Toolbox 2019) is a free and open-source toolbox containing a library of blocks used for thermal modelling of buildings by considering the building construction, thermal zones, systems such as HVAC, internal building gains and additional parameters to fully define building construction elements or climate data. The IBPT is used to model the interaction of these five elements through a block flow diagram, the behaviour of which is then simulated, using a time-based approach, using Simulink (Mathworks 2019).

BEM is traditionally used to analyse a thermal building envelope and is widely used for residential and commercial building assessment (e.g. DesignBuilder (https://www.designbuilder.co.uk/), EnergyPlus Simulation Engine (https://energyplus.net/), Green Building Studio (https://gbs.autodesk.com/GBS/), International Building Physics Toolbox (IBPT) (http://www.ibpt.org/index.html), Integrated Environmental Solutions (IES) Virtual Environment (VE) (https://www.iesve.com/), Modelica Buildings Library (https://simulationresearch.lbl.gov/modelica/) and Sefaira (https://sefaira.com/)). MPS is traditionally used to optimise a manufacturing process line by assessing parameters such as machine utilisation and throughput (e.g. AnyLogic (https://www.anylogic.com/manufacturing/), Arena (https://www.arenasimulation.com/industry-solutions/industry/manufacturing-simulation-software?/industry-solutions/manufacturing-simulation-software), DELMIA (https://www.3ds.com/products-services/delmia/), FlexSim (https://www.flexsim.com/), Simio (http://www.simio.com/applications/manufacturing-simulation-software/)).

Alwisy et al. (2018) introduces an energy-based target cost modelling framework (eTC) that achieves the balance between project cost and performance metrics through the combination of target costing principles and energy analysis techniques. The introduction of standardized energy factors, utilisation of energy simulation, and implementation of statistical analysis results in the development of energy-based mathematical models capable of efficiently evaluating construction system alternatives. Rule-based analysis is then employed to automatically select the construction system(s) that yield an optimised energy consumption according to a targeted cost and defined set of performance criteria (Alwisy et al. 2018).

In residential-energy-systems research, the most common areas are load modeling and control, renewable energy integration, energy optimization, energy cost analysis, power quality analysis, home-to-grid (H2G) bidirectional energy transfer analysis, and electrical protection systems analysis. It is important to analyze the energy modeling and management concept before its real implementation (Mahmud et al. 2018).

A pictorial representation of the tools categorized based on their applications to model and analyze building electrical loads is in Fig. 1. All tools are color coded based on their availability, i.e. free, commercial, limited, and open source. Free tools are available to download and by all types of users. Commercial tools are not freely available, however most of the commercial tools offer a free demonstration version with limited features for a particular duration. Limited tools are only freely available for a particular organization, or a group of people. Open-source tools are freely available to download, use, and also to develop the source code. (Mahmud et al. 2018)

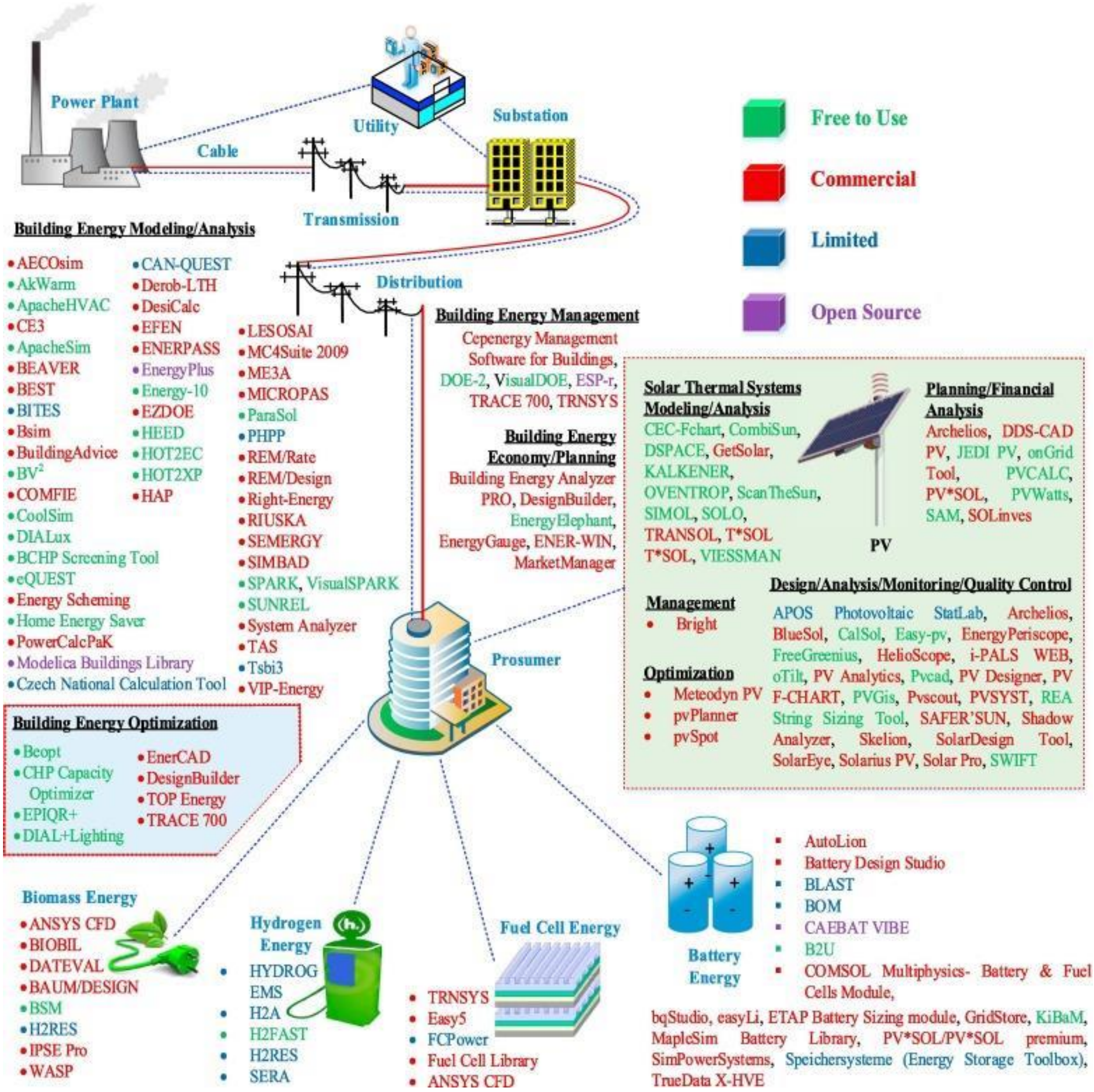

Figure 1. Residential energy systems simulation tools categorized based on their applications and availability.

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Mahmud, K., Amin, U., Hossain, M. J., & Ravishankar, J. (2018). Computational tools for design, analysis, and management of residential energy systems. Applied Energy, 221, 535-556.

Mathworks. 2019. Simulink – simulation and model-based design; n.d.〈https://uk.mathworks.com/products/simulink/index.html?S_tid=gn_loc_drop〉

Mondrup, T. F., Karlshøj, J., & Vestergaard, F. (2014). Building Performance Simulation tools for planning of energy efficiency retrofits. In 10th Nordic Symposium on Building Physics. Lund University.

Porcar, B., Soutullo, S., Enriquez, R., & Jiménez, M. J. (2018). Quantification of the uncertainties produced in the construction process of a building through simulation tools: A case study. Journal of Building Engineering, 20, 377-386.

Aim and key learning outcomes of this topic

The aim of the second topic is to ensure that students understand the different interests of building users, their use behaviours and how to model these for achieving energy efficient

buildings. (Contributes to overall Learning Outcome O1: Students will understand the different interests of stakeholders in achieving energy efficient buildings.)
On completion of this topic, students will:

- Appreciate the interests of building users
- Appreciate different building user behaviours
- Be able to model building user behaviours for energy efficiency solutions.

Assessment

Formative assessment in the form of quiz questions to check familiarity and comprehension of the readings provided.

Recommended sources of further information

ZERO Code Energy Calculator: https://zero-code.org/energy-calculator/
Home Energy Calculator:
http://c03.apogee.net/calcs/rescalc5x/Question.aspx?hostheader=singingriver&utilityid=singingriver
Saving money on lighting:
https://c03.apogee.net/mvc/home/hes/land/el?spc=lcc&utilityname=singingriver
Selection of renewable energy system:
http://www.vaillantrenewables.co.uk/homeowner/index

3 - Client's objectives and information requirements

Reading: Client's objectives and information requirements

BIM adoption has been on a steady increase since 2007 (McGraw Hill Construction 2012). In 2007, 28% of the industry adopted BIM, almost half (49%) in 2009 and 71% in 2012. In 2012, 70% of architects, 67% of engineers, and 74% of contractors were implementing BIM. Another McGraw Hill Construction (2014a) survey of contractors around the world reported that half of the contractors in the USA and Canada have been using BIM for 3–5 years and 8% for over 11 years. The demand for BIM from public and private owners has also been a factor that has encouraged these fast adoption rates amongst design and construction companies. In 2014, one- fourth of the owners in the USA required use of BIM while 43% encouraged but did not require BIM use (McGraw Hill Construction 2014b). Several government entities, like the US General Services Administration (GSA), have required implementation of BIM on all new projects (U.S. General Service Administration 2007, Moreno et al. 2019).

Organizational and people centered issues pose the greatest challenge for Building Information Modeling (BIM) implementation. Maturity and adoption of BIM depends mainly on the client or the owner in construction projects. Public sector clients often think that the market is not ready for BIM and are afraid to increase project costs by limiting competition. (Porwal, Hewage 2013).

In public sector, central issue is moving from a low-bid process to any of the other alternative project delivery methods. As the public sector client is accountable to the public, an open competitive bidding process, that is awarded based only on price, is highly preferable. However, selecting a contractor based solely on price greatly diminishes the significance of importance of criteria, such as time and quality, which does not guarantee a maximum value (U.S. Department of Transportation 2012). Low bid price as the sole award criterion encourages unqualified contractors to submit bids (Herbsman, Ellis 1992) along with bidders that submit a very low bid with the intent of recovering their losses through change orders and claims, also known as predatory bidding (Crowley, Hancher 1995). Therefore, low bid is not necessarily the ‘best value’ for the owners. The means of obtaining the ‘best value’ under this system is to award a contract to the responsive and compliant bidder, that is willing to fulfill the terms of the contract, for the lowest dollar value with innovative ideas.

Institute for BIM in Canada suggested that one way to facilitate BIM adoption may be to make BIM a mandatory requirement for public projects (Institute for BIM… 2012). Moreover, it was recommended to develop supplements to existing contract and procurement documents (French Centre for automation of Organizations…2011). Public sector is more focused on administrative decision making, where using BIM is not their first priority, but only one of many responsibilities (French Centre for automation of Organizations…2011). Thus, it becomes important to review and evaluate the current performance of the procurement process, to ensure that public sector obtains a greater value for the money in their construction projects. No such methodology, framework, or analysis in public procurement with BIM is available in the published literature. BIM's usage will certainly increase in the future, especially with its' eventual adoption by the public sector; with appropriate project delivery methods that seek to make the most efficient use of a collaborative BIM model.

For public organizations, especially in democratic countries like Canada, there are political sensitivities, deadlines, quality requirements, and strict budgets. This research was aimed to focus on the following questions to position BIM adoption in the public sector:

- How BIM process can be smoothly introduced to the existing public procurement system?
- Is it possible to achieve maximized benefits out of BIM, through a coordinated modeling process, during the project design phase?
- How the contractor could be involved early in the modeling process along with the design team?
- Can interoperability issues be handled with Industry Foundation Class (IFC)?
- What are the available BIM guidelines in other countries to handle legal, intellectual property, and copyright issues?

Green Public Procurement (GPP) plays an important role in facing the challenge of reducing the environmental impacts from construction sector-related products, services and works, and creating environmental and innovative value for society in favour of a greener and more sustainable economy. Table 1 presents the literature review in the field of Green Public Procurement (GPP) that deals specifically with the construction sector (Braulio-Gonzalo, Bovea 2020). Varnäs et al. (2009) found that environmental criteria are usually considered as requirements but rarely affect the award decisions set by the contracting authorities due to a fear of project delays, the desire to simplify the project and the risk of incurring in increased costs and limitations. Uttam and Balfors (2014) provided an overview of the growth of GPP among several European countries and beyond Europe, and highlighted the need for the bidder to demonstrate, before the contract is awarded, the ability to comply with the stipulated criteria. In another step, Uttam and Le Lann Roos (2015) analysed the consequences of changes in the weight of environmental requirements on contract award decision-making, and revealed that increasing this weight might not always ensure that GPP is implemented correctly. Also in relation to the weight of the criteria, Testa et al. (2016) determined that technical specifications and award criteria are the ones that include the most environmental requirements. Some other research has been carried out on specific case studies related to the construction sector: wooden windows (Tarantini et al., 2011), lighting systems (Deambrogio et al., 2017), educational buildings (Fuentes-Bargues et al., 2018) or net-zero energy buildings (Sparrevik et al., 2018). Finally, with a more general approach regarding geographical and application scope, Montalbán-Domingo et al. (2018) identified the need to develop policies to promote the use of social and environmental criteria, together with metrics, in the awarding of the evaluation of projects in the construction industry.

Table 1. GPP Literature review within the construction sector (Braulio-Gonzalo, Bovea 2020)

Author/s	Country	Research method	Purchasing type	Tender analysis	No. Tenders analysed	Scope: Construction sector in general	Scope: Educational buildings	Scope: Office buildings	Scope: Civil works	Scope: Construction materials/ elements	Scope: Building and demolition waste	Scope: Construction sector stakeholders	Purpose: GPP effects/ insights	Purpose: GPP policy	Purpose: GPP uptake level
Sterner (2002)	SE	Interviews, survey	W							●	●	●	●	●	
Varnäs et al. (2009)	SE	Interviews, survey	W			●						●		●	●
Tarantini et al. (2011)	IT	LCA	P							●			●	●	
Uttam and Balfors (2014)	SE,PL,NL,NZ,KR	Qualitative analysis	W							●			●	●	●
Uttam and Le Lann Roos (2015)	SE	Interviews, multicriteria analysis, case study	W	●	3				●					●	
Testa et al. (2016)	IT	Interviews, qualitative and statistical analysis	W	●	164	●								●	●
Deambrogio et al. (2017)	IT	Case study	P,S							●			●	●	
Fuentes-Bargues et al. (2017)	EU, ES	Qualitative and quantitative analysis	W	●	100	●			●				●		●
Fuentes-Bargues et al. (2018)	ES	Qualitative and quantitative analysis	W	●	316		●						●	●	
Sparrevik et al. (2018)	NO	Case study	W			●							●	●	
Montalbán-Domingo et al. (2018)	AR,AU,CA,CL,CO, PA,FE,ES,UK,USA	Quantitative and statistical analysis		●	461	●			●					●	●

Delgado et al. (2015) developed the Web3D visualizer, which integrates 3D documentation with building planning following the BIM methodology using just Open Source software. The

main contribution is the merging of project planning and 3D documentation into a single model, which can be visualized in a modern web browser without plugins. Different construction phases are visualized in a unique and shared global model, which is updated along execution time according to a well-specified visual planning. The use of Open Source software and standard protocols and technologies allows a wide spread and rapid adoption of the solution, which can be easily extended to support future use cases. Main *customers* in AEC (Architectural, Engineering and Construction) environments are given by technicians (architects, civil engineers, topographs), Public Administration (City Halls, regional planners for metropolitan areas) and enterprises. Delgado et al. (2015) have developed an HTML5 web based application called 3DSIMOS to visualize different construction stages according to a well specified planning. The most important functional requirements of the 3DSIMOS application have been determined by taking into account the need of tools for collaborative monitoring of building projects. Simultaneously a project manager can visualize the construction advances, whereas the potential customers can navigate the same 3D model to take an overview of the final result. These requirements can be summarized in the following list (Delgado et al. 2015):

- The user can import the tasks and activities of the planning of the building from a Microsoft Project file. This kind of file is commonly used by users which work with entity-based modelling.
- The user can import the design of the building project from 3D models represented in compressed COLLADA files. The system will be able of recognizing the layer identifiers, the geometric groups and the objects.
- The application provides a user interface with a dialog for interactive association of the different planning stages with the layers of objects belonging to the 3D model.
- The application is able of visualizing the building in 3D in a web browser with WebGL support. In this way the application is able of running in different devices with different kind of operating systems.
- The user can navigate the 3D model in an interactive way using the typical orbit camera control with mouse actions which is translated into rigid transformations up to scale (zoom, translation, rotation).
- The application can perform a simulation of the evolution of building construction

activities by displaying next advances by means of space-time representations.

Taking into consideration the requirements and from a functional analysis viewpoint, it is possible to identify the following meaningful functionalities (Delgado et al. 2015):

- *Interaction with 3D model*: the user can navigate the model by means of mouse and/or keyboard.
- *Rendering 3D model*: the browser displays a rendered model in the screen, according to the capabilities of the (mobile vs. desktop) device
- *Simulation of workflow*: the browser enables layers in a successive way, till a certain stage which can provide a simulation of workflow.
- *Project creation*: the user binds planning stages with the model layers which are imported from its own computer.

Warkentin, Orgeron (2020) explores the impact of blockchain (BC) technology on public sector processes through the lens of information security. It is increasingly paramount that all transactions within government and between governmental entities and outsiders be recorded, documented, logged, and archived with high information integrity. Blockchain is especially valuable for this objective, as it provides for strong non-repudiation properties. This affordance of the BC process provides reliable data provenance and ensures a high level of trust in the integrity of the data in the system. So, for example, in the contracting process when a government (or governments) manage large construction projects or military acquisition from multiple vendors, there are numerous transactions among and between many organizations that must occur reliably and often in a sequential manner. The distributed ledger using BC is ideal for this objective. Consider that all the players in a complex set of transactions (all building contractor and subcontractors, for example, who must be paid only upon verified completion of their inspected work) must access the same set of transactional data, and there may be incentives for improper data alterations. The use of BC in this context would make such data tampering a nontrivial exercise that would be nearly impossible, thereby ensuring accurate data provenance and trust (Warkentin, Orgeron 2020).

Project management research is one of the most successful SD application areas (Papachristos et al. 2020). In real CSCs (construction supply chain) many partners operate and interact in and across project stages, through physical and information project flows. The SD model is based on a simplified CSC that aggregates partner organizations at the project stage (Love et al. 2004). The CSC consists of design, construction, and operation stages, each representing aggregate partner with a remit of responsibilities, task and information flows, and partner alignment within and across stages (Figure 1) (Papachristos et al. 2020).

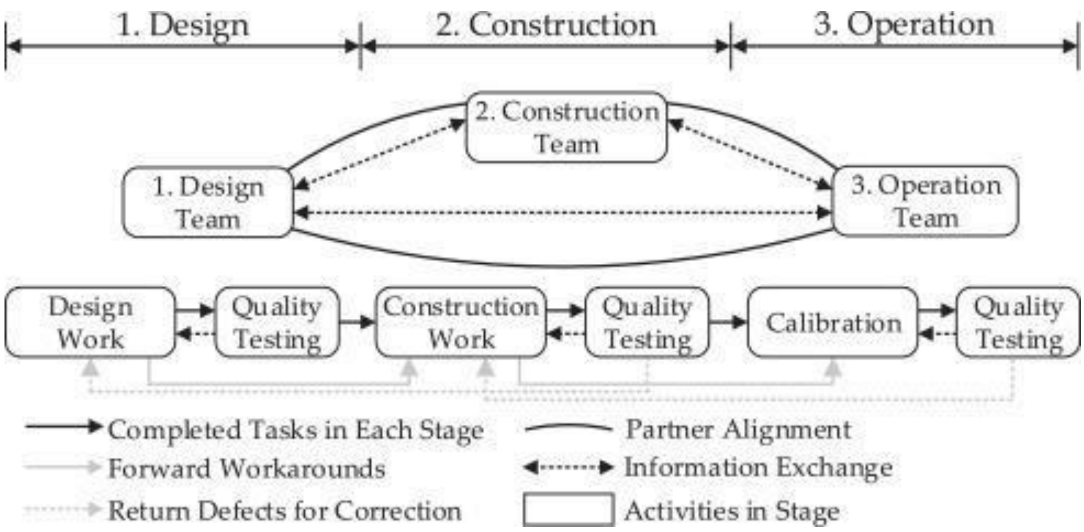

Figure 1. Conceptualization of project stage physical flows between design and construction stages (Papachristos et al. 2020).

The client requirements on time, cost, quality, *and* energy performance, and their inter-relations increase building project complexity (Baccarini 1996, Baskhi et al. 2016, Dooley, Van de Ven 1999). The extensive use of subcontractors in UK building industry increases CSC fragmentation and project complexity effects that can lead to low understanding of project dynamics and low performance (Bendoly 2014, Papadonikolaki, Wamelink 2017, Vrijhoef, Koskela 2000). Project performance suffers as project partners may not share the same understanding about project scope and inter-organizational relations that are critical to project success in construction and other industries (Autry, Golicic 2010, Laan et al. 2011, Molenaar, Songer 1998, Songer, Molenaar 1997). High project performance requires CSC integration, coordination and alignment of partner goals (Gulati et al. 2005). Alignment and coordination are important in the delivery of high-quality buildings as they moderate workflow control and CSC coordination. Goal alignment creates shared interests across partners and increases their cooperative behaviour and communication (Jap, Anderson, 2005, March, Simon 1958). Communication of partner ambitions, design intent and responsibilities may increase project performance and reduce the performance gap (De Wilde 2014). It is necessary to account for their effects in SD model development (Papachristos et al. 2020).

Lam et al. (1999) provided an overview of the usage of performance-based simulation tools for building design and evaluation in Singapore based on an extensive industry survey. It highlights the status and difficulties encountered in the usage and the needs of the industry for such tools. Figure 2 shows the major reasons for the usage of performance-based simulation tools. 69% of the firms surveyed utilize the tools to enhance the design in terms of providing better understanding of impact of design on building performance. 58.6% felt that the tools speed up the design process as well as provide confidence in the design. Only about 35% expressed that the usage is to fulfill the client’s requirements. Some firms also expressed that the adoption of such simulation tools will enhance the image of their companies and thus increase their competitiveness in securing projects (Lam et al. 1999).

Figure 3 reveals the major reasons for not using the simulation tools. 70% felt that most clients do not stipulate the employment of such tools as an essential requirement. Most firms viewed the use of simulation tools as involving extra cost and effort but with little recognition and appreciation from the clients. Very tight project schedule and budget further aggravate this problem. Other major reasons include staff lacking the skills and training in the usage, the high cost of simulation tools and the belief that the use of such tools would incur more design time in the process. 50% also expressed that most of the tools have very steep learning curves and not user-friendly. Most firms surveyed also felt that the usage of such simulation tools was beyond their scope of work. The opinion is that such tools should be utilized only by the specialist consultants or the suppliers. The lack of "suitable projects" further hampered the regular utilization. The lack of support from the local software developer is another obstruction since such software was not easily available and those developed in US or Europe may not be suitable for local use. The output generated from the simulation tools could be extremely difficult to interpret and utilize for design decisions. It could also be difficult to justify cost savings in the design to the clients. Their basic objective of the design was to fulfill the requirement as specified by the codes of practice; thus the usage of complicated simulation tools was not essential. Of greater concern is perhaps the apparent lack of awareness of the existence of such tools (Lam et al. 1999).

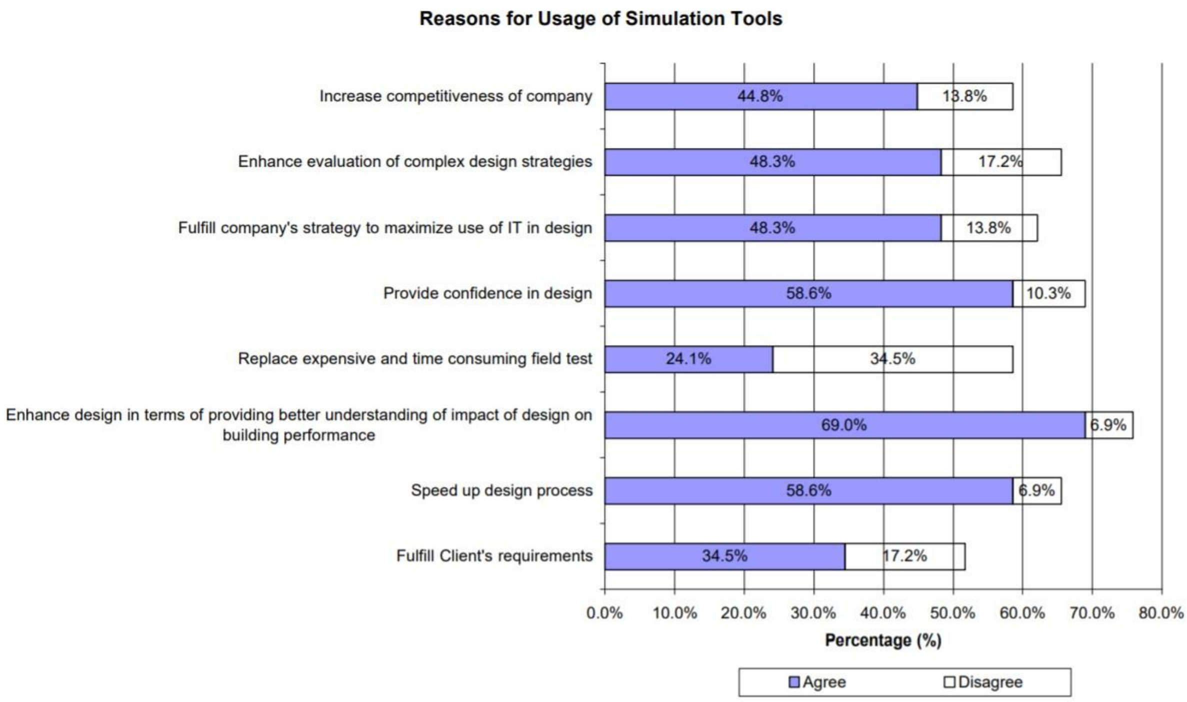

Figure 2. Reasons for using simulation tools.

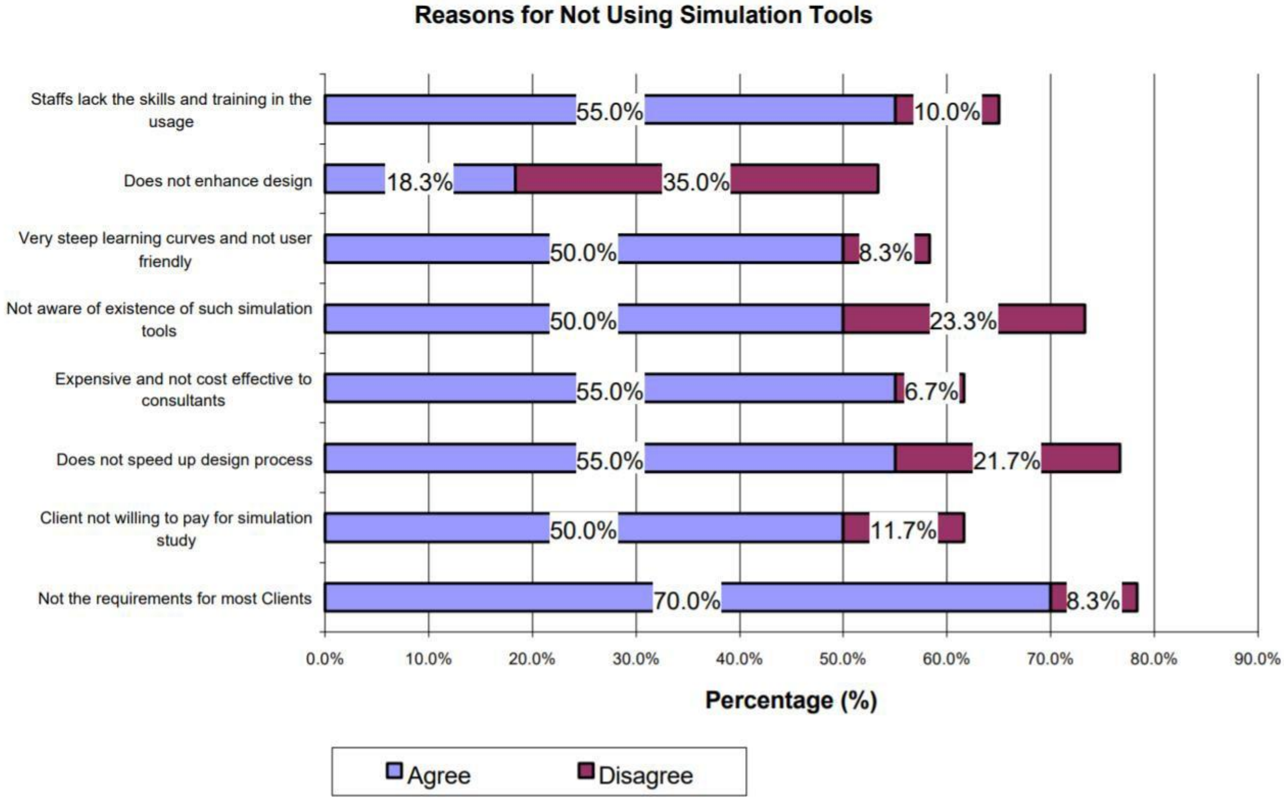

Figure 3. Reasons for not using simulation tools.

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Aim and key learning outcomes of this topic

The aim of this topic is to ensure that students understand the different interests of clients for achieving energy efficient buildings. (Contributes to overall Learning Outcome O1: Students will understand the different interests of stakeholders in achieving energy efficient buildings.) On completion of this topic, students will:

- Appreciate the interests of building clients
- Be able to apply their knowledge of building clients in developing energy efficiency solutions.

Assessment

Formative assessment in the form of quiz questions to check familiarity and comprehension of the readings provided.

Recommended sources of further information

What are Employer's Information Requirements?:

https://www.youtube.com/watch?v=VwMe2cM8t_M&ab_channel=TheB1M

10 Adding BIM Scope LOI Information Requirements from the Owner Client:

https://www.youtube.com/watch?v=n7zFyngFMX4&ab_channel=Plannerly-TheBIMManagementPlatform

BIM / EIR - Employers Infromation Requirements:

https://www.youtube.com/watch?v=ZU7A97EjRpA&ab_channel=ArcDox

What BIM service do clients want from constructors?:

https://www.youtube.com/watch?v=yAyamCBI7IQ&ab_channel=ConstructionManager

Meet Client Requirements: https://www.youtube.com/watch?v=PKHfiYPi7-c&ab_channel=AutodeskBuildingSolutions

Experiences from a public client in the introduction of the BIM methodology:

https://www.youtube.com/watch?v=UwHhUb583fQ&ab_channel=Lietuvosstatybinink%C5%B3asociacijaJD

4 - Designers' objectives and information requirements

Reading 1: Architects' objectives and information requirements

The successful design and construction of houses require complex interactions between clients and professional service providers, such as architects, engineers, planners, and contractors (Lapidus, 1967, Siva and London, 2012). Despite the importance of each of these project actors, the architect has, for decades, traditionally played the role of master builder and head of the design team and is responsible for managing the project and the activities of different actors (Cuff, 1991, Finch et al., 2005). Essentially, the architect has been perceived as the "spiritual leader" of the project (Royal Institute of British Architects [RIBA], 2015, Frimpong, Dansoh 2018). In the modern construction industry, however, this role is no longer "the exclusive domain of architects. Other disciplines have gradually encroached on the architect's core activities" (van Gulijk, 2009). The Royal Institute of British Architects (RIBA) (2011) reported that architects, especially "small general practices" and individual architects "working for private clients with local builders" are facing an invasion of their traditional role from "non-architect[s]" such as contractors and draftsmen. Evidence suggests that clients are unwilling to fully employ architects on projects where they may not be mandatory (Frimpong and Dansoh, 2016, The Guardian, 2017). In response to this trend, architects have repeatedly attempted to remedy this situation at the institutional level . (Frimpong, Dansoh 2018)

Meex et al. (2018) analysed possible solutions to apply LCA, including operational energy demand simulation, in early design from two different perspectives: design-oriented user requirements, derived from literature, a survey, interviews and a focus group with architects, and LCA simplification strategies based on a literature review. They also developed the evaluation framework that can be used to check the suitability of LCA-based environmental impact assessment (EIA) tools for use by architects during early design stages and a new design- supportive LCA-based EIA tools. A framework with requirements for LCA-based EIA application in early design is developed from two different perspectives (Fig. 1): 1) user requirements for 'architect-friendly' LCA-based EIA tools (i.e. usable by architects during the early stages of the design process); 2) criteria for simplifying the LCA methodology and parametrizing the calculation method in order to make it more applicable in an EIA software tool during the early stages of the design process. This framework can be used to evaluate (future) LCA-based EIA tools on their suitability for application by architects in the early design stages and to develop new, design-integrated, LCA-based EIA tools (Meex et al. 2018).

Figure 1. Methodological approach for the framework development (Meex et al. 2018)

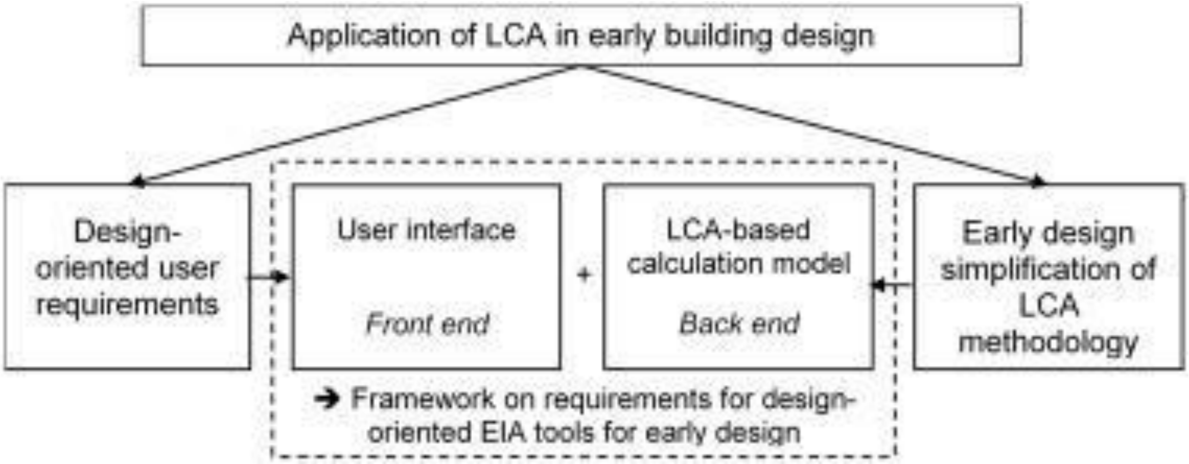

Table 1 shows the framework with requirements for applying LCA-based EIA tools by architects in early design. This framework is subdivided into four themes: 1) Data-input, 2) Calculation, 3) Output and 4) Usability in the design process. The left column represents all user requirements ('what they want'). The right column addresses all criteria related to the simplification of the LCA methodology. The middle column represents suggestions of how these criteria could be met and merged into an EIA software tool, both regarding the user interface and the background calculation model. In the next paragraphs, all framework themes and their corresponding criteria are discussed (Meex et al. 2018).

Table 1. Evaluation framework with requirements for early design application of LCA-based EIA tools by architects (Meex et al. 2018)

Structure		User	EIA tool		LCA methodology	
Theme	Subtheme	User requirements	Front end (user interface)	Back end (calculation model)	Screening LCA	Simplified LCA
INPUT	-	Limited data-input, consistent with the design phase: both for building geometry and material specification	Clearly structured, extensive material library with standard materials, building components (e.g. based on national averages)	Consistent model that allows use of default settings / values but can also be filled/extended with detailed data with access to different material libraries	Use of generic environmental data	Specific environmental data if available, if not average or generic
			Default values and/or settings for assessment of 'incomplete' buildings		At least include: Exterior walls, windows, roofs, ceilings, slabs, interior walls, columns, foundations, finishing, building services + default values for other data	
		Quick data-input via a simple and intuitive procedure	Link to common design tools to be easy to learn and avoid additional effort (e.g. Sketch-Up)	Automatic take-off of material / element quantities from the 3D model	-	
CALCULATION	Methodological and calculation choices	Transparency of methodological and modelling choices, not adaptable but clearly communicated	Provide detailed manual / description of predefined calculation settings and assumptions + a clear help function or discussion platform for Q&A and support	Predefined calculation settings per building type and design stage, such as the reference study period, impact indicators, etc.	Report at least the indicators PENRT and GWP and a single-score indicator (endpoint) if possible	Report the indicators GWP, EP, AP, ODP, POCP, ADP, PET, PENRT and a single-score indicator (endpoint) if possible
					Life cycle stages: A1-A3, B4, B6, B7, C3, C4, (D)	
		Objective, correct information and data (regional, verified, independent)		Database with verified and independent data, representative for the assessment context	Assure representativeness of data (time, regional) and data quality	
	Scope of the assessment	Holistic approach: integrate energy performance, link to economic costs, health, … to enable well-balanced decision making	Provide combined calculation and presentation of outcome for energy performance and environmental assessment	Combined calculation of operational energy demand and environmental impact assessment	Operational energy calculation based on performance targets (statistical data)	Operational energy calculation based on quasi-steady state energy calculation
	Time investment	Minimal interruption of the design process / implementation in workflow of architect	Interoperability with other design or analysis tools	Import / export features to other tools	-	
		Quick application, minimal time required to operate tool	Real-time calculation, in tune with design process	Computation time <1s		
OUTPUT	-	Simple but supportive information for design decisions, adapted to design stage	Aggregated score + more detailed scores (per element, per life cycle stage), combined with design-supportive feedback	Calculate aggregated single score and individual indicators	Optional aggregation into single score	
				Optional: calculation of points in sustainable building certification systems		
		Easy to interpret, clear and limited output, which is communicative towards the client	Visual output (e.g. graphs, grading scale) instead of extensive report	Aggregation of results on different levels of detail (per building, per element, per life cycle stage)	-	Reporting templates for LCA practitioners
			Visualization of output relative to benchmarks/average values/regulatory targets	Provide European or national average/target values for individual building components and whole buildings	Normalization using national targets or benchmarks for buildings	
			Visualization of possible deviation of results (sensitivity / uncertainty)	Calculation of uncertainty based on information in environmental data and level of detail of geometry model	-	Information on uncertainty using statistical methods
USABILITY IN THE DESIGN PROCESS	Adaptability & flexibility	Adaptable to / in tune with design stages	One software tool for different types of projects, which evolves with the design progress	Flexible / parametric calculation model with different levels of detail	-	
		Easy data review / change	Parametric control, e.g. number slider, for input of material thicknesses, etc.			
		No loss of data	Automatic save function, redo/undo function	Provide sufficient memory capacity / provide space in the cloud		
		Quickly and easily create and test alternatives (parallel)	Copy-paste function / duplicate instead of start from scratch	Database to store variants		
	Comparison & feedback loops	Comparing a number of different design alternatives in detail (parallel)	Visualization of changes (improvements) between variants	Enable opening multiple variants and comparing them in parallel	-	
		Real time feedback on design changes				
		Clear indication of problem areas	Visualization of problem areas in 3D model	Comparison of environmental impact per building component e.g. with average values and indications for large deviations		
		Generate suggestions / alternatives for improvement	Indicate optimization potential and generate suggestions / alternatives	Provide the possibility to use optimization algorithms to propose solutions		

Ellis, Mathews (2001) developed a new simplified thermal design tool for architects. Energy-efficient design strategies require architects and engineers to work closely together in optimising the building shell. However, this is not always practical. Architects must therefore, be able to perform a preliminary thermal analysis if energy efficient design strategies are to succeed. Existing tools do not cater for them or fit their design methodology.

Firstly, researchers determined architects requirements. The basic needs identified during the third International Congress on Building Management (ICBEM) in Lausanne (1987) are still applicable today. They are as follows (adapted from Holm (1993)):

- The design tool should be user-friendly and easy to use.
- Input formats must be user orientated and in terms of building materials rather than thermal properties.
- Solutions must be obtained quickly, in minutes rather than hours. This is more important than the accuracy of the tool.

- It should be able to handle ‘what if’ alternatives readily.

Developed tool enables architects to reduce building energy consumption, save on the initial HVAC system cost, and benefit the environment by spending as little as 30–60 min more on the design of the building shell. An additional advantage of the new tool is that it uses the same simulation model as an existing integrated building and HVAC design tool. Project data is easily transferred from the preliminary design stage to the detailed design stage. The tool thus improves communication between the architect and engineer (Ellis, Mathews 2001).

Attia et al. (2012) summarized a study undertaken to reveal potential challenges and opportunities for using building performance simulation (BPS) tools. They identified user (architects and engineers) requirements and selection criteria for BPS tools. Attia et al. (2012) classified criteria as follows:

1. Usability and Information Management (UIM) of interface
2. Integration of Intelligent design Knowledge-Base (IIKB)
3. Accuracy of tools and Ability to simulate Detailed and Complex building Components (AADCC)
4. Interoperability of Building Modelling (IBM)
5. Integration with Building Design Process (IBDP)

The BPS was also analysed by Alsaadani, De Souza (2016). They examines collaborative relationships between architects and energy consultants, for the uptake and use of building performance simulation (BPS). BPS is thought to hold massive potential for the AEC industry, by allowing professionals to quantify impacts of architectural design-decisions. However, a number of technical barriers are widely-cited in the literature preventing the uptake of these tools. Barriers identified include: negotiating control over decision-making, differences in problem-solving approaches, cliental roles and regulatory frameworks, professional trust and communication.

Future BPS tools should work as a design tool, being able to support comparisons between competing design alternatives in relation to energy use and production in order to support the architects. Architects and other actors can save costly time when the import and export of geometry between programs will run without errors, something which is currently not the case.

Kanters et al. (2014) interviews with Scandinavian architects with the objective to identify barriers of existing tools and methods for solar design, the needs for improved tools, and to gain an insight into architects’ methods of working during the design process. The interviews strongly indicate the need for further development of software tools for solar architecture, focusing on a user-friendly, visual tool which can generate clear and meaningful results.

Implementing BPS tools into current CAAD software will require a shift from tool developers’ focus from purely CAAD towards a whole performance simulation tool. The recent launch of several BPS tools with such features has made clear that the industry is working towards such programs. A parallel could be drawn to the role of visualisation programs. During the last decade, these programs helped architects to judge design options but more importantly, it helped them to ‘sell’ their ideas visually. If BPS tools could be used in the same way throughout the design process, architects would be able to sell energy concepts much better. Communicating with the client is crucial for making design decisions in the design process. If the client is shown what consequences some design decisions have on the energy performance of buildings as well as the financial consequences are provided, a better performing, low-energy solar architecture can be reached (Kanters et al. 2014).

Petersen et al. (2014) reviewed studies regarding the use of thermal and daylight building simulation tools in the early design phase and conducted their own qualitative survey to identify the barriers among Danish architects for using these types of simulation tools in the early design phase. The overall conclusion from the literature review was that architects in general are interested in using information from such tools in the early design phase to inform their process, but only if they are conformed to fit their design process. Furthermore, the following main barriers for using building simulation tools in the early design phase were indicated in the qualitative study:

- engineering performance issues regarding indoor climate is basically considered irrelevant in relation to form-giving in early design phases,
- a concern that (measurable) engineering performance issues may overrule (“non-measurable”) architectural design issues,
- mindset and workflow mismatch between architects and engineers when designing,
- a desire to use simulation tools for design but current ones are insufficient and inappropriate
- limited economy allocated to the early design phase (e.g. in competitions) is a barrier to close collaboration between architects and engineers.

In this case, Purup, Petersen (2020) proposed a research framework for the development of BPS tools conformed to fit common design practice in the early design stage. The framework can therefore enable researchers to continuously improve and test their ideas and suggestions on how to make BPS tools that are conformed to fit common design practice in the early design stage.

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Simulations and digital tools for architects (Arch20, 2020, Kilkelly 2020)

Title	Description
The Legacy OpenStudio	Makes it easy to create and edit building geometry in EnergyPlus input files. It also allows to launch EnergyPlus simulations and view the results within SketchUp, which is used as a parent software here.
DesignBuilder	Enable a full design team to use the same software to develop comfortable and energy-efficient building designs from concept through to completion, with packages for engineers, architects and energy assessors covering performance indicators such as energy consumption, carbon emissions, thermal comfort, daylight availability and cost.
Vabi Apps, by Vabi Software	Provides a suite of apps for calculating and visualizing a project’s environmental, financial, and programmatic performance. The Thermal Comfort Optimizer calculates ideal heating and cooling set points for each room in a building, while the Daylight Ratio Evaluator calculates the amount of daylight a space is receiving and highlights rooms that do not meet requirements. The Energy Assessor, which is forthcoming, estimates the project’s monthly and yearly energy use and costs.

Sefaira Architecture, by Sefaira	Provides interactive building-performance feedback through its Sefaira Architecture plug-in, which calculates and graphically displays metrics, including daylighting factors, energy use intensity, and energy use breakdown by building system, in real-time on a performance dashboard. The Element Performance chart, which is integrated into the dashboard for convenient access, offers more in-depth insights on how building components, such as walls and windows, affect overall heating and cooling loads. The Daylighting Visualization tool shows the distribution of natural light throughout the building. Similarly, the Direct Sunlight Analysis tool quantifies the amount of direct sunlight each space receives throughout the day, a metric used in certification programs such as Australia's SEPP 65 program and the BREEAM system, which is popular in the U.K.
Green Building Studio, by Autodesk	Green Building Studio (GBS) is available as a standalone cloud-based service or as part of Revit's add-on Energy Analysis tools. Using the DOE-2.2 analysis engine, this service provides a very detailed analysis and, as a cloud service, runs quickly on Autodesk's servers. Ordinarily, the DOE-2.2 engine requires a thorough description of a building's envelope and mechanical systems. However, GBS makes assumptions for many of these parameters using ASHRAE standards, allowing architects to focus on the design areas that have the most significance on the building's overall energy footprint without getting bogged down in technical details. In addition to calculating energy consumption, electricity use, and annual carbon emissions, GBS also estimates the building's Energy Star score, points for glazing factor and water credits for the U.S. Green Building Council's LEED rating system, and solar energy potential.
OpenStudio, by the National Renewable Energy Laboratory	Provides a visual, user-friendly interface for the EnergyPlus analysis engine— a console-based program that reads and writes only text files. The SketchUp plug-in generates building geometry formatted specifically for input into EnergyPlus. After the geometry is created, users can define material properties, systems, and zones in the OpenStudio application. Once the model is fully attributed, they can then run multiple simulations with the Parametric Analysis Tool (PAT), test different configurations with a drag-and-drop editor, and obtain life-cycle cost information.
IES Virtual Environment for Architects, by Integrated Environmental Solutions	Integrated Environmental Solutions (IES) offers a range of energy modeling tools based on the Apache simulation engine. IES Virtual Environment (IESVE) for Architects is an architect-friendly version of the developer's base IESVE product, which is targeted to engineers and energy-modeling professionals. Using a plug-in for Revit, SketchUp, or Vectorworks, architects can export their models to the IESVE application for analysis and then simulate water usage, daylighting, solar shading, energy use, and heating and cooling demand. A simulation report conveys results through charts and diagrams. This program performs a very thorough building analysis, but it is not as user- friendly as some of the other options listed here, nor does it provide the real- time feedback that is helpful during early design stages. Also, since IES is based in Scotland, the software references European energy standards though it will calculate potential LEED credits.

eQuest	Graphical energy analysis tool, making an easier task of reviewing analysis data in a 3D environment instead of plain and sometimes incomprehensible tables and forms.

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Reading 2: Structural engineers' objectives and information requirements

Application of BIM in different area is expanding, as researchers realize the potential values BIM can offer. While application of BIM for Structural and energy analysis is reported with a frequently of 27% and 25%, respectively, its major use still seems to be for faster development of 3D geometric models and 3D coordination with a use frequency of 60% (Kreider et al. 2010). Application of BIM is not limited to architects and engineers. There are also motives for homeowners, facility managers, contractors, and fabricators to use BIM (Eastman et al. 2011). Most of the important factors that lead to adopting BIM in a project are focused on automation in modeling process, improving the accuracy of construction documents, improving the communication among parties in design and construction process, automatic reflection of changes in all views after modifying one view, and reducing the field coordination problems (Eastman et al. 2011, Woo et al. 2011, Young et al. 2009, Ramaji et al. 2016).

Various researcher developed frameworks, tools for construction simulations for structural engineers (Lin et al. 2019, Heigermoser et al. 2019, Rausch et al. 2019, Lai et al. 2019). These frameworks, tools are described below.

Lin et al. (2019) proposed framework consists of a bridge safety information model (BrSIM), algorithms for data integration and semi-automatic time-dependent structural model generation, and methods for structural safety warning and assessment. The proposed BrSIM and algorithms integrate data related to 3D products, schedule, structural simulation and monitoring from various engineering systems, which covers the main data for structural safety management during construction. Closed-loop management of structural safety can be divided into two levels: the workflow level and the data level. At the workflow level, tasks of a PDCA loop are completed by different stakeholders. That is, structural simulation, construction planning, structural monitoring and safety risk evaluation are conducted by designers, contractors, consultants, respectively. At the data level, work of different stakeholders uses different systems and could not share all the data easily, so the printed documents and drawings are widely used. Which means, the PDCA loop is achieved through manually inputting and interpreting data, thus taking a long time and leading to overlooking of safety hazards. In this situation, it is difficult to effectively account for the entire process of construction safety management when the systems of project management, structural simulation analysis, and structural monitoring are independent of each other. To solve this problem, a framework consisting five layers as shown in Figure 1, is proposed (Lin et al. 2019).

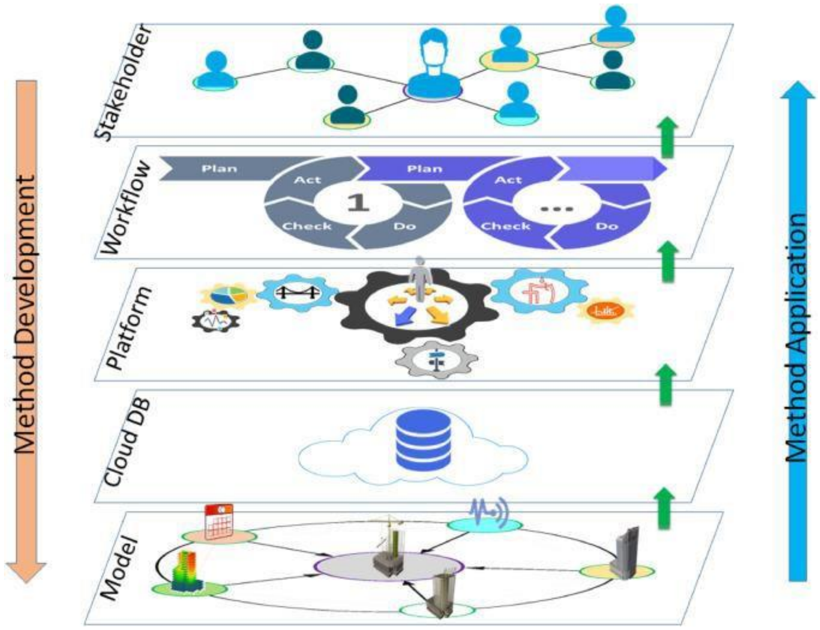

Figure 1. Framework for closed-loop management of structural safety (Lin et al. 2019)

The final layer is the stakeholder layer in which different stakeholders are involved. Generally, the project manager, structural engineer, safety manager, monitoring engineer, and inspector are the main stakeholders involved in structural safety management.

Heigermoser et al. (2019) proposed a construction management tool that combines the LPS with the 3D visualization of construction projects to improve productivity and reduce construction waste. The prototype tool is mainly aimed to be used as a construction management tool during the construction phase. The tool allows dividing construction projects into work zones, obtaining a fully automated quantity take-off, and offers a color-coded 4D construction simulation for the short-term planning process of the LPS. It allows for a systematic evaluation and analysis of the construction planning in terms of productivity, manpower allocation, and quantification of waste considering the short-term planning process, which promotes continuous improvement of future construction planning (Heigermoser et al. 2019).

Rausch et al. (2019) made a Monte Carlo simulation for tolerance analysis in prefabrication and offsite construction. Tolerance analysis through Monte Carlo simulation is shown to be a proactive design tool with several key advantages for prefabricated and offsite construction. First, complex three-dimensional geometric interactions can be readily modelled using very basic tolerance configurations. Secondly, potential misalignments at key connection points can be identified and quantified in terms of a probability distribution of variation. Finally, design improvements can be achieved by comparing alternate construction processes to mitigate the risk of assembly rework. The proposed framework for tolerance analysis is shown in Figure 2 and has two primary modules. Module 1 is the tolerance identification process that involves decomposing the overall assembly into its core components, identifying the connections between these components and configuring the corresponding tolerances at these connections. The second module is the tolerance simulation process, where results are expressed as probability distributions at critical measurement points. While the input to the framework is an initial 3-D design (including fabrication processes, tolerances and a 3-D model), the output is a design that is optimised for tolerances and risk management. The success of the optimisation process relies on the iterations

involved with specifying part tolerances and fabrication processes that result in acceptable deviations at the critical measurement points (Rausch et al. 2019).

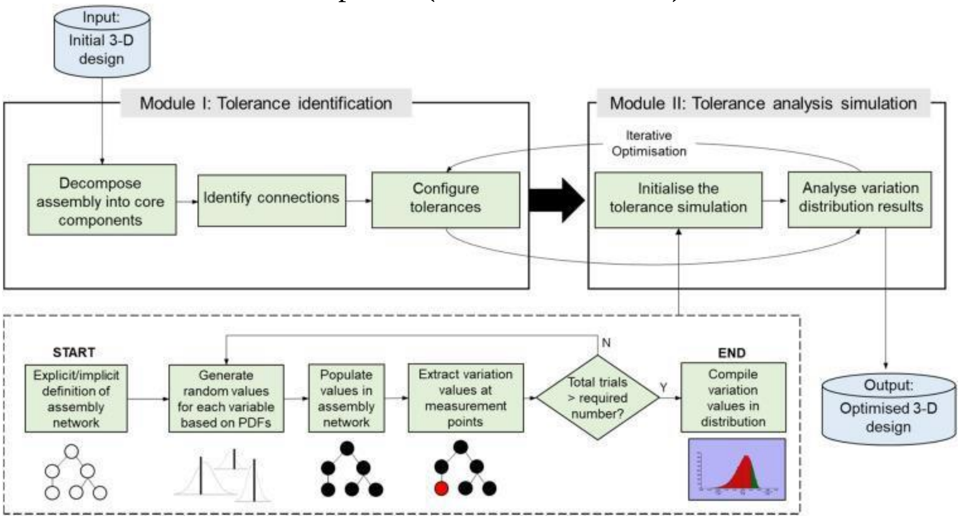

Figure 2. Overview of the proposed framework for simulation-based tolerance analysis of construction assemblies.

Table 1. Tasks for different activities in the PM of structural design (Lai et al. 2019)

	Activity	Task
S.1	Conceptual structural design	– Determine structural type (such as steel structure, concrete structure, and composite structure) according to the description and scope of the building project; – Determine structural system (such as frame structure and shear wall structure) according to the height, function, and structural type of the building project; – Determine spatial arrangement of beams, columns, walls, slabs, and supports according to the structural system of the building project.
S.2	Conceptual structural design review	– Check the structural type determined at the conceptual design stage, and ensure its validity.
S.3	Preliminary structural design	– Determine antiseismic requirements; – Determine structural loads; – Determine strength grade of materials; – Determine cross-sectional dimensions of structural components; – Complete the basic selection and preliminary settings; – Build the preliminary design model.
S.4	Preliminary structural design review	– Check the rationality of antiseismic information, load information, and member section at the preliminary design stage; – Check structural layout at the preliminary design stage.
S.5	Detailed structural design	Based on the preliminary design model, the structural engineer builds the detailed model in terms of detailed information at this stage: – For the steel structure, structural joints between components and local stiffening measures are designed in detail after selecting the section of stressed members; – For the concrete structure, when determining the section of members, member reinforcements and local structure measures need to be identified. A large number of structural joints in the building project are designed in detail.
S.6	Detailed structural design review	– Check the detailed structural model and related drawings, and review the validity of reinforcements and structural joints.
S.7	Structural model for BIM collaboration	– Deliver the structural model for BIM collaboration between multiple disciplines.

In Architecture, engineering, and construction (AEC) collaboration, exchange requirements (ERs) vary in different projects with different platforms. In order to ensure the completeness and accuracy of data sharing and exchange for structural engineering in collaborative design, Lai et al. (2019) proposed an ER-based delivery method to improve the delivery of structural design

information. Based on the interviews with structural engineers, the tasks for each activity in the Product Modeling (PM) of structural design are documented in Table 1. In addition, Table 2 presents an example of the process specification in detailed structural design (S.5), including task, analysis, and ER. Because of the paramount importance of the analysis in structural design, the description about structural analysis is added into this table template (as shown in Table 2) (Lai et al. 2019).

Table 2. Process specification in detailed structural design (Lai et al. 2019)

Detailed structural design (S.5)	
Task	Based on the preliminary design model, the structural engineer builds the detailed model in terms of detailed information at this stage: – For the steel structure, structural joints between components and local stiffening measures are designed in detail after selecting the section of stressed members; – For the concrete structure, when determining the section of members, member reinforcements and local structure measures need to be identified. A large number of structural joints in the building project are designed in detail.
Analysis	Structural analysis, such as the analysis for reinforcements and structural joints.
ER	Build a detailed structural model (S_ER.2), including the foundation, reinforcements, and structural joints.

CadCAm Group (2020) suggest the Structure Design within the framework of the 3DEXPIRENCE platform which is a specially developed module to enable engineers and architects to provide a unique possibility of virtual presentation of the conceptual model, and performing engineering simulations. The module creates, analyzes and connects interconnected applications into one whole, by which several users can simultaneously manage in accordance with the set requirements. Any changes in one of the components are updated in the system. For more complex calculations, the Abaqus software package has been developed, developed in the 1978 and has been upgraded to date to solve the most complex problems. It is used to solve metaphysical non-linear problems, such as elasto-plastic analysis, structural damage analysis, thermal analysis, and diffusion effects analysis, dynamic analysis etc. For basic calculations of construction structures, there are a number of software solutions that satisfy static and basic dynamic calculations. However, for the calculation of complex dynamic problems, such as the dynamics of the entire earthquake construct, including contacts, which occur in dynamics and where the development of the cracks or cracks is required, the Abaqus software solution is used (CadCAm Group 2020).

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Software packages list for engineering analysis of structure against applied loads using structural engineering and structural engineering theory (Wikipedia 2020)

Name	Description
Advance Design	BIM Software for FEM structural analysis
ArchiCAD	BIM & 3D modeling software applied for civil & structural engineering
COMSOL Multiphysics	Simulation and multiphysics applied for structural engineering
Extreme Loading for Structures	Advanced non-linear structural analysis software
FEATool Multiphysics	Simulation and multiphysics applied for structural engineering
FEMtools	FEM software program providing advanced analysis and scripting solutions for structural engineering

MicroStation	BIM & 3D modeling software applied for civil & structural engineering
OpenSees	Earthquake engineering software
Realsoft 3D	General 3D analysis and design software
Revit	BIM & 3D modeling software applied for civil & structural engineering
RFEM	3D structural analysis & design software
SDC Verifier	Structural verification and code-checking according to different industrial standards
SimScale	Multiphysics simulation (CFD, FEA, Thermal Analysis) applied for structural and civil engineering
SketchUp	BIM & 3D modeling software applied for civil & structural engineering
Tekla Structures	BIM & 3D modeling software for civil & structural engineers

References:

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Reading 3: MEP engineers' objectives and information requirements

In a typical construction project, the basic structure organization of the team includes client, project manager, architect, civil engineer, structural engineer, mechanical engineer and electrical engineer. It is now possible for them to work together within the model in an improved coordination and organization. This interaction depends on multi party tools to success. The method is called Integrated Design Process (IDP). The IDP's purpose is to utilize a collaborative team effort to prepare design and construction documents that result in an optimized project system solution (Rossi et al. 2009, Stamp 2012). As building codes are updated to take building performance into account, there is an increasing obligation on the part of designer to provide higher degrees of insight regarding building outcomes. The design team needs to define technology standards to encourage opportunities for increased project and data flexibility (Bahar et al. 2013).

Various researcher developed frameworks, tools for construction simulations for MEP engineers (Tserng et al. 2011, Hu et al. 2016, Shin, Haberl 2019, Apak et al. 2017, Ghannadzadeh et al. 2012). Some of them are described below.

Tserng et al. (2011) presented an algorithm for efficiently designing, fabricating, and constructing the mechanical, electrical, and plumbing (MEP) systems for buildings. MEP facility construction presents numerous challenges related to its complexity, space limitations, and interference with other trades working in confined areas. Besides, schedule delays can easily be caused by the uncontrolled delivery schedule of the components. Reserachers provides a rational planning algorithm which packages large and complex MEP systems into several smaller fabricated components using spatial planning algorithms to increase the efficiency of the installation process, create a safer work environment, improve construction quality and productivity, reduce construction cycle time, and minimize cost (Tserng et al. 2011).

Hu et al. (2016) proposed a multi-scale solution to address the insufficiencies of the current applications in the construction and facility management of MEP projects. Several challenges have been found in the current applications of building information modelling/model (BIM) technology in large-scale mechanical, electrical and plumbing (MEP) projects, such as the huge modelling workloads of MEP models and details, untapped potential in supporting cooperative construction management with multiple participants and insufficient functions for intelligent facility management. Based on this model, researchers presented a BIM-based construction management system to provide virtual construction scenes with appropriate scales for various participants to communicate and cooperate, as well as a BIM-based facility management system to share information delivered from previous phases and improve the efficiency and safety of MEP management during the operation and maintenance period. The application in a real-world airport terminal illustrates that the proposed model and two systems can support collaborative construction management and facility management with multi-scale functionalities among participants (Hu et al. 2016).

Shin, Haberl (2019) research provides a systematic literature review of building thermal zoning for building energy simulation. The results indicate that future research is needed to develop a well-documented and accurate thermal zoning method capable of assisting designers with their building energy simulation needs. Several leading Computer-Aided Design (CAD) vendors now offer Building Information Modeling (BIM) software that they claim is capable of accurately simulating building energy use, and even automatically generating HVAC thermal zones in a proposed design. For instance, one commercially available schematic design tool, Autodesk Revit (2016), has a feature for automatically dividing a building's geometry into perimeter and core zones at each floor, based on ASHRAE 90.1–2016. However, Autodesk has not released the details of their zoning algorithm or provided a discussion of how the procedure works in their software. Therefore, how can HVAC design engineers know if the program accurately represents their designs? Furthermore, the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) does not provide guidelines regarding the methods for the correct thermal zoning of producing a complete thermal model from printed floor plans, CAD models, or BIM applications, which includes instructions about thermal zoning (Shin, Haberl 2019).

BIM is an intelligent, 3D model-based process that helps MEP professionals design, detail, and document building systems more efficiently. Working in a BIM process gives project teams more insight into designs and constructability, reducing risk and improving outcomes. BIM helps MEP firms improve accuracy, reduce and resolve clashes, and optimize building systems design. MEP BIM software helps project teams improve collaboration, share data, and speed project delivery from design to construction (Autodesk, 2020). Autodesk (2020) presents MEP firms which are using BIM:

- MECHANICAL, INC. Chicago Pipefitters Local 597 trains more than 800 apprentices each week on the Revit BIM (Building Information Modeling) platform. The union partners with more than 400 contractor signatories—one of which is Mechanical, Inc. Working with skilled tradespeople who are knowledgeable in BIM processes lets Mechanical keep paper, pencils, and tape measures off the jobsite and improve collaboration and productivity. Using Revit, BIM 360, and GTP Stratus, Mechanical continues to find new efficiencies—reducing rework and waste—through BIM and prefabrication.

- GLUMAC. Using BIM 360 Design, engineers and designers were able to boost productivity, improve collaboration, and condense months-long project phases into days for a net-zero Sacramento high-rise.
- JOHNSON CONTROLS. This MEP firm used BIM-based energy analysis to design building systems for its new Asia-Pacific headquarters in Shanghai – China's first triple- certified green building.

MEP software allows engineers, designers and contractors in the mechanical, electrical, and plumbing (MEP) fields to design building systems in their particular discipline. These solutions streamline the design, modeling, documentation, and construction of these systems and ensure they integrate seamlessly with the building its being placed into. MEP software enables users to conduct simulations, helping ensure their building systems do not cause any interference with the rest of the building (G2.com, 2020).

MEP software is incredibly beneficial to any business involved in business construction. Every building requires some combination of mechanical, electrical and plumbing systems within the structure. Utilizing MEP software will ensure users that everything within their building is running smoothly (G2.com, 2020).

These solutions can typically integrate with general-purpose CAD software to enhance the overall design and modeling process. To qualify for inclusion in the MEP category, a product must (G2.com, 2020) :

- Provide the functionality to design mechanical, electrical and plumbing systems
- Offer clash detection early in the design process
- Offer reporting capabilities to help users make informed decisions in the construction process

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The top 10 MEP Softwares (G2.com, 2020)

Name	Description
AutoCAD MEP	AutoCAD® MEP software helps you draft, design, and document building systems.
Revit MEP	Revit helps engineers, designers and contractors across the mechanical, electrical and plumbing (MEP) disciplines model to a high level of detail and easily co-ordinates with building project contributors.
HEC-RAS	HEC-RAS is a computer program that models the hydraulics of water flow through natural rivers and other channels. The program is one- dimensional, meaning that there is no direct modeling of the hydraulic effect of cross section shape changes, bends, and other two- and three-dimensional aspects of flow.
SolidWorks Flow Simulation	SOLIDWORKS Flow Simulation is an intuitive Computational Fluid Dynamics (CFD) solution embedded within SOLIDWORKS 3D CAD that enables you to quickly and easily simulate liquid and gas flows through and around your designs to calculate product performance and capabilities.
SolidWorks Electrical Professional	Embedded electrical systems planning requires a unified electrical toolset that provides single- and multi-line schematic tools. Embedded system design also requires all work in 2D and 3D to be synchronized with integrated Bills of Materials (BOMs) for both mechanical and electrical parts.
MagiCAD	MagiCAD for Revit and AutoCAD is the number one BIM solution for Mechanical, Electrical and Plumbing (MEP) design used by thousands of companies in over 80 countries worldwide. It enables powerful modelling and engineering calculations. MagiCAD makes the design of accurate BIM models easier, more flexible and less time-consuming. With MagiCAD, you

	design with over 1,000,000 intelligent BIM objects of real MEP products from leading international manufacturers.
Vectorworks Spotlight	Vectorworks Spotlight is the industry-leading design software for the entertainment business. It works like you think, facilitating improvisation and creativity so you can transform your designs into award-winning productions. Whether you work in lighting, scenic, event, tv, film, rigging or exhibit design, Spotlight software balances your process with the need for coordinated, accurate information so you can create unmatched experiences.
Design Master Electrical	Design Master Electrical is a MEP design software that allows you to do your calculations and drafting, organize your files, manage time with calculations, design, and drafting by automating those functions and more.
Trimble SysQue	Trimble SysQue enables designers and contractors to design in Autodesk Revit with real world, manufacturing specific MEP content.
	that is ready for fabrication. The software provides MEP designers and contractors with a seamless workflow from design to fabrication to construction improving the accuracy and coordination of their models.
Trimble Field Points	Trimble Field Points is designed for MEP contractors who need to create field layout points in SketchUp, Revit, or AutoCAD for direct integration with Trimble's robotic total stations.

References:

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Aim and key learning outcomes of this topic

The aim of this topic is to ensure that students understand the objectives and information requirements of the designers for achieving energy efficient buildings. (Contributes to overall Learning Outcome O1: Students will understand the different interests of stakeholders in achieving energy efficient buildings.)

On completion of this topic, students will:

- Appreciate the different objectives and information requirements of building designers
- Be able to apply their knowledge of building designers' objectives and information requirements in developing energy efficiency solutions.

Assessment

Formative assessment in the form of quiz questions to check familiarity and comprehension of the readings provided.

5 - Construction objectives and information requirements

Reading: Construction Objectives and Information Requirements

The twenty-eight Member States of the European Union (EU) have set an energy saving target of 32.5% by 2030 (European Commission, 2019), which will need to be reached mainly through energy efficiency measures. The EU has also committed to reducing greenhouse gas (GHG) emissions by 80–95% by 2050 (European Commission, 2011), as part of its roadmap to move to a competitive low-carbon economy in 2050. Buildings are one of the world's largest energy-consuming sectors. Considering the residential and service sector buildings account for nearly 33% of the final global energy consumption (OECD, 2011) and 40% of EU consumption (European Commission, 2017), energy refurbishment in the existing building stock is of particular relevance.

One of the primary objectives in the refurbishment of buildings is to identify the best combination of Energy Conservation Measures (ECMs) in terms of energy efficiency. The current Building Energy Performance (BEP) simulation tools require a great deal of time and effort because data from multiple sources must be properly combined (e.g., building/urban models, ECM catalogues, weather condition files) in order to create energy simulation models. Costa et al. (2019) present a system that takes advantage of the capabilities of these technologies to integrate ECM data into BEP simulation models in an automated way. The system is composed of a catalogue of ECM measures described in Resource Description Framework (RDF) and a software component that facilitates their application in the models. The system has been developed in the context of OptEEmAL, a research project aimed at creating a web platform to facilitate building simulations at a district scale.

There are a lot of simulations tools developed for construction practitioners to serve as the basis for further development in construction automation (Desgagné-Lebeuf et al. 2019) which is presented in Table 1.

Table 1. List of the computer-assisted tools (Desgagné-Lebeuf et al. 2019)

Computer-assisted tools	**References**
CasCADe	(Ivson et al., 2018)
Automated scheduling using context aware construction requirements	(Yeoh Justin K. W. et al., 2017)
Cost schedule integration system	(Fan et al., 2015)
Spatial information reasoner	(Kim and Cho, 2015)
BIM-based construction scheduling	(Liu et al., 2015)
Fuzzy project scheduling with minimal precedence relations	(Ponz-Tienda et al., 2015)
Multi-objective genetic optimization for scheduling	(Agrama, 2014)
Scheduling with genetic algorithm	(Faghihi et al., 2014)
Automated multi-objective construction logistics optimization system (AMCLOS)	(Said and El-Rayes, 2014)
Automated scheduling using context-aware construction requirements	(Shan and Goodrum, 2014)
Simulation-based scheduling for modular building	(Taghaddos et al., 2014)

BIM and simulation integrator for schedule support	(Wang et al., 2014)
Resource-constrained scheduling	(Benjaoran an
N-Dimensional project Scheduling and Management system	(Chen et al., 2013)
FReMAS	(Chua et al., 2013)
Space planning with simulation and Pareto	(Dang and Bargstadt, 2013)
Automated data extraction and scheduling using BIM	(Kim et al., 2013)
Safety compliance checker	(Melzner et al., 2013)
Scheduling with discrete event simulation	(Konig et al., 2012)
Post sim visualization to schedule modular building construction	(Moghadam et al., 2012)
BIM-based structural framework optimization and simulation	(Song et al., 2012)
Space planning with GIS and topology	(Bansal, 2011)
Temporary facility planning of a construction project using BIM	(Kim and Ahn, 2011)
Multi-dimensional project scheduling system	(Feng and Chen, 2010)
Visual scheduling application	(Karshenas an
High-rise building strategies using linear scheduling and 4D CAD	(Russell et al., 2009)
Construction Project Management Information System (MD-CPMIS)	(Feng and Chen, 2008)
Weather-aware BIM and simulation scheduler	(Hegazy an

Since this Desgagné-Lebeuf et al. (2019) study focuses on scheduling, time and cost appear as the most frequent objectives of the tools, with the addition of a few unconventional (though interesting) indicators. Figure 1 shows the frequency of the various performance indicators considered by the tools.

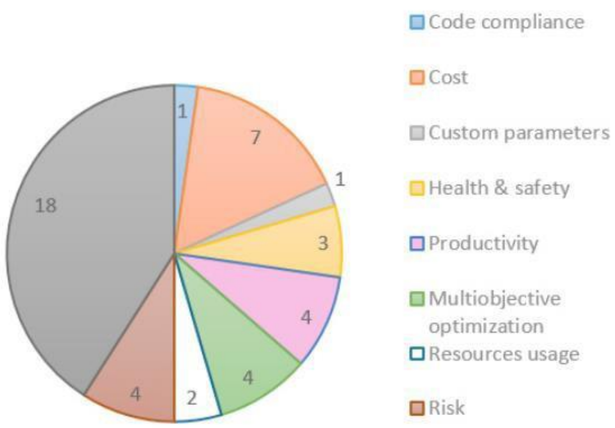

Figure 1. Frequency of performance indicators in the tools (Desgagné-Lebeuf et al. 2019)

Currently, the AEC industry is undergoing major changes, mostly driven by the implementation of Building Information Modeling (BIM), and the integration of new technologies. When coupling these with Lean principles, there is the potential to improve the productivity and efficiency of construction projects. Although Lean Construction and BIM are approaches with quite different initiatives, both have a profound impact on the industry. Heigermoser et al. (2019) defined the BIM functionalities with the highest concentration of unique interactions:

a) Aesthetic and functional evaluation;
b) Multi-user viewing of merged or separate multi-discipline models;
c) 4D visualization of construction schedules;
d) Online communication of product and process information.

Realizing that the BIM functionalities a), b), and d) are mostly concerned with the field of construction management it can be asserted, that integrating the Lean Management approach with the technical capabilities of BIM will bring benefits to the overall productivity and efficiency of construction projects and enhance the planning process in the Last Planner System (LPS) (Sacks et al. 2010). However, even decades after adopting the Lean Production System in the AEC industry, commercial software does not fully support the LPS. When applying the LPS to construction projects, it is common to use sticky notes and self-created spreadsheets without making use of the added value of holding the data in a cloud-based data system – also with regards to subsequent projects. This lack of commercial BIM software integrating Lean has been tackled in previous research: Sriprasert & Dawood's (2003) developed Lean Enterprise Web-based Information System (LEWIS), Dave et al.'s (2011) VisiLean tool, and Sacks et al.'s (2013) KanBIM Workflow Management System. All research methods developed and tested a prototype construction management tool. To capitalize on these synergies and promote the combined use of Lean and BIM a prototype tool was developed to provide the integration of the LPS workflow using BIM. The developed tool meets all basic requirements of commercial BIM software and covers the functional requirements and features of previously developed research projects. Heigermoser et al. (2019) proposes a construction management tool that combines the LPS with the 3D visualization of construction projects to improve productivity and reduce construction waste. The objectives of the prototype tool are shown in Figure 2. These objectives consist of the Lean fundamentals, BIM functionalities with the highest concentration of unique

interactions, and further Lean principles that are considered as fundamental for the management of construction projects during the execution phase.

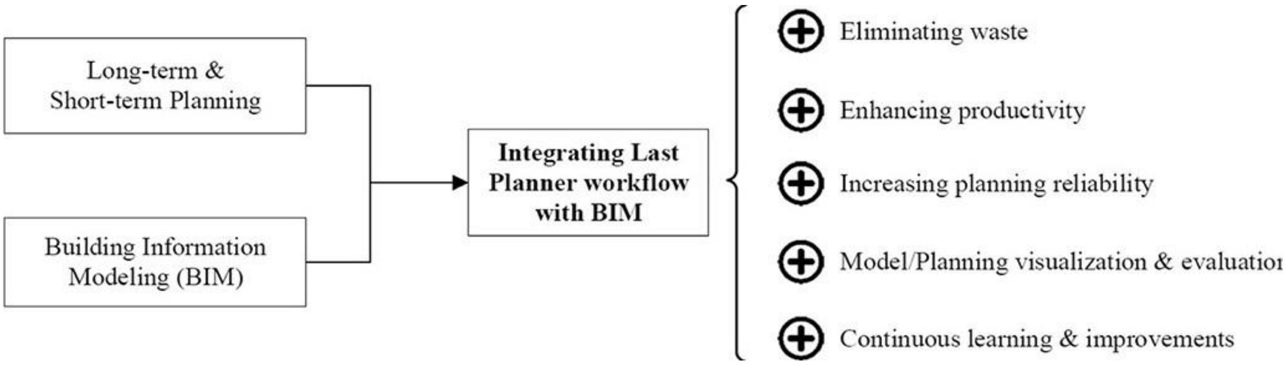

Figure 2. The objectives of the integrated Lean Management approach using BIM (Heigermoser et al. 2019)

Research efforts have been proving that computer simulation is a useful decision-support tool for construction projects for more than four decades. Nevertheless, it has not gained widespread adoption by the industry. Abdelmegid et al. (2020) summarises the barriers to adopting simulation in the construction industry and the level of attention those barriers have received from researchers to date. Reserachers carried out the systematic literature review by searching databases and the profiles of the top researchers in this field to identify the journal papers, conference articles, and theses that have addressed the barriers from 2000 to 2019. Recent studies investigated the determinants that lead to the gap between construction simulation state-of-the-art and state-of- practice using different methodologies. Lee et al. (2013) studied several challenges in construction simulation as identified in a focus group discussion by the Visualization, Information Modelling, and Simulation (VIMS) committee under the American Society of Civil Engineers (ASCE) umbrella. Similarly, Leite et al. (2016) presented 6 grand challenges in construction simulation as derived by the VIMS committee. These challenges were then assessed by a survey on 17 academics and 10 industry practitioners to rank their relative importance. Overcoming some of these challenges, such as the complexity of building simulation models and the amount and nature of simulation input data, has been the primary objective of several construction simulation studies over the past two decades.

Table 2 lists the findings of the content analysis. Identified barriers were classified into four main categories: (1) Nature of construction projects, (2) Industry practitioners, (3) Simulation technology, and (4) Construction simulation research. Figure 3 sorts the identified barriers based on their frequency of reporting in the selected documents (Abdelmegid et al. 2020).

Table 2. Barriers to simulation adoption in the construction industry. (Abdelmegid et al. 2020)

Construction projects (CP)
1. Dynamic and risky nature of construction operations
2. Temporariness and uniqueness of construction projects
3. Time constraints

Simulation technology (ST)
1. The amount and nature of input data requirements
2. The complexity of simulation methodologies
3. The high cost of simulation studies
4. The high level of effort required to build simulation models
5. The long cycle time of simulation studies
6. The sophisticated nature of simulation outputs
The special skills required to develop simulation models

Industry practitioners (IP)
1. Industry culture and low confidence in simulation technologies
2. Lack of proper simulation knowledge among construction practitioners

Construction simulation research (CSR)
1. Lack of collaborative construction simulation studies
2. Limitations in construction simulation tools and methods

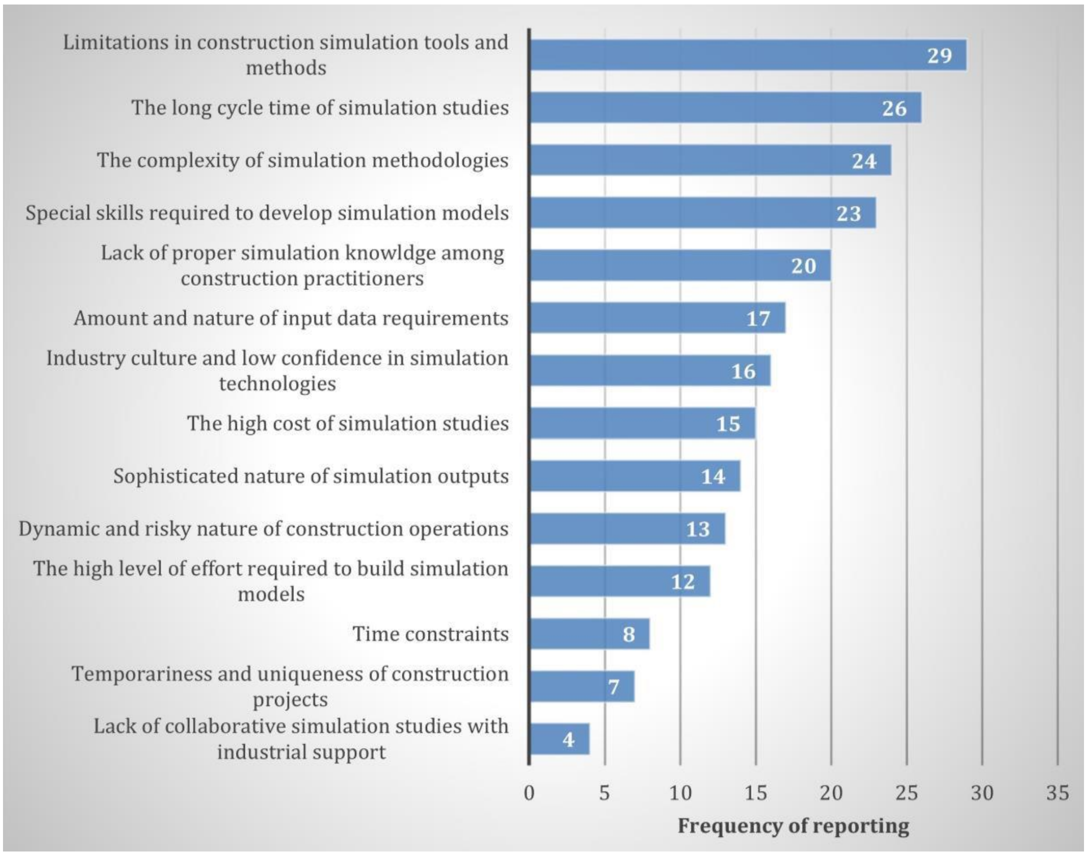

Figure 3. Analysis of barriers to simulation adoption in the construction industry (Abdelmegid et al. 2020)

Figure 4 depicts the cumulative frequency for each barrier against the publication year. It can be found that barriers related to "Simulation Technology" (ST in blue) have high frequency over the years in general, especially long development time, special skills, and complexity of simulation methodologies. Barriers that belong to the category of "Industry Practitioners" (IP in red) have fluctuated frequency, but in general, they received average interest compared to other barriers. Barriers of "Construction Projects" (CP in green) have low frequency and are of the least interest to researchers. Finally, the two barriers related to "Construction Simulation Research" (CSR in orange) have different results. It seems that the lack of collaborative studies did not catch the attention of most researchers in general as it has the lowest frequency for most years. On the other hand, the barrier of limitations of current construction simulation methods was the most frequent barrier by 2019 (Abdelmegid et al. 2020).

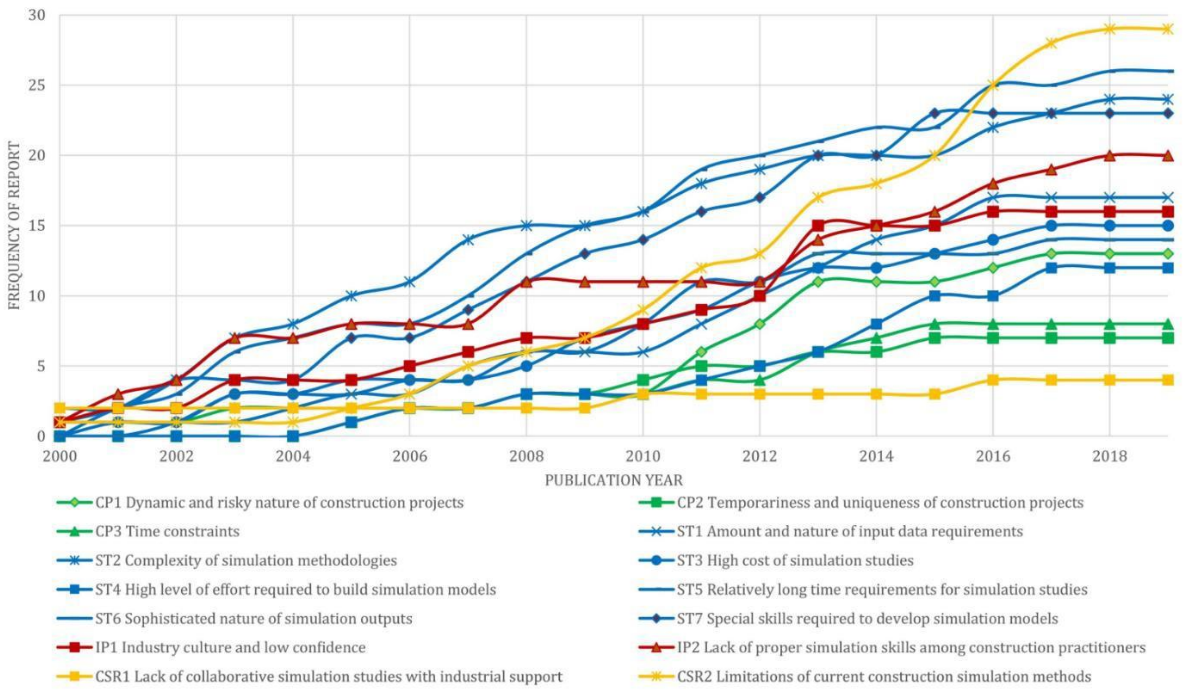

Figure 4.Trends in barriers (Abdelmegid et al. 2020)

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Aim and key learning outcomes of this topic

The aim of this topic is to ensure that students understand the objectives and information requirements of construction for achieving energy efficient buildings. (Contributes to overall Learning Outcome O1: Students will understand the different interests of stakeholders in achieving energy efficient buildings.)

On completion of this topic, students will:

- Appreciate the construction objectives and information requirements
- Be able to apply their knowledge of construction objectives and information requirements in developing energy efficiency solutions.

Assessment

Formative assessment in the form of quiz questions to check familiarity and comprehension of the readings provided.

Recommended sources of further information

Construction Project Management: Objectives of a Cost System:

https://www.youtube.com/watch?v=no-k_Ve0sfA&ab_channel=RedVectorOnline

Virtual Design and Construction (VDC) overview:

https://www.youtube.com/watch?v=Y6qJ_KG6Jwo&ab_channel=MMoserAssociates

Virtual Design and Construction, VDC, by NCC:

https://www.youtube.com/watch?v=aqLcDI_vW7g

Virtual Design and Construction (VDC): https://www.youtube.com/watch?v=RfrprapVnQ8

SYNCHRO 4D BIM/VDC Construction Project Management:

https://www.youtube.com/watch?v=sX0NUKDJ3b4&ab_channel=SYNCHROConstruction

6 - Facilities management objectives and information requirements

Reading: Facilities Management (FM) Objectives and Information Requirements

Facilities management (FM) refers to the practices used in adopting design and management knowledge to ensure the environment satisfy the needs of the people (Alexander 1996; Amaratunga 2001). FM consists of three major components: space management, building services, and supporting facilities components (Leung et al. 2012, 2014, Leung, Liang 2019). Capturing a building's intricate and expanding portfolio of data requirements for facilities management (FM) is complex and requires facilities managers with tenacious strategic and tactical skills (Antje Junghans et al. 2014, Codinhoto et al. 2013). These skills encompass diverse roles and duties may include the strategic planning and management of: plant operations; computer systems analysis; building assets; interior operations; and day-to-day tactical operations of assets and staff (Demkin 2006).

Undoubtedly, Information Communication Technology (ICT) can provide powerful strategic and tactical tools for organisations, which, if properly applied and used, could bring significant advantages in promoting and strengthening their competitiveness (Aziz et al. 2016a). Referring to Figure 1, the history of ICT in FM history briefly summarize in emerging style and specification of software/tools reviewed in this parallel graphic. Each type of software has limitations and advantages (Weygant, 2011) but, many software applications already have changed management and tracking features that can help building industry professionals maintain a record of the evolution of the information (Smith, Tardif 2009). Some of the software can be operate integrated with other software/ tools such as Building Energy Management Systems (BEMS) and CAFM.

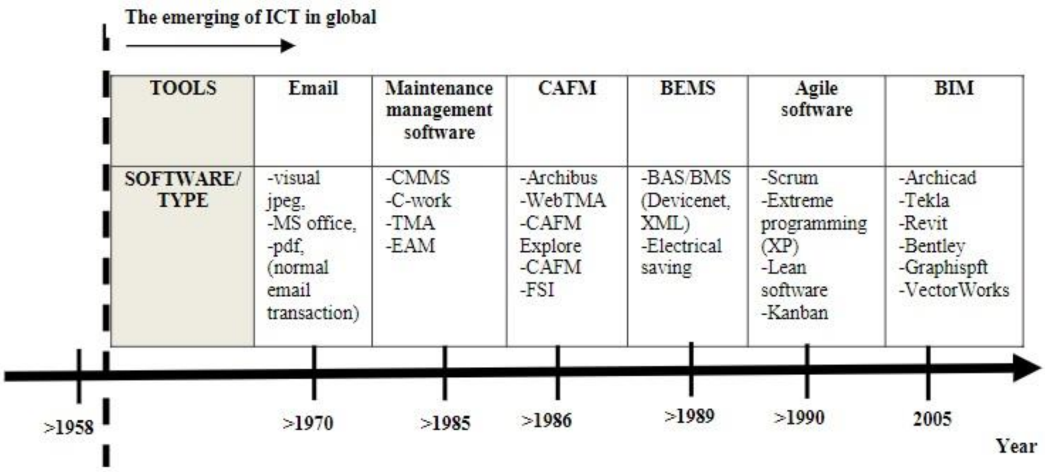

Figure 1. ICT evolution in FM for over 40 years (Aziz et al. 2016a)

The diversity of software in the market can induce confusion of Facility Managers to select the best the most suitable software in FM. Furthermore, Facility Manager can select best the software/ tools for higher job satisfaction among employee or building occupant suit with business objective. In term of QOL, life become easier and simpler with aided of these complicated technology. The contribution of new technology to economic growth can realize when and if the new technology is widely adopted and used. The greater risk taken, the higher benefit gain if Facility Manager adopt new technology in organization (Aziz et al. 2016a).

Current facility management practice relies on different systems which require new technologies to integrate and manage information more easily. Building information modeling offers a good opportunity to improve facility information management by providing a unified platform for various data sources rather than an intuitive information interface. Among the practical implications found: Improved technological and environmental performances assessment; better visualization of building condition; improved decision-making process; facilitated maintenance tasks planning and maintenance records management (Marmo et al. 2019). BIM provides a unified platform (Figure 2) for various data sources needed for daily operations and maintenance (O&M) activities, so that data regarding technical specification, planned activities, and building performances (simulated or monitored) can be integrated to

facilitate the decision-making process (Marmo et al. 2019).

Facility Management Information Systems		
BEMS/BAS • Monitoring equipment conditions • Optimizing performances • Reporting failures	CMMS • Tracking work orders • Scheduling task • Recording interventions • Managing inventory	DMS • Capturing and versioning documents • Supporting workflow and collaboration

Figure 2. Facility management (FM) information systems (Marmo et al. 2019).

Information exchange between BIM models and FM systems is not a straightforward process, as software interoperability remains a significant challenge. Bridging this gap requires (Matarneh et al. 2019):

- a seamless information exchange process between BIM and FM systems,
- holistic guidance for facility owners and managers that encapsulates all required information for efficient FM operations across all systems and building types,
- a well-defined information quality process that ensures owner/FM needs are considered carefully in BIM models,
- standardized practical processes to integrate different information sources related to maintenance management and health & safety management tasks, to provide a rich semantic database to support FM systems,
- a standardized process for feedback loops between operations and design phases to provide rich actual feedback to support efficient facilities design, and
- more real-world case studies to investigate the current status of BIM implementation in FM.

Figure 3 presents an abridged timeline overview of prominent UK and international standards governing FM, alongside the key developments in FM and BIM documentation in the UK. These standards provide coverage of: data management; naming conventions; common data environment; IFCs data management and interoperability; as well as construction information transfer. Construction Operations Building Information Exchange (COBie) standards (published since 2007 in the US and later adopted as British Standard in 2014) help to improve the handover of asset related data via the BIM model to the facility managers and/or building owners (Pärn et al. 2017)

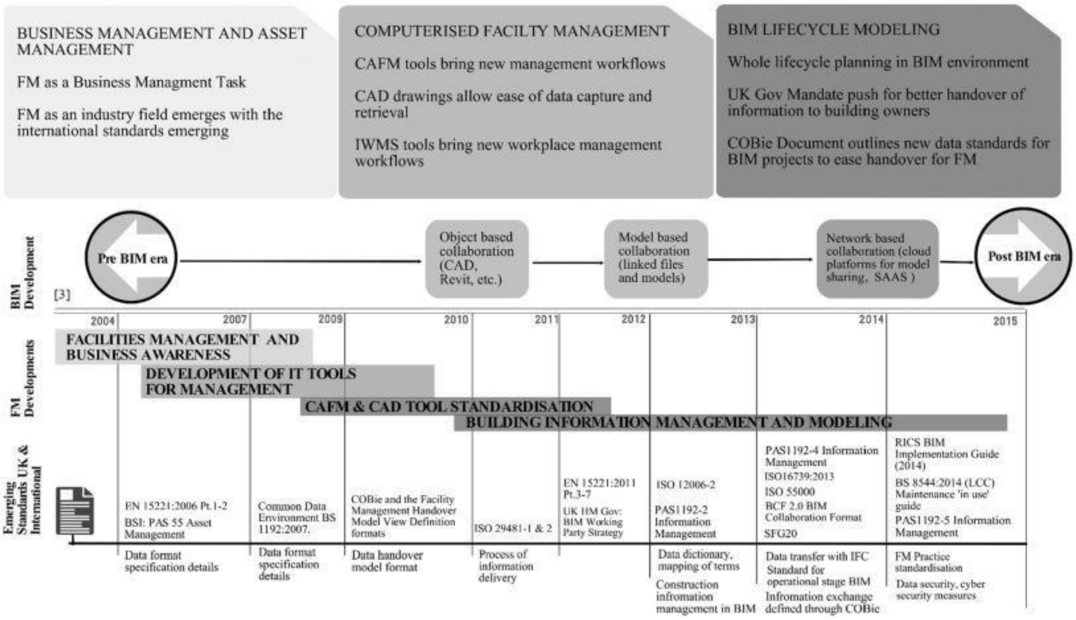

Figure 3. Development of BIM and FM standards (Pärn et al. 2017)

Figure 4 presents a diagrammatic representation of the potential for a knowledge based feedback loop from BIM and FM data integration. This development could improve interoperability in several key areas. First, data pertaining to a building's operational performance during the O&M phase allows clients to develop optimum strategic maintenance plans. Second, comparison between actual and predicted building performance will allow both designers and contractors to improve the performance of future building developments (British Institute of Facilities… 2013, Pärn et al. 2017)

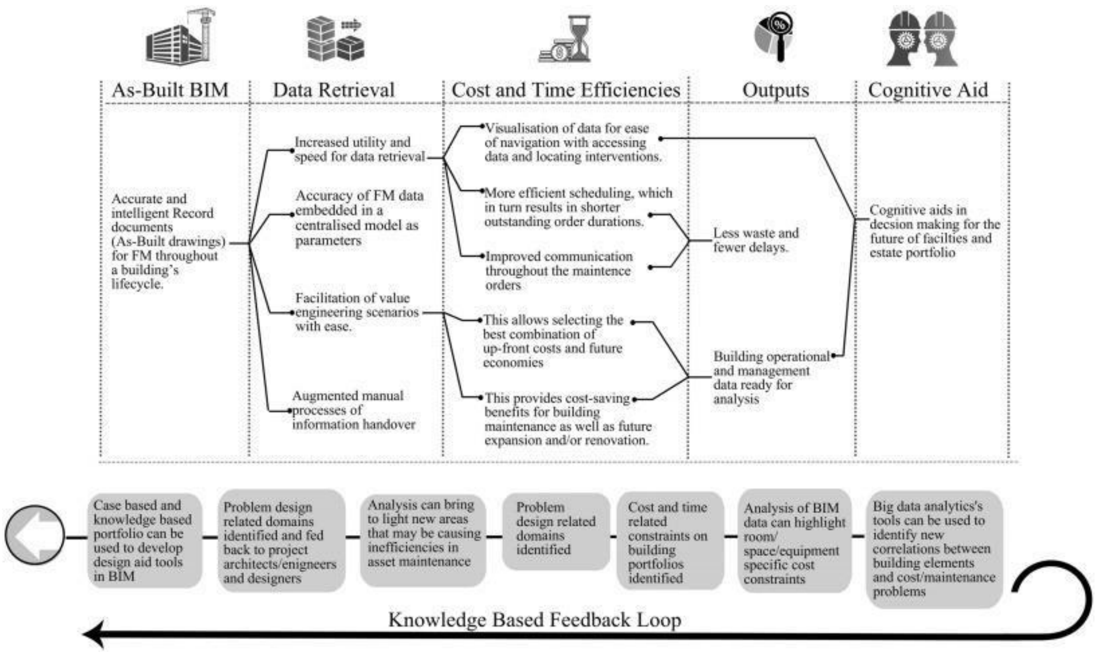

Fig. 4. Diagrammatic representation of the potential for knowledge based feedback loop from BIM and FM data integration (Pärn et al. 2017)

The demand of Building Information Modelling (BIM) is increasing recently as much international organisation and government taking the initiative to promote BIM in building life- cycle. Although the implementation of BIM is not an easy thing, BIM promising to benefits of efficient Information Management (IM) in Facilities Management (FM) (Aziz et al. 2016b).

FM often misunderstood that task limited tactical level, but FM is competencies include in strategic level. In 2009, the Global Job Task Analysis (GJTA) done a comprehensive survey that included facility managers in 62 countries categorized 11 core competencies (refer Table 1) in FM that can view in narrow or broader perspective. Indeed, FM definition from IFMA is considered to be defined that FM is a profession that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, place, process and technology. The integration of 3P and 1T created the sustainable built environment by appreciating professional (Aziz et al. 2016b).

Table 1. Core competencies in Facilities Management (IFMA 2013, Aziz et al. 2016b).

Scope	Core Competencies
Facilities Management (FM)	Communication Emergencies Preparedness and Business Continuity Environmental Stewardship and Sustainability Finance and Business Human Factors Leadership and Strategy Operations and Maintenance Project Management Quality Real Estate and Property Management Technology

Aziz et al. (2016b) finding reveal that the benefit gained for the benefit of quality of life are 1) Operational cost; 2) Shorter time for decision making; 3) Resource for decision making; 4) Better documentation system; 5) Collaboration and work flexibility; 6) Updated information and clash detection. To achieve quality of life in FM for a sustainable workplace integrated with 3P and 1T in built environment, BIM is recommended. The practical practice of conceptual framework among stakeholder may increase the organization reputation and enhance value of asset as outgoing smooth data management may conduct working environment much systematic.

Ammari, Hammad (2019) discussed the development of a collaborative BIM-based MR approach to support facilities field tasks. Facilities Management (FM) tasks are fragmented and require gathering and sharing large amounts of information related to facilities spaces and components, and covering historical inspection data and operation information. Despite the availability of sophisticated Computerized Maintenance Management Systems (CMMSs), these systems focus on the data management aspects (i.e., work orders, resource management and asset inventory) and lack the functions required to facilitate data collection and data entry, as well as data retrieval and visualization when and where needed.

The proposed framework integrates multisource facilities information, BIM models, and feature-based tracking in an MR-based setting to retrieve information based on time (e.g. inspection schedule) and the location of the field worker, visualize inspection and maintenance operations, and support remote collaboration and visual communication between the field worker and the manager at the office. The field worker uses an Augmented Reality (AR) application

installed on his/her tablet. The manager at the office uses an Immersive Augmented Virtuality (IAV) application installed on a desktop computer. Based on the field worker location, as well as the inspection or maintenance schedule, the field worker is given work orders and instructions from the office. Interactive visual collaboration is shown in Figure 5. Other sensory data (e.g., infrared thermography) can provide additional layers of information by augmenting the actual view of the field worker and supporting him/her in making effective decisions about existing and potential problems while communicating with the office in an Interactive Virtual Collaboration (IVC) mode (Ammari, Hammad 2019).

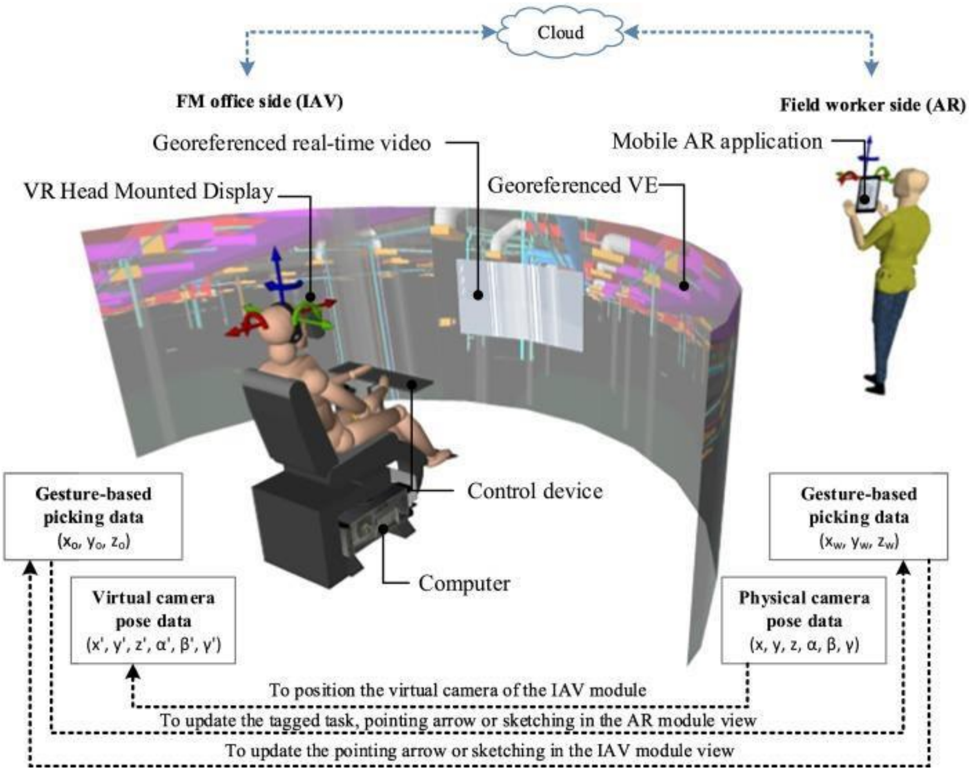

Figure 5. Interactive visual collaboration (Ammari, Hammad 2019).

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FM simulations tools

Title	Description
Flomerics	Flovent software from Flomerics reduces the time and skill required to simulate complex ventilation problems. SmartParts for the company's Flovent software improves accuracy in simulating the performance of diffusers. SmartParts models can simply be dropped into a Flovent model and require only commonly available data for the diffuser such as outside dimensions, flow rate and temperature data.
Autodesk AutoCAD for Mac	Stay at the forefront of design with Autodesk® AutoCAD® for Mac software. Easily share precise drawings, and work across connected desktop and mobile solutions with the reliability of TrustedDWG™ technology.

IMAGINiT Clarity Owner Data Portal	IMAGINiT Clarity Owner Data Portal bridges the gap between BIM and FM, removing barriers to distributing Revit data within an owner organization.
Autodesk Architecture, Engineering & Construction Collection	Autodesk® Architecture, Engineering & Construction Collection: One essential BIM package for building, civil infrastructure, and construction.
Autodesk AutoCAD	Subscribe to Autodesk® AutoCAD® including specialized toolsets and get access to industry-specific functionality, greater mobility with the new web and mobile apps, and the latest feature updates. Speed up your work with specialized features & libraries while working in a familiar AutoCAD interface. Only AutoCAD, with the new web and mobile apps, gives you the freedom and flexibility to work on anything, anywhere, at any time.
Archibus Healthcare Compliance	Archibus Healthcare Compliance allows organizations to measure, assess and improve performance while meeting reporting requirements for The Joint Commission, NFPA, and other accrediting agencies.
Archibus Smart Client Extension	Archibus Healthcare Compliance allows organizations to measure, assess and improve performance while meeting reporting requirements for The Joint Commission, NFPA, and other accrediting agencies.
Archibus	Archibus is the #1 provider of real estate, infrastructure and facilities management solutions in the world. With over three million users, Archibus is one of the most widely used Integrated Workplace Management System (IWMS) in the world.

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Aim and key learning outcomes of this topic

The aim of this topic is to ensure that students understand the Facilities Management (FM) objectives and information requirements for achieving energy efficient buildings. (Contributes to overall Learning Outcome O1: Students will understand the different interests of stakeholders in achieving energy efficient buildings.)

On completion of this topic, students will:

- Appreciate the Facilities Management (FM) objectives and information requirements
- Be able to apply their knowledge of Facilities Management (FM) objectives and information requirements in developing energy efficiency solutions.

Assessment

Formative assessment in the form of quiz questions to check familiarity and comprehension of the readings provided.

7 - Other stakeholders' objectives and information requirements

Video material for other stakelolders (local government, utilities companies)

Title	Link	Description
UK Government Construction Strategy 2016-2020 Explained | The B1M	https://www.youtube.com/watch?v=nTizPwr-1Es	The UK Government have published their new Construction Strategy for 2016 to 2020, building on the progress made in the 2011-2015 version. Here, we take a quick look at the Strategy's four principal objectives and the plans to achieve them over the course of the current Parliament.
Design-Build Procurement	https://www.youtube.com/watch?v=Mg0m_31ZlVY	
The basics of Construction (Design and Management) Regulations 2015	https://www.youtube.com/watch?v=V1jLyWTscjs	Never heard about the Construction (Design and Management) Regulations? What does that have to do with your job in construction?
Getting A Building Permit: From Start to Finish	https://www.youtube.com/watch?v=VW_-b6ZHiuQ	A permit is a legal document required by state law to allow you to start construction to ensure the safety of the occupants within the structure. This video takes you through the process of obtaining a building permit in Fairfax County, including the inspections process.
BUILDING PLAN APPROVAL	https://www.youtube.com/watch?v=Xf7fOV3guxk	
Permit Like a Pro | How to Obtain a Building Permit	https://www.youtube.com/watch?v=TnZ22ukoSh0	In this video you will learn how to obtain a residential building permit from the City of Phoenix Planning and Development Department. The permit and the plan review process is very important.
The Construction Permit Process	https://www.youtube.com/watch?v=uN1Ih30_pNw	
Choosing a Construction Project Delivery Method	https://www.youtube.com/watch?v=jAz0I2BPyks	Before taking on a building project, learn the basics about four common construction project delivery methods--hard bid, construction management agency, construction manager at-risk, and design-build--so you can choose the one that's right for you.
A typical pipeline construction	https://www.youtube.com/watch?v=47yFvw0lJyw	Many of our water supply projects involve laying a new pipeline
Underground Electrical Piping Gallery	https://www.youtube.com/watch?v=NHosMyzTPRE	North East Water Pollution Treatment Facility New Gravity Thickner Building underground electrical, communication and manhole PVC conduit gallery
Plumbing in Revit MEP Beginner Tutorial	https://www.youtube.com/watch?v=Mvb-lu6ivq0	
Designing Electrical Substation For Future Tutorial	https://www.youtube.com/watch?v=k4DwwS393AY	Designing Electrical Substation in AutoCAD Tutorial Autodesk Inventor Professional & Substation Design Suite (SDS) SDS is an add-in for inventor that deals specifically with substation design tools.

Telecommunication Webinar: Engineering & Design	https://www.youtube.com/watch?v=omZvLPCsD4c	Planning, designing and constructing fiber networks on time and within budget is critical in a highly competitive environment where customer bandwidth demands are growing exponentially. Learn how 3-GIS delivers network solutions that leverage the ArcGIS platform to automate and streamline processes, ensuring you cost effectively deliver the best fit plans with the right architecture. You will maximize your engineering resources to be able to accelerate time to revenue and leverage existing fiber assets. www.esri.com/industries/telecom
GNS3 Free Network Emulator Tool	https://www.youtube.com/watch?v=iLmEJv9yo0M	Download the GNS3 Free Network Emulator: http://bit.ly/GNS3FreeNetworkEmulator Build, Design and Test your network in a risk-free virtual environment and access the largest networking community to help. Whether you are studying for your first networking exam or building out a state-wide telecommunications network, GNS3 offers an easy way to design and build networks of any size without the need for hardware. And the best part is it's free!
Telecommunication Solution: Node Capacity Analysis	https://www.youtube.com/watch?v=XYw-uX3Nu0Q	Demonstration of node capacity analysis and bandwidth monitoring using Insights for ArcGIS.
Roadway Design Software	https://www.youtube.com/watch?v=6vt0m6SbQAQ	Design Roadways, Highways and Motorways easily and effectively with ROAD CEM software.
Mining and construction economy map - How to Asphalt a Road - mod pack	https://www.youtube.com/watch?v=2QnNkzJiSY8	
Construction Simulator 3 Asphalt #2 HD	https://www.youtube.com/watch?v=SnKmoXSlNGE	Construction Simulator 3 returns to Europe! Discover an idyllic European town in the sequel to the popular Construction Simulator 2 and Construction Simulator 2014 with officially licensed vehicles by famous brands: Caterpillar, Liebherr, CASE, Bobcat, Palfinger, STILL, MAN, ATLAS, Bell, BOMAG, WIRTGEN GmbH, JOSEPH VOGELE AG, HAMM AG and MEILLER Kipper. Take on diverse and challenging contracts. Build and repair roads and houses. Shape the skyline of your city and expand your vehicle fleet. Explore a completely new map and unlock new contracts and vehicles with your growing company.
4d construction schedule animation	https://www.youtube.com/watch?v=k2lfuiYmT0w	V5D help contractors to win bids by presenting the programme schedule and site logistics into a visual narrative that is easily understandable to both a professional or non-technical audience. We supply a 3 to 6-minute animation that is shown during a bid presentation supported by stills supplied for the document submission. Our animations contain two elements, the construction sequence of the build and the site logistics methodology.

Construction Simulation for Viaducts and Stations	https://www.youtube.com/watch?v=_2AkbkgakzQ	Let's have a look at the video made by Fuzor to show the Construction Sequence Simulation for Viaducts and Stations in daytime and nighttime.

Aim and key learning outcomes of this topic

The aim of this topic is to ensure that students understand other stakeholders' objectives and information requirements for achieving energy efficient buildings. (Contributes to overall Learning Outcome O1: Students will understand the different interests of stakeholders in achieving energy efficient buildings.)

On completion of this topic, students will:

- Appreciate the other stakeholders' objectives and information requirements
- Be able to apply their knowledge of other stakeholders' objectives and information requirements in developing energy efficiency solutions.

Assessment

Formative assessment in the form of quiz questions to check familiarity and comprehension of the readings provided.

8 - Setting energy efficiency optimization criteria and functions

Open Source Tools for Setting Energy Efficiency Optimization Criteria and Functions

List of tools to analyze the integration of renewable energy sources to buildings (Mahmud et al. 2018)

Tool	Description/source	Availability	Application
ApacheHVAC, ApacheSim	Integrated Environmental Solutions (IES), (www.iesve.com)	Commercial	Analysis of building energy systems, solar and thermal systems
BITES	BITES (Buildings Industry Transportation Electricity Scenarios), NREL, (https://bites.nrel.gov/index.php)	Limited	Analyze buildings energy and renewable energy generation and their impact, and carbon emissions
Bsim	BSim, (http://sbi.dk/en/bsim)	Commercial	Building-attached PV and electrical systems modeling and analysis
BuildingAdvice	Building energy software, (www.buildingenergysoftwaretools.com)	Commercial	Whole-building energy systems modeling and simulation, renewable energy systems
CHP Capacity Optimizer	Cooling, heating, and power (CHP) capacity optimizer, ORNL, (www.buildingenergysoftwaretools.com)	Free to use	Analysis and optimization of distributed generation systems, and on-site cogeneration systems evaluation
MC4Suite	Mc4Software, (www.mc4software.com)	Commercial	Modeling and analysis of commercial and residential building energy systems (specially HVAC systems), and PV systems
REM/Rate, REM/Design	REM/Rate, (www.remrate.com)	Commercial	Modeling and analysis of building energy systems, and PV systems
SEMERGY	XYLEM Technologies, (www.xylem-technologies.com)	Commercial	Modeling and efficiency analysis of building energy systems, and PV systems

List of tools to analyze the economy of building energy systems (Mahmud et al. 2018)

Tool	Description/source	Availability	Application
DOE-2, VisualDOE	DoE, U.S., (http://doe2.com/DOE2/index.html)	Free to use	Forecasting and management of building energy demand, and their cost analysis
EnergyElephant	EnergyElephant, (https://energyelephant.com)	Commercial	Building energy billing analysis and pricing comparison
EnExPlan	Energy Expert Planning (EnExPlan), (www.almiranta.com/enexplan)	Commercial	Building energy load and energy savings calculations

Tool	Description/source	Availability	Application
EnergyGauge	EnergyGauge, (www.energygauge.com/)	Commercial	Modeling, analysis, and economy analysis of building energy systems
ENER-WIN	Degelman Engineering Group, and Texas A&M University, (http://pages.suddenlink.net/enerwin/)	Commercial	Modeling, analysis, and economy analysis of building energy systems, and emission calculation
HAP	Hourly analysis program (HAP), (www.carrier.com)	Commercial	Modeling and analysis of building energy systems, economy analysis and cost comparison
MarketManager	Abraxas Energy, (www.optegy.com/sware.html)	Commercial	Modeling, analysis, and planning of building energy systems, and cost analysis

References:

Mahmud, K., Amin, U., Hossain, M. J., & Ravishankar, J. (2018). Computational tools for design, analysis, and management of residential energy systems. Applied Energy, 221, 535-556.

Aim and key learning outcomes of this topic

The aim of this topic is to ensure that students are able to determine energy efficiency optimization criteria and functions and are aware of various tools to help them carry this out. (Contributes to overall Learning Outcome O3: Students will have gained near real-life experience in decision-making, communication and teamworking to achieve energy efficiency in buildings.)

On completion of this topic, students will:

- Have a working knowledge of energy efficiency optimization criteria and functions
- Be able to apply their knowledge and various tools in the development of energy efficiency solutions.

Assessment

Assessment takes the form of practical application of this knowledge and these tools in order to develop and to evaluate energy efficiency solutions that are developed in the project simulation part of the course (next topic).

Recommended sources of further information

ZERO Code Energy Calculator: https://zero-code.org/energy-calculator/

Selection of renewable energy system:

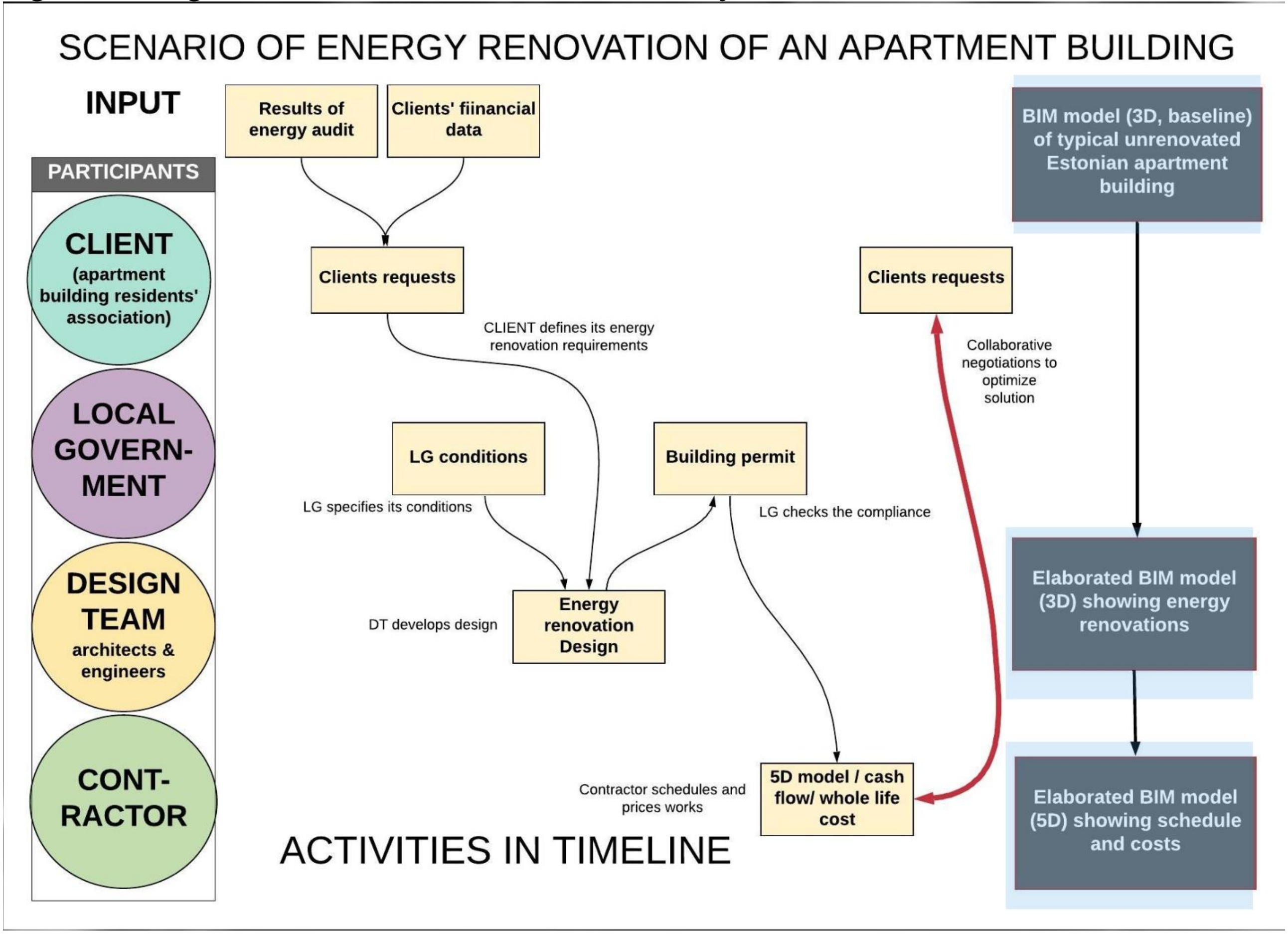
http://www.vaillantrenewables.co.uk/homeowner/index

9 - Project simulation

Project Simulation Group Work

Scenario - Energy renovation of an apartment building

Figure showing Work flow and Stakeholders for the Project Simulation



CLIENT INFORMATION

The Client (residents' association) defines its energy renovation requirements on the basis of an energy audit report and its own financial data. (see examples in Appendix)

DESIGN TEAM INFORMATION

The Design Team develops the client's requirements into a detailed design in compliance with all conditions set by Local Government.

LOCAL GOVERNMENT INFORMATION

Local Government checks compliance and issues a building permit.

CONTRACTOR INFORMATION

The Construction Contrator schedules and prices the works. The resulting price / cash flow is unnacceptable to the Client. Negotiations proceed to optimise the design on the basis of the whole life project cost / cash flow. (see examples in Appendix)

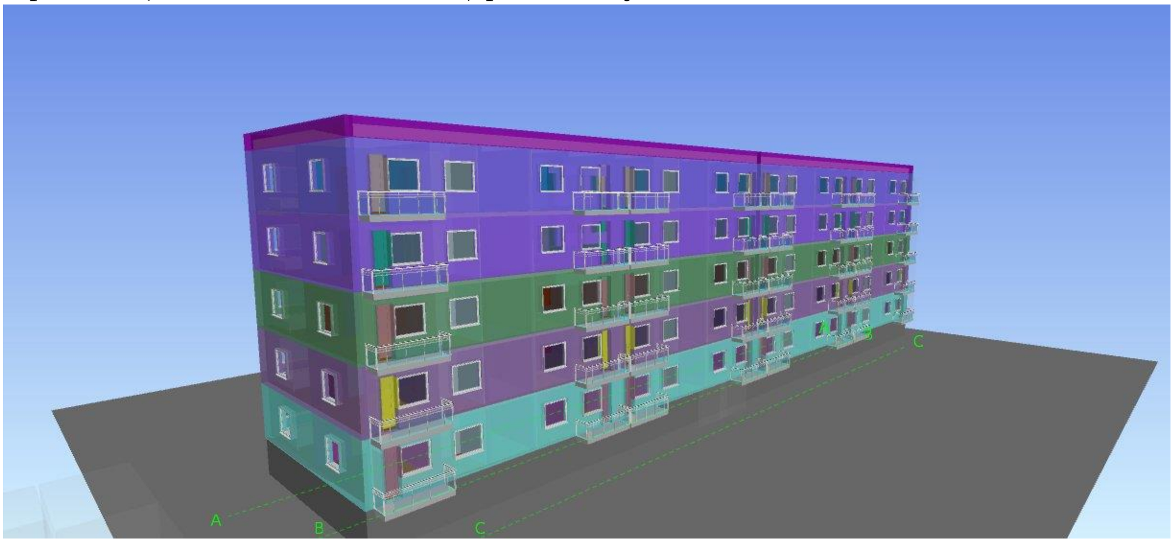
General principles of the simulation group work approach:

- Collaborative - all stakeholders have their own knowledge, expertise and information / needs with respect to this energy renovation project. Through collaboration, an optimised solution can be derived that benefits all stakeholders.

- BIM-enabled - BIM enables all steps of the work flow. The exercise work flow starts with a (baseline) BIM model and ends with a (further elaborated) BIM model. The initial, 3D baseline model helps the Client to visualize their requirements. Local Government conditions come in the form of (BIM-based) data format requirements for submission of the detailed design (as an elaborated BIM model showing the energy renovation design) by the Design Team. The initial and optimised solutions are represented as a 5D BIM model.

Work flow

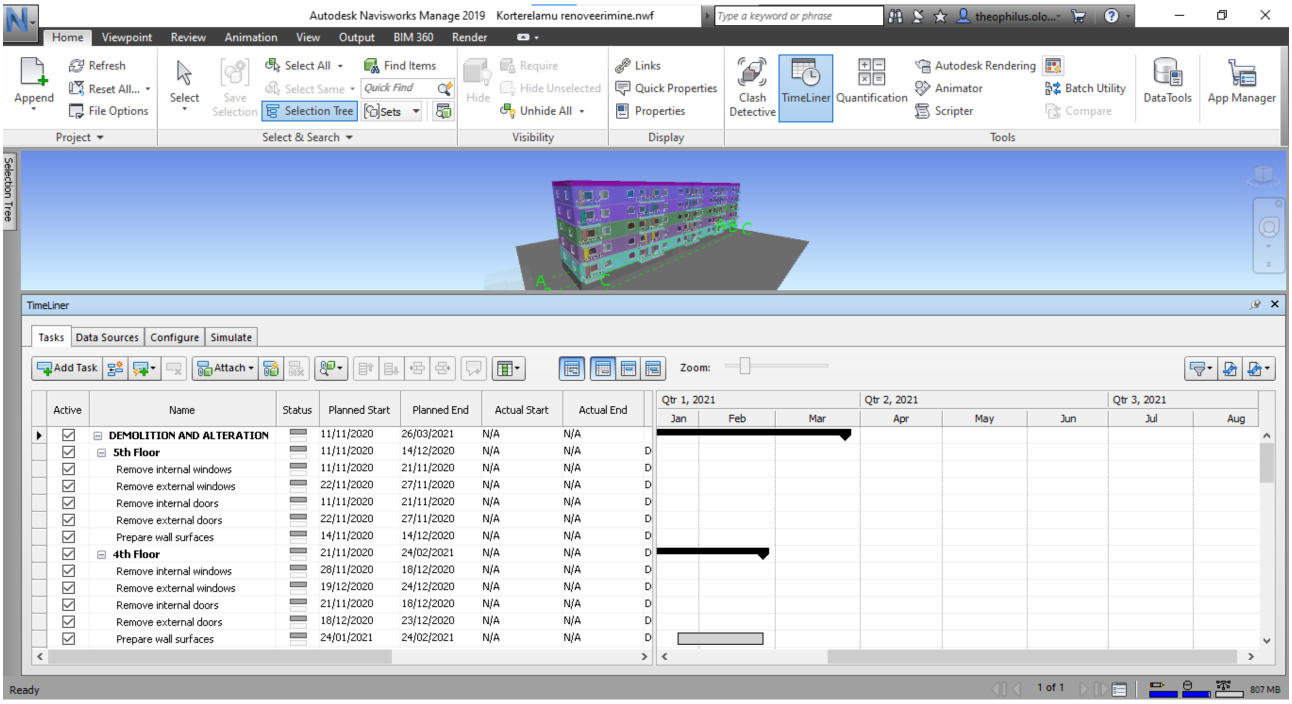
1. Input data (BIM model & other data) provided by instructors



2. Client defines its energy renovation requirements

(see examples in Appendix)

3. Local Govt specifies its conditions (Instructors may assume the role of Local Goverment)
4. Design Team develops design
5. Local Govt checks compliance
6. Construction Contractor schedules and prices works



7. Collaborative negotiations to optimise solution

For example, on the basis of the project cash flow (see example in Appendix).

Reading: Project Simulation

Simulation games are widely used in the study process (Sacks et al. 2007, Lam 2018, Nikolic 2011, Lee at al. 2011, Castronovo et al. 2015, González et al. 2015, Construction Simulator Pro 2017). For example, Lam (2018) developed sustainability performance simulation tools for building design. It is a physics-based software for simulating building energy use, taking as inputs the building description including geometry, construction materials, lighting, HVAC, refrigeration, water heating, renewables, and control strategies. Sacks et al. (2007) developed The Technion LEAPCON™ (Technion Lean Apartment Construction) game, which simulates construction of an eight story building with four apartments on each floor. It was initially developed to test the impact of a Lean management model that was proposed in response to the significant waste identified in the conventional approach to scheduling and managing construction of high-rise residential buildings. It was found to be an excellent tool for introducing project managers, site engineers, supervisors, senior management, and students at all levels to some of the basic concepts of lean construction: single-piece vs. batch flow, pull vs. push scheduling and control, and multi-skilling vs. task specialization.

The Virtual Construction Simulator (VCS) is another example of an educational simulation game. The aim of the VCS is to teach students the changeable nature of the construction process and the unpredictable factors that influence it. The VCS allows the learner to develop and manage construction schedules, while experiencing the variance between the as planned and the as-built schedule (Nikolic 2011, Lee at al. 2011). The game has gone through several iterations and the latest development efforts have produced the VCS3 (Lee at al. 2011). The VCS3 was developed with the Microsoft XNA Game Studio Express game engine. Castronovo et al. (2015) developed VCS4 game by using Building

Information Models. They developed a model for solving construction engineering problems (Fig. 1). This model mainly focuses on cognitive and metacognitive problem solving processes, prior knowledge, and the utilization of visual representations.

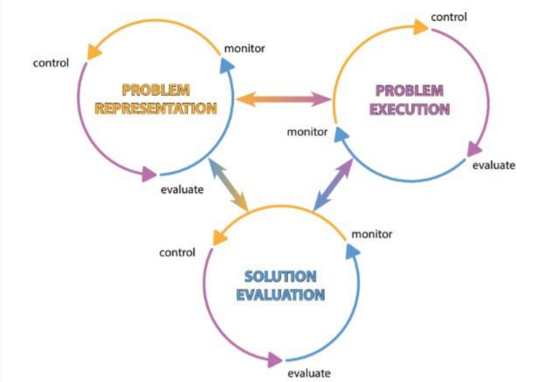


Figure 1. Problem-Solving Model for Construction Engineering Education

Game mechanics are the rules that direct the game play. The mechanics provide a structure for the game where the students can view their challenge, interact with the problem, and achieve a goal. Since the new research questions aimed at assessing the VCS's potential to enhance students' problem solving ability, the VCS4's game mechanics had to be redeveloped, and additional features, not present in the VCS3, had to be implemented. The research focus on problem solving required adding an iterative nature to the game in the way learners evaluate their proposed plans. The iterative nature of playing will allow the students to test their mental model and develop better problem-solving skills. Additionally, these new mechanics focused on laying out the game's structure, goals, scenes, interactions, and data flow. With this iterative nature at its core, the research team developed new game mechanics (see Fig. 2).

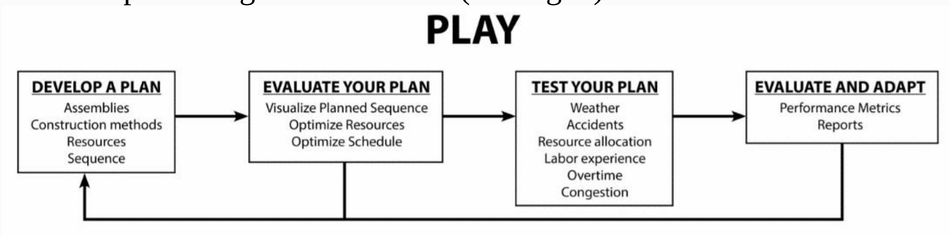


Figure 2. VCS4 Game Mechanics

One more simulation game is developed by González et al. (2015). They developed the new

simulation management game called LEBSCO, which simulates aspects of the Last Planner System (LPS) and Lean Production principles. LPS requires continuous and collaborative effort from all stakeholders for the planning and control of a construction project, making it especially appropriate for the experiential learning allowed by simulation. LEBSCO consists of the assembly of Lego™ pieces to form a schematic house, and it is played by teams meeting in rounds simulating weeks of work. Each team is composed of stakeholders, such as a planner, resource suppliers and trade foremen, mirroring the planning and control process of a typical construction project.

Construction Simulator Pro 2017 could also be used in the study process. It is one of the best games out there in describing the construction process from the very beginning to the end. You get the chance to operate a number of different vehicles (eg. cranes, bulldozers, etc.). Furthermore, you have the opportunity to build a name for yourself in the industry, starting from a contractor and moving further up in the hierarchy. Have a look at the video below and start building your empire in the construction industry.

References:

Castronovo, F., Zappe, S. E., Messner, J., & Leicht, R. M. (2015, January). Design of a construction simulation educational game through a cognitive lens. In ASEE Annual Conference and Exposition, Conference Proceedings (Vol. 122, No. 122nd ASEE Annual Conference and Exposition: Making Value for...).

Construction Simulator Pro 2017. Link: https://constructionsimulatorpro.com/

González, V. A., Orozco, F., Senior, B., Ingle, J., Forcael, E., & Alarcón, L. F. (2015). LEBSCO: Lean-based simulation game for construction management classrooms. Journal of Professional Issues in Engineering Education and Practice, 141(4), 04015002.

Lam, K. P. (2018). Sustainability Performance Simulation Tools for Building Design. Encyclopedia of Sustainability Science and Technology, 1-68.

Lee, S., Nikolic, D., Messner, J. I., & Anumba, C. J. (2011). The development of the virtual construction simulator 3: an interactive simulation environment for construction management education. In Computing in Civil Engineering (2011) (pp. 454-461).

Nikolic, D. (2011). Evaluating a simulation game in construction engineering education: The virtual construction simulator 3.

Sacks, R., Esquenazi, A., & Goldin, M. (2007). LEAPCON: Simulation of lean construction of high-rise apartment buildings. Journal of Construction Engineering and Management, 133(7), 529-539.

Aim and key learning outcomes of this topic

The aim of this topic is to allow students to experience a near-real energy renovation project scenario through project simulation group work. It also provides students with insights into the theoretical basis of project simulation for learning. (Contributes to Learning Outcome O2: Students will be able to argue their points of view and justify their decisions regarding energy efficiency; and Learning Outcome O3: Students will have gained near real-life experience in decision-making, communication and teamworking to achieve energy efficiency in buildings.)

On completion of this topic, students will:

- Appreciate the process through which energy renovation decisions are made and optimized.
- Be able to make and defend decisions in terms of energy efficiency renovations.

Assessment

Groups' outputs are peer reviewed and evaluated by other groups who must build on their work outputs.

In addition, formative assessment in the form of quiz questions to check familiarity and comprehension of the reading provided.

Recommended sources of further information

ZERO Code Energy Calculator: https://zero-code.org/energy-calculator/
Concrete Calculator: https://www.trachte.com/resources/calculator/concrete-calculator/
Conversion Investment Calculator: https://www.trachte.com/resources/calculator/conversion-investment-calculator
Calculation of construction materials, construction calculators and building constructors: http://www.zhitov.ru/en/
Selection of renewable energy system: http://www.vaillantrenewables.co.uk/homeowner/index

10 - Energy optimization

List of tools for modeling and analysis of building energy systems (Mahmud et al. 2018)

Tool	Description/source	Availability	Applications
AECOsim	Bentley Systems, (www.bentley.com)	Commercial	Residential energy performance analysis
AkWarm	AkWarm, (www.analysisnorth.com)	Free to use	Analysis of building energy systems and energy ratings
BCHP Screening Tool	Oak Ridge National Laboratory, U.S., (http://eber.ed.ornl.gov/bchpsc/)	Free to use	Modeling and analysis of institutional and commercial buildings
BEAVER	Building Energy Consumption Estimation, (http://members.ozemail.com.au/~acadsbs g/)	Commercial	Residential energy systems, energy consumption, and demand analysis
BEST	Building energy simulation tool (BEST), (www.ibec.or.jp/best/english/about/program.html)	Commercial	Analysis of building energy systems
BV^2	BV^2, (www.bv2.se/9eng/)	Free to use	Analysis of annual building energy usage
Czech National Calculation Tool	Czech Technical University, National Calculation Tool II, (http://nkn.fsv.cvut.cz/)	Limited	Analysis of building energy demand and performance
DIALux	DIAL GmbH, (www.dial.de/en/dialux/)	Free to use	Building lighting systems modeling and analysis
eQUEST	Quick Energy Simulation Tool, DoE, U.S., (www.doe2.com/equest/)	Free to use	Modeling and analysis of building energy systems
CAN-QUEST	Natural Resources Canada, (www.nrcan.gc.ca/energy/efficiency/buildings/eenb/16600)	Limited	Modeling and analysis of building energy systems (specialized for Canada)
EcoDesigner Star	EcoDesigner Star, (www.graphisoft.com/archicad/ecodesigner_star/)	Commercial	Modeling and analysis of building energy systems
EE4	Natural Resource Canada (NRCan), (www.nrcan.gc.ca/energy/software-tools/7453)	Free to use	Modeling and analysis of building energy systems
EFEN	EFEN, (www.fenestration.com/efen.php)	Commercial	Modeling and analysis of building energy systems
EnergyPlus	DOE, Building technologies office, (https://energyplus.net/)	Open source	Modeling and analysis of building energy systems
Energy-10	NREL, DOE, (www.nrel.gov/buildings/energy_analysis.html)	Free to use	Modeling and analysis of building energy systems
EZDOE	LBNL, DOE, (www.elitesoft.com/web/hvacr/elite_ezdoe_info.html)	Commercial	Modeling and analysis of commercial building energy systems
Tool	**Description/source**	**Availability**	**Applications**

Home Energy Saver	LBNL, (www.homeenergysaver.lbl.gov/consumer/)	Free to use	Building energy systems analysis using internet
HOT2EC	NRCan, (http://www.nrcan.gc.ca/energy/software-tools/7451)	Free to use	Analysis of building energy consumption
HOT2XP	CanmetENERGY, (http://www.nrcan.gc.ca/energy/software-tools/7445)	Free to use	Analysis of building energy consumption
Insight 360	Autodesk Insight 360, (https://insight360.autodesk.com/oneenergy)	Commercial	Modeling and analysis of building energy systems
IDA ICE	IDA indoor climate and energy (IDA ICE), (www.equa.se)	Commercial	Modeling and analysis of building energy systems
OpenStudio	Open-source SDK, (www.openstudio.net)	Free	Modeling and analysis of building energy systems
PHPP	PHPP 9, Passive House Planning Package, (http://passivehouse.com/04_phpp/04_phpp.htm#PH9)	Limited	Performance analysis of building energy systems, and the modeling of passive houses
RIUSKA	Granlund, (www.granlund.fi/en/software/riuska/)	Commercial	Modeling and analysis of building energy consumption
SPARK, VisualSPARK	Simulation Problem Analysis and Research Kernel, LBNL, DOE (http://gundog.lbl.gov/VS/spark.html)	Free to use	Modeling and analysis of building energy and complex energy systems, and energy performance
SUNREL	Centre for Building and Thermal Systems, NREL, (www.nrel.gov/buildings/sunrel.html)	Free to use	Modeling and analysis of building energy systems
TAS	Environmental Design Solutions Limited, (www.edsl.net)	Commercial	Analysis of building thermal energy systems, and dynamics
TREAT	TREAT energy audit software, (http://psdconsulting.com/software/treat/)	Commercial	Comprehensive building energy simulation
VIP-Energy	StruSoft, (www.strusoft.com/products/vip-energy)	Commercial	Modeling and analysis of residential and commercial building energy systems and energy performance

List of tools to manage and optimize residential energy systems (Mahmud et al. 2018)

Tool	Description/source	Availability	Application
Beopt	Beopt (Building Energy Optimization), NREL, (http://en.openei.org/wiki/BEopt)	Free to use	Optimize building energy systems
Tool	**Description/source**	**Availability**	**Application**

Cepenergy Management Software for Buildings	Artequim, (www.artequim.com)	Commercial	Modeling and management of building energy systems
ESBO	ESBO (Early Stage Building Optimization), (http://www.equa.se/en/esbo)	Commercial	Building energy optimization
Derob-LTH	University of Texas, Lund Institute of Technology, (www.ebd.lth.se/english/research/software/derob-lth/)	Commercial	Building peak load and energy demand analysis, demand balancing, and analysis of energy performance
DesignBuilder	DesignBuilder, (www.designbuilderusa.com)	Commercial	Residential energy systems modeling and analysis, cost calculation, energy optimization
DIAL + Lighting, EPIQR+	Estia, DIAL+, (www.estia.ch), (www.dialplus.ch)	Commercial	Energy demand analysis and optimization
ECOCITIES	XYLEM Technologies, (www.xylem-technologies.com)	Commercial	Energy efficiency optimization tool for an entire building
EnerCAD	EnerCAD, (www.enercad.ch)	Commercial	Designing and optimization of large buildings (universities, schools), and energy efficiency analysis
ESP-r	ESRU, University of Strathclyde, (https://github.com/ESP-rCommunity/ESP-rSource)	Open source	Management of building energy systems
GBS	Autodesk Green Building Studio (GBS), (https://gbs.autodesk.com/GBS/)		Residential energy systems design and performance optimization
GenOpt	Generic optimization program (GenOpt), (http://simulationresearch.lbl.gov/GO/index.html)	Free to use	Energy systems optimization
HEED	Home energy efficient design (HEED), (www.energy-design-tools.aud.ucla.edu/heed/)	Free to use	Residential energy systems design and optimization
TOP-Energy	TOP-Energy, (www.top-energy.de)	Commercial	Energy systems design and optimization
TRACE 700	Trane, Ingersoll Rand, (www.trane.com)	Commercial	Residential energy systems analysis, optimization, and cost calculation

References:

Mahmud, K., Amin, U., Hossain, M. J., & Ravishankar, J. (2018). Computational tools for design, analysis, and management of residential energy systems. Applied Energy, 221, 535-556.

Aim and key learning outcomes of this topic

The aim of this topic is to ensure that students are able to model and analyze building energy systems and are aware of various tools to help them carry this out. (Contributes to overall Learning Outcome O3: Students will have gained near real-life experience in decision-making, communication and teamworking to achieve energy efficiency in buildings.)

On completion of this topic, students will:

- Have a working knowledge of building energy modelling and analysis.
- Be able to apply their knowledge and various tools in the development of energy efficiency solutions.

Recommended sources of further information

ZERO Code Energy Calculator: https://zero-code.org/energy-calculator/
Home Energy Calculator:
http://c03.apogee.net/calcs/rescalc5x/Question.aspx?hostheader=singingriver&utilityid=singingriver

11 - Feedback and reporting

This topic covers the format and protocols for the individual reflection of students on the modelling and simulation of energy efficiency in buildings and group presentations in terms of their process, decisions, solutions and results. It provides an opportunity to draw together all the learning material in the module as a whole into a signle discussion.

The individual reflection takes the form of a structured essay or online questionnaire with open-ended questions. The group presentations are in the form of compiled slide (or equivalent) presentations jointly developed by each group. For both, emphasis is placed on reflections on their learning experiences and demonstration of their grasp of the need for collaboration as well as the difficulties, compromises, competing interests among stakeholders. In addition, their appreciation of the limitations of the simulation and how real, industrial processes might differ from the classroom simulation.

Aim and key learning outcomes of this topic

The aim of this topic is to bring together the whole module and reflect on it and discuss it both individually and in groups. (Contributes to all overall Learning Outcomes - Learning Outcome O1: Students will understand the different interests of stakeholders in achieving energy efficient buildings; Learning Outcome O2: Students will be able to argue their points of view and justify their decisions regarding energy efficiency; and Learning Outcome O3: Students will have gained near real-life experience in decision-making, communication and teamworking to achieve energy efficiency in buildings.)

On completion of this topic, students will:

- understand the different interests of stakeholders in achieving energy efficient buildings;
- be able to argue their points of view and justify their decisions regarding energy efficiency
- have gained near real-life experience in decision-making, communication and teamworking to achieve energy efficiency in buildings.

Assessment

Individual essay / online questionnaire with open-ended questions. Group presentations on their process, outcomes and reflections.

Appendix - Examples from the Project Simulation

(STARTS NEXT PAGE)

Client's requirements for design

Rough plan

The purpose of the rough plan is to coordinate the architectural appearance of the building, correcting the plans of the floots prepared by the designed, etc. with the client for the preparation of the preliminary design.

Preliminary design

The purpose of the preliminary design is to start the process of processing a building notice or building permit in the KOV at the earliest possible stage of the design. The preliminary design should include: Architectural appearance of the building (tones, materials used, etc.) as drawing and explanatory note; The constructive part of the building knot drawings to the minimum extent necessary for processing; Description of technical systems as explanatory note; Energy performance certificate; Fire safety.

Detailed design

When drawing up the detailed design, it must be taken into account that the tendering procedure(s) for the construction works is organised on the basis of a construction project. A building design project should be of a technical level and detail which enables the contractor(s) of the construction works to be completed, drawing up additional product and assembly drawings for construction and to complete the constructions without any additional materials or explanations. The colume of the main project must clearly set out the descriptions of the volumes of all the construction works to be carried out and the quality levels required by them and the basic parameters of the specified building materials and products.

Stages of the construction project

Pursuant to Regulation No 97 of the Minister of Economic Affairs and Infrastructure. 17.07.2015	
Rough plan (*YES / NO*)	
Preliminary design (*YES / NO*)	
Detailed design (*YES / NO*)	

Source data

Basic drawings to be given by the client *(construction project, inventory drawings, previous construction projects, energy audit, etc.)*	Energy audit

Energy audit *(AVAILABLE / NONE)*	Available
Preparation of inventory drawings of buildings *(YES / NO)*	No
Technical conditions for HVAC from service providers *(YES / NO / IF NECESSARY)*	If necessary

In the absence of other agreements, the contractor shall draw up the baseline drawings on the basis of control measurements and drawings of the standard project.

Approvals and authorisation procedures

Coordination of building design to the extent necessary for submission of building notice *(YES / NO)*	YES
Formalisation of applications for the submission of a building notification on behalf of the holder *(YES / NO)*	YES

Site investigations

Surveying *(YES / NO / IF NECESSARY)*	IF NECESSARY
Geology *(YES / NO / IF NECESSARY)*	IF NECESSARY
Ventilation duct study *(YES / NO / IF NECESSARY)*	YES
Radon *(YES / NO / IF NECESSARY)*	NO
Noise *(YES / NO / IF NECESSARY)*	YES
Asbestos *(YES / NO / IF NECESSARY)*	IF NECESSARY
Condition of building structures *(YES / NO / IF NECESSARY)*	YES
Additional investigations	IF NECESSARY

Parts of construction project

Energy efficiency

according to Regulation No 23 of the Minister of Economic Affairs and Infrastructure No 23. *(15% / 25% / 40% / WITHOUT SUPPORT)*	
Preparation of the calculated energy performance certificate	YES

General layout

General layout	YES

Underground part of the foundation

Existing insulation of the foundation *(NONE / YES, THICKNESS ... mm, depth)*	NONE
The underground part of the foundation is insulated *(NO / YES, ... m depth)*	NO

Check the risk of sleds infiltrating the basement *(YES / NO / IF NECESSARY)*	YES
Insulation of the basement ceiling *(YES / NO / IF NECESSARY)*	NO
Construction of a new paving strip on the perimeter of the building *(YES / NO)*	NO
Comments	

Socle

Existing insulation of the socle *(NONE / YES, THICKNESS ... mm, finish /TO BE REMOVED)*	YES, thickness ...mm
Designed thermal insulation system *(Ventable system/composite system)*	Ventable system
Insulation and thickness of the socle*	
Socle finishing	
Comments	

Cladding

Existing end wall insulation *(NONE / YES, THICKNESS ... mm, finish /TO BE REMOVED)*	YES, 100mm
Existing longitudinal wall insulation *(NONE / YES, THICKNESS ... mm, finish /TO BE REMOVED)*	YES, 100mm
Designed thermal insulation syster *(ventable system/composite system)*	Ventable system
Cladding insulation material	Wool
Thickness of insulation of longitudinal wall *(mm)*	Up to the designer
Thickness of end wall insulation *(mm)*	Up to the designer
Cladding finishing material	Marmoroc?
Comments	

Openings

Apartment windows *(PRESERVE already replaced plastic windows / REPLACE all windows)*	REPLACE
Stairwell windows *(PRESERVE already replaced plastic windows / REPLACE all windows)*	REPLACE
Cellar windows *(PRESERVE already replaced plastic windows / REPLACE all windows)*	REPLACE if exist
Position of windows in relation to insulation *(Remain IN THE AVAILABLE POSITION/LIFTED TO THE SURFACE OF THE EXISTING CLADDING/LIFT THE INSULATION LAYER)*	LIFT THE INSULATION LAYER
Doors of stairwells *(PRESERVED/REPLACED)*	REPLACED
Interior doors of stairwells *(PRESERVED/REPLACED)*	NONE

Exterior doors of apartments *(PRESERVED/REPLACED)*	REPLACED
Comments	

Flat roof

Existing roofing *(Ruberoid during construction / later added bitumen roll material / other)*	SBS roofing membrane
Existing insulation *(Insulation during construction/additional insulation installed) and its thickness (mm)*	Install additional insulation, … mm
Roofing cover *(Existing / new [bitumen roller material/ PVC / other])*	SBS roofing membrane
Designable insulation material and its thickness *(mm)*	Up to the designer
Sewer pipes *(Preserve existing / replace)*	Firstly evaluate and make decision during project
Ventilation chimneys (EXISTING, if necessary extended/REBUILT according to the ventilation project)	Preserved
Sunroofs *(Preserve existing / replace)*	None
Sunroof type *(if changed)*	None
Requirements for waterproofing material	Up to the designer
Eaves	
Drainpipes *(Preserve existing/replace)*	Evaluate first
Drainage pipe in the house / Drainage pipes on the cladding *(Preserve existing/replace)*	Not renovated
Comments	

Gable roof

Existing roof covering *(Stain [profile, rolling, stone/other)*	
Existing insulation *(Insulation during construction/additional insulation installed) and its thickness (mm)*	
Slopes *(Preserve existing / replace)*	
Designed roofing cover *(Existing/new [stain , asbestos cement, stone, other])*	
Designable insulation material and its thickness *(mm)*	
Sewer pipes *(Preserve existing / replace)*	
Ventilation chimneys *(EXISTING, if necessary extended/REBUILT according to the ventilation project)*	
Sunroofs *(Preserve existing / replace)*	
Attic doors or trap doors *(Preserve existing / replace)*	
Attic trap door type *(if changed)*	
Drainage systems *(Preserve existing / replace)*	

Comments	

Other structures

Stairwell entrances *(Existing/new ones to be built)*	Preserve existing
Exterior stairs *(Existing/new/reconstruction)*	Renovate if needed
Stairwell canopies *(Existing solution is maintained/new ones to be built)*	Build new ones
Canopies for last floor balconies *(Exist/canopies to be built/no desire for canopies)*	Canopies to be built
Balcony *(Previously renovated/to be renovated)*	To be renovated
Balcony front railings *(Preserve existing situation/refurbishment/new fences to be built)*	To be renovated
Balcony glazing *(Without glazing / glazing system without frames / built with windows closed)*	Glazing system without frames
Flags *(Location)*	NO
Cladding tags *(Location)*	YES
Comments	

HVAC section

Heating system

Existing heating *(Central heating [single or double pipe system]/furnace heating/electricity/air heat pump/other)*	Central heating single pipe system
Rebuilt into a two-pipe system *(YES / NO)*	YES
Radiators *((Existing [what type?] / Replace [tin, cast iron, fresh air radiator])*	Replace with fresh air radiators
Thermostatic valves *(YES / NO)*	YES
Heating pipes *(Preserve existing / replace with [pipe type])*	Replaced
Heating main pipe systems *(Preserve existing / replace with [pipe type])*	Replaced
Heat distribution system *(Preserve existing / reconstruction [volume of works])*	Renovate
Adding heat distribution system to ventilation heat reclamation *(YES / NO)*	NO
Bathroom heating *(Preserve existing/added radiator for warm water use)*	Preserve existing
Additional information	

Ventilation (air-to-air)

Existing ventilation system *(Natural/forced ventilation/other)*	
Ventilation *(Preserve existing / new to be built)*	
Ventilation type *(Apartment based / central)*	

Location of the ventilation unit *(Basement, attic, roof, apartment)*	
Location of the ventilation system pipes (in case of central system) *(inside building, on cladding, combined)*	
Additional information	

Ventilation (air-to-water)

Existing ventilation system *(Natural/forced ventilation during construction/ etc.)*	Natural
Ventilation *(Preserve existing / new to be built)*	
Location of the ventilation unit *(Basement, attic, roof, apartment)*	
Additional information	

Water supply and sewerage

Cold domestic water pipeline *(Preserve existing/reconstruction/to be built)*	Preserve existing
Additional information (cold domestic water pipeline): volume of works in case of reconstruction or field construction *(From general water meter to apartment water meter / main trunks / other)*	
Domestic hot water pipelines *(Preserve existing/reconstruction/to be built)*	Preserve existing
Additional information (domestic hot water pipeline): volume of works in case of reconstruction or field construction *(From general water meter to apartment water meter / main trunks / other)*	
Sewerage pipelines *(Preserve existing/reconstruction/to be built)*	Preserve existing
Additional information (sewerage pipeline): volume of works in case of reconstruction or construction of field *(To the first wells/out of the house /other)*	Preserve existing
Water meter *(Preserve existing/replace [normal/remotely readable])*	Preserve existing
Additional information	

Electrical installation

General electricity *(Preserve existing/renovate)*	Renovate
Additional information (general electricity): *volume of works in case of reconstruction*	Cellar to be renovated
Main switchboard *(Preserve existing/reconstruction)*	Up to the designer
Trunk lines (floor switchboard from main switchboard) *(Preserve existing/reconstruction)*	Up to the designer
Corridor switchboards *(Preserve existing/reconstruction)*	Up to the designer
Exterior lighting *(Preserve existing/reconstruction)*	Preserve existing

Lighting installation for public spaces (cellar and/or corridors) *(Preserve existing/reconstruction)*	Renovate cellar
Automation and low current for the control and monitoring of the ventilation system and heating system to be built *(YES / NO)*	No
Earthing *(Preserve existing/reconstruction)*	Up to the designer
PV solar panels *(YES / NO / IF NECESSARY)*	No
Low voltage installations *(Phonolock / ATS)*	ATS
Additional information	

Contacts and communication

Contacts (Client)

Representative of the Management Board of the Apartment Association	First name Last name GSM: +372 XXXX XXXX Email: name@domeen.ee
Technical consultant	First name Last name GSM: +372 XXXX XXXX Email: name@domeen.ee
Additional contact	First name Last name GSM: +372 XXXX XXXX Email: name@domeen.ee

Contacts (Contractor)

Project manager	First name Last name GSM: +372 XXXX XXXX Email: name@domeen.ee
Architect	First name Last name GSM: +372 XXXX XXXX Email: name@domeen.ee
Heating and ventilation designer	First name Last name GSM: +372 XXXX XXXX Email: name@domeen.ee
Designer of water and sewerage	First name Last name GSM: +372 XXXX XXXX Email: name@domeen.ee
Electricity designer	First name Last name GSM: +372 XXXX XXXX Email: name@domeen.ee

Information exchange agreements:

CLIENT'S FINANCIAL POSITION

Apartment association financial annual report

Address	Maleva 18, Tallinn
Dates	From xx.xx.xxxx to xx.xx.xxxx

EXPENSES		15372	17975		16472
Activity	20xx planned		20xx	20xy planned	
	monthly	yearly	actual	monthly	yearly
1 Management, including	515	6180	6870	597	7164
1.1 Accounting	240	2880	3200	270	3240
1.2 Legal services	50	600	700	62	744
1.3 Participation in training	40	480	500	50	600
1.4 Board work	124	1488	1500	126	1512
1.5 Other (bank services, notary)	20	240	300	30	360
1.6 Car compensation	9	108	200	17	204
1.7 Revision	25	300	400	34	408
1.8 Internet	7	84	70	8	96
2 Servicing, including	148	1776	2060	165	1980
2.1 Heating system servicing	14	168	150	15	180
2.2 Electrical system servicing	4	48	50	5	60
2.3 Lighting	67	804	900	70	840
2.4 Basement cleaning	6	72	80	7	84
2.5 Window cleaning	17	204	450	27	324
2.6 Tree servicing	21	252	200	20	240
2.7 Other expenses	9	108	110	10	120
2.8 Other systems and territory servicing	10	120	120	11	132
3 Maintenance, including	63	756	1856	74	888
3.1 Cleaning supplies	15	180	200	18	216
3.2 Cleaner wage	6	72	200	8	96
3.3 Grass mowing	9	108	300	9	108
3.5 Gas	8	96	400	10	120

3.6 Other expenses	9	108	500	11	132
3.7 Snowploughing	16	192	256	18	216
SUM	726	8712	10786	836	10032
4 Repairs, including	430	5160	5989	445	5340
4.1 Repairing electrical systems	270	3240	3300	265	3180
4.2 Changing basement windows	160	1920	2689	180	2160
Repairs fund carryover xx.xx.xxxx		1500	1200		1100
REPAIRS SUM		6660	7189		6440

BENEFITS		22572	20000		25104
Tegevus	20xx planned		20xx	20xy planned	
	monthly	yearly	actual	monthly	yearly
1 Non-intended benefits, including	531	6372	7100	602	7224
1.1 Overdue charges and penalties	240	2880	3200	270	3240
1.2 Servicing and maintenance payments from members	241	2892	3200	270	3240
1.3 Other benefits	50	600	700	62	744
2 Intended benefits, including	1350	16200	12900	1490	17880
2.1 Ose of repairs fund	500	6000	4500	550	6600
2.2 Construction expertise benefit	450	5400	5000	470	5640
2.3 Construction project benefit	400	4800	3400	470	5640

Yearly net outcome (=benefits-expenses)	8632	€

Previous year used water, heat and electricity			
Description	Volume	Average price (€/unit)	Price (€)
Water (including sewage cleaning fee) (m^3)	2456	2,08	5108,48
Heat energy (MWh)	500	50,14	25070

Electricity (kWh)	46700	0,06	2802

Co-funded by the
Erasmus+ Programme
of the European Union

ENERGY AUDIT TEMPLATE

heating mainly + a little bit of energy

Energy consumption profile									
Month/year	Electricity			Other fuels		Water & sewer		Totals	
	Electricity demand (kW)	Electricity use (kWh)	Electricity cost (€)	Other fuel use (unit)	Other fuel cost (€)	Water & sewer use (m^3)	Water & sewer cost (€)	Total energy use (unit)	Total energy cost (€)
January									
February									
March									
April									
May									
June									
July									
August									
September									
October									
November									
December									
1st year totals									
January									
February									
March									
April									
May									
June									
July									
August									
September									
October									
November									
December									
2nd year totals									

	Electric use	Other fuel use	Total site energy use
End use category	kWh	Unit	% of total
Space cooling			
HVAC pumps			
HVAC fans			
Interior lighting			
Exterior lighting			
Misc. equipment			
Other electric			
Space heating			
Domestic hot water			
Other fossil fuel use			
TOTAL			0%

Consumption of heat energy	20xx	20xy	20xz	Unit
Estimated consumption (electricity)				MWh/year
Estimated consumption (heat pump)				MWh/year
Estimated consumption (natural gas)				MWh/year
Estimated consumption (solar heating)				MWh/year
Estimated consumption (ground-source heating)				MWh/year
Total measured consumption				MWh/year
Actual amount of yearly degree days				˚C d
Normal year amount of degree days				˚C d
Degree day corrulated heat consumption (electricity)				MWh/year
Heat tarif/price (electricity)				€/MWh

Heat expenses (electricity)				€/year
Degree day corrulated heat consumption (heat pump)				MWh/year
Heat tarif/price (heat pump)				€/MWh
Heat expenses (heat pump)				€/year
Degree day corrulated heat consumption (natural gas)				MWh/year
Heat tarif/price (natural gas)				€/MWh
Heat expenses (natural gas)				€/year
Degree day corrulated heat consumption (solar heating)				MWh/year
Heat tarif/price (solar heating)				€/MWh
Heat expenses (solar heating)				€/year
Degree day corrulated heat consumption (GS heating)				MWh/year
Heat tarif/price (GS heating)				€/MWh
Heat expenses (GS heating)				€/year
Expenses summary				€/year

Water & sewer consumption	20xx	20xy	20xz	Unit
Tarbevesi				m^3/year
Tarbevee tarif/price				€/m^3
Water expenses				€/year
Warm tarbevesi				m^3/year
Sooja tarbevee tarbimine				MWh/year
Sooja tarbevee tarif/price				€/m^3
Sooja tarbevee expenses				€/year
Elanike arv				persons

Apartment building components	Before renovation	After renovation

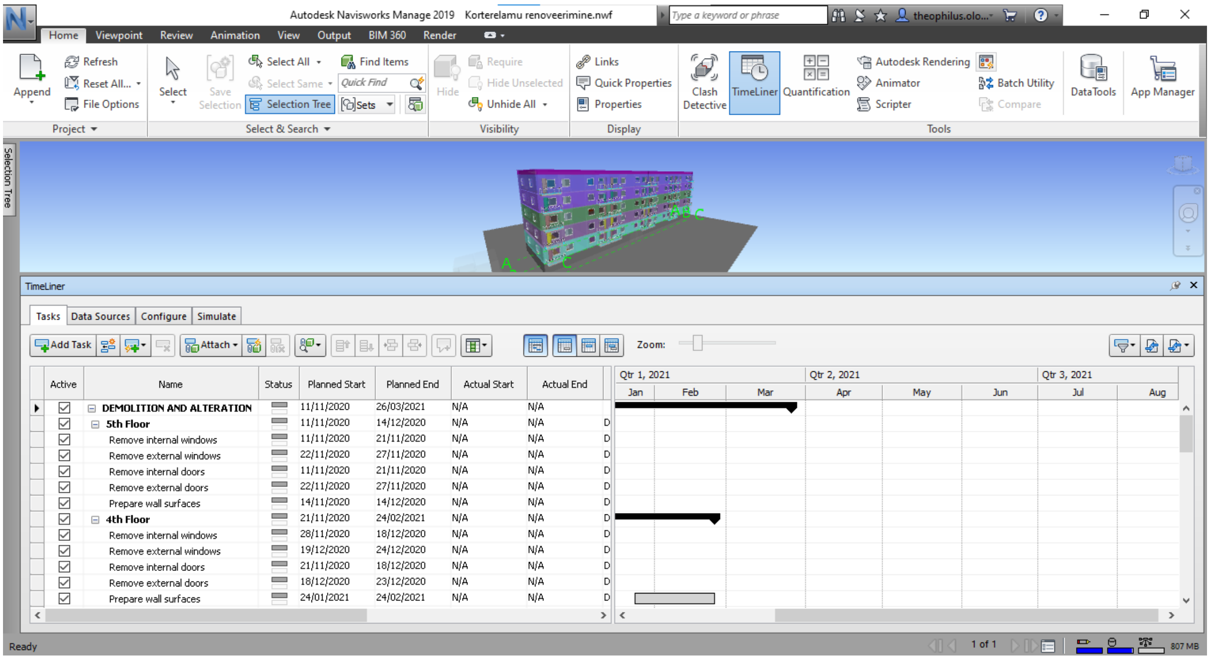
Component	Material/type	Comment	Area (m^2)	Estimated U-value ($W/(m^2K)$)	Estimated heat losses (MWh/year) Q	Measures taken	Estimated U-value after renovation ($W/(m^2K)$)	Estimated heat losses after renovation (MWh/year) Q	Energy savings MWh/year
Roof	Flat roof, ruberoid	Panel, 450mm	567	0,5	30,7	Additional thermal insulation 200 + 30mm	0,13	7,6	23,2
Exterior walls	Concrete panel	Noninsulated	1535	0,7	108,2	Additional thermal insulation 150mm + cladding	0,21	33,1	75,1
Ground floor floor	Concrete panel + flooring	Noninsulated	567	0,5	30,7	Not renovated	0,5	29,1	1,6
Windows/balcony doors	Wooden frames with 2 glasses	Bad condition	252	2,4	43,6	New 3-layered glass windows	1,4	6	7,6
Exterior doors	Metallic doors	Good condition	11	1,4	1,6	Not renovated	1,4	1,5	0,1
SUM					214,8			77,3	107,6

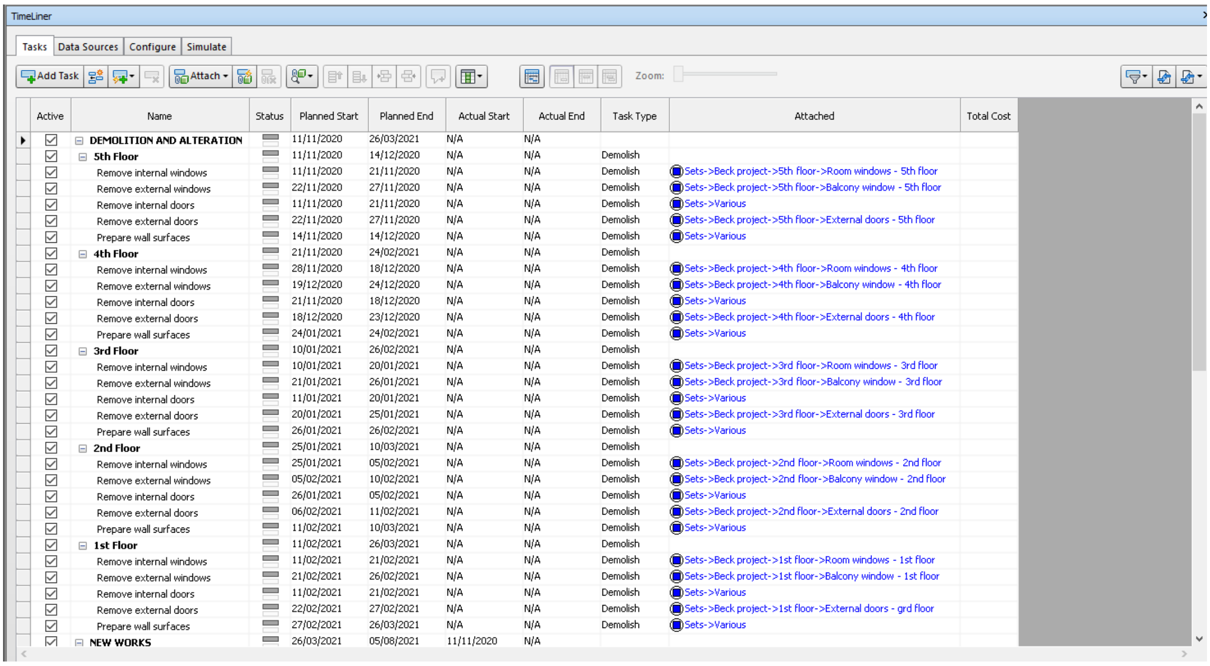
CONTRACTOR'S INFORMATION

Summary Cost Estimate

Code	Description	Materials	Labour	Equipment	Subcontract	Total
08.1.1	Doors: Drehflügel 1-flg - Stahlzarge - Glasfüllung: 76 x 2.26	9 600,00	600,00	960,00	800,00	11 960,00
08.2.2	Windows: 1700*1500	24 000,00	1 500,00	2 400,00	2 000,00	29 900,00
08.2.1	Windows: Windows_Sgl_Plain: 1400 x 1400	9 600,00	600,00	960,00	1 000,00	12 160,00
07.6.1	Walls: Wall-Ext_22Rdr-100Blk-50Air-30Ins-100LBlk-12P	13 860,00	1 155,00	1 848,00	200,00	17 063,00
	SUBTOTAL	57 060,00	3 855,00	6 168,00	4 000,00	**71 083,00**
	DEMOLITION COST					27 807,25
	Building Permit					300,00
	Bond					200,00
	SUBTOTAL					**99 390,25**
	Profit and Overhead Markup					40%
	Profit and Overhead					39 756,10
	TOTAL					**139 146,35**

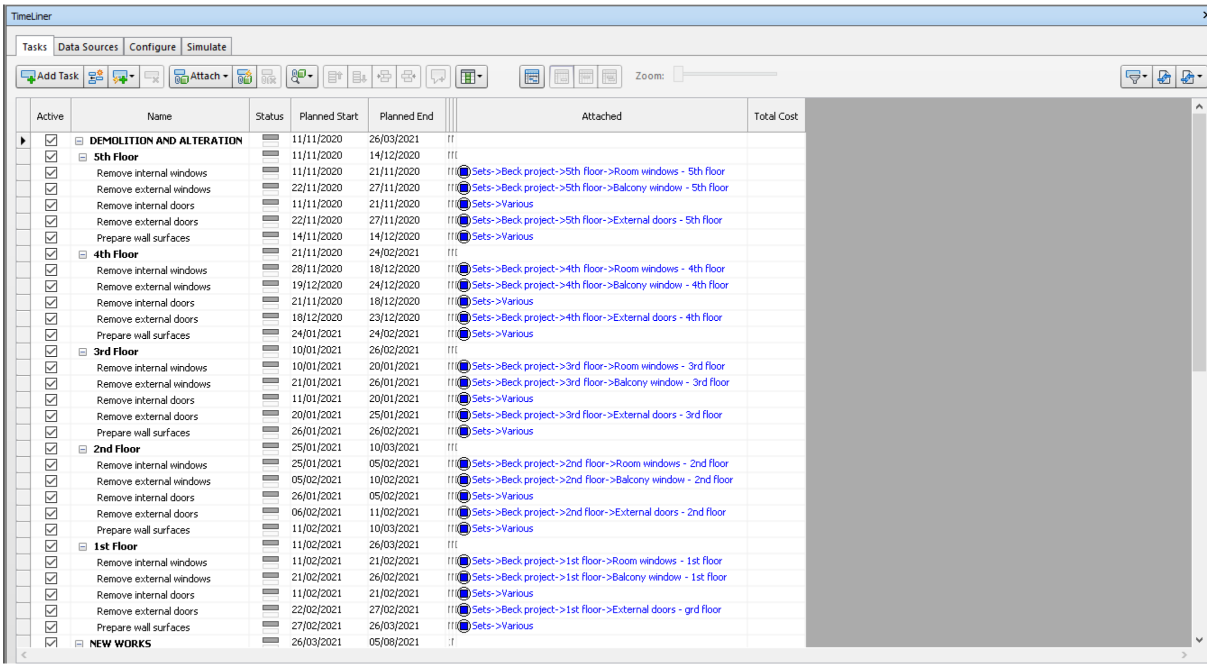
Time Schedule





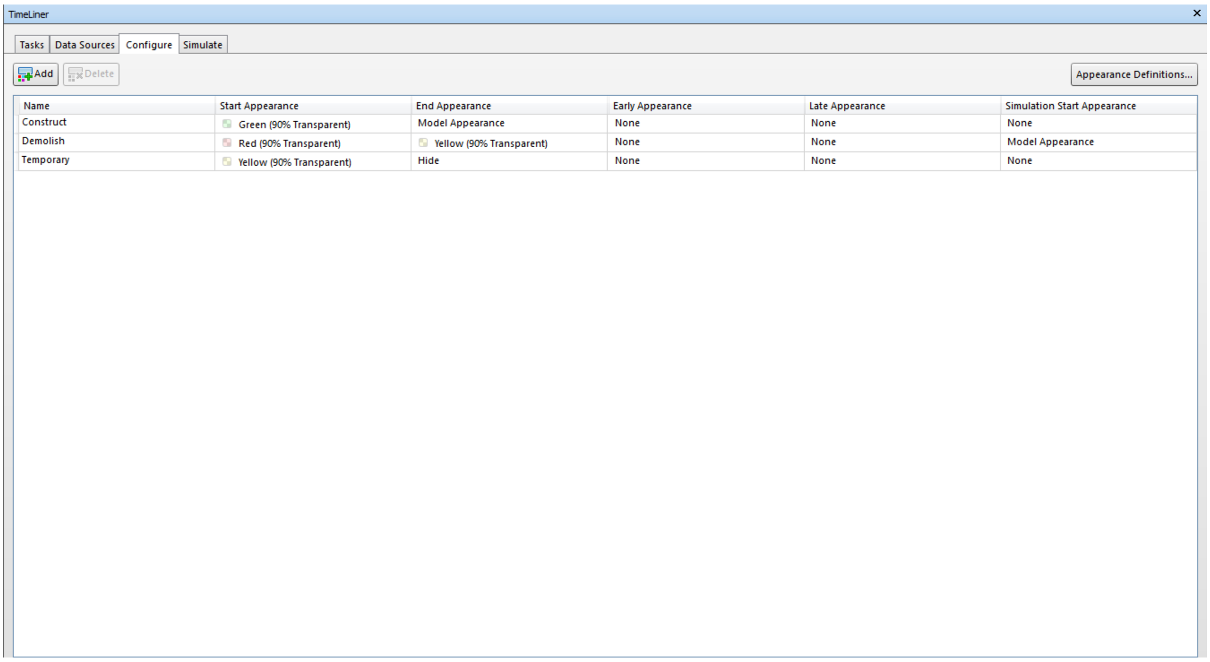
TimeLiner

Active	Name	Status	Planned Start	Planned End	Actual Start	Actual End	Task Type	Attached	Total Cost
☑	**DEMOLITION AND ALTERATION**		11/11/2020	26/03/2021	N/A	N/A			
☑	**5th Floor**		11/11/2020	14/12/2020	N/A	N/A	Demolish		
☑	Remove internal windows		11/11/2020	21/11/2020	N/A	N/A	Demolish	Sets->Beck project->5th floor->Room windows - 5th floor	
☑	Remove external windows		22/11/2020	27/11/2020	N/A	N/A	Demolish	Sets->Beck project->5th floor->Balcony window - 5th floor	
☑	Remove internal doors		11/11/2020	21/11/2020	N/A	N/A	Demolish	Sets->Various	
☑	Remove external doors		22/11/2020	27/11/2020	N/A	N/A	Demolish	Sets->Beck project->5th floor->External doors - 5th floor	
☑	Prepare wall surfaces		14/11/2020	14/12/2020	N/A	N/A	Demolish	Sets->Various	
☑	**4th Floor**		21/11/2020	24/02/2021	N/A	N/A	Demolish		
☑	Remove internal windows		28/11/2020	18/12/2020	N/A	N/A	Demolish	Sets->Beck project->4th floor->Room windows - 4th floor	
☑	Remove external windows		19/12/2020	24/12/2020	N/A	N/A	Demolish	Sets->Beck project->4th floor->Balcony window - 4th floor	
☑	Remove internal doors		21/11/2020	18/12/2020	N/A	N/A	Demolish	Sets->Various	
☑	Remove external doors		18/12/2020	23/12/2020	N/A	N/A	Demolish	Sets->Beck project->4th floor->External doors - 4th floor	
☑	Prepare wall surfaces		24/01/2021	24/02/2021	N/A	N/A	Demolish	Sets->Various	
☑	**3rd Floor**		10/01/2021	26/02/2021	N/A	N/A	Demolish		
☑	Remove internal windows		10/01/2021	20/01/2021	N/A	N/A	Demolish	Sets->Beck project->3rd floor->Room windows - 3rd floor	
☑	Remove external windows		21/01/2021	26/01/2021	N/A	N/A	Demolish	Sets->Beck project->3rd floor->Balcony window - 3rd floor	
☑	Remove internal doors		11/01/2021	20/01/2021	N/A	N/A	Demolish	Sets->Various	
☑	Remove external doors		20/01/2021	25/01/2021	N/A	N/A	Demolish	Sets->Beck project->3rd floor->External doors - 3rd floor	
☑	Prepare wall surfaces		26/01/2021	26/02/2021	N/A	N/A	Demolish	Sets->Various	
☑	**2nd Floor**		25/01/2021	10/03/2021	N/A	N/A	Demolish		
☑	Remove internal windows		25/01/2021	05/02/2021	N/A	N/A	Demolish	Sets->Beck project->2nd floor->Room windows - 2nd floor	
☑	Remove external windows		05/02/2021	10/02/2021	N/A	N/A	Demolish	Sets->Beck project->2nd floor->Balcony window - 2nd floor	
☑	Remove internal doors		26/01/2021	05/02/2021	N/A	N/A	Demolish	Sets->Various	
☑	Remove external doors		06/02/2021	11/02/2021	N/A	N/A	Demolish	Sets->Beck project->2nd floor->External doors - 2nd floor	
☑	Prepare wall surfaces		11/02/2021	10/03/2021	N/A	N/A	Demolish	Sets->Various	
☑	**1st Floor**		11/02/2021	26/03/2021	N/A	N/A	Demolish		
☑	Remove internal windows		11/02/2021	21/02/2021	N/A	N/A	Demolish	Sets->Beck project->1st floor->Room windows - 1st floor	
☑	Remove external windows		21/02/2021	26/02/2021	N/A	N/A	Demolish	Sets->Beck project->1st floor->Balcony window - 1st floor	
☑	Remove internal doors		11/02/2021	21/02/2021	N/A	N/A	Demolish	Sets->Various	
☑	Remove external doors		22/02/2021	27/02/2021	N/A	N/A	Demolish	Sets->Beck project->1st floor->External doors - grd floor	
☑	Prepare wall surfaces		27/02/2021	26/03/2021	N/A	N/A	Demolish	Sets->Various	
☑	**NEW WORKS**		26/03/2021	05/08/2021	11/11/2020	N/A			



TimeLiner

Active	Name	Status	Planned Start	Planned End	Attached	Total Cost
☑	**DEMOLITION AND ALTERATION**		11/11/2020	26/03/2021		
☑	**5th Floor**		11/11/2020	14/12/2020		
☑	Remove internal windows		11/11/2020	21/11/2020	Sets->Beck project->5th floor->Room windows - 5th floor	
☑	Remove external windows		22/11/2020	27/11/2020	Sets->Beck project->5th floor->Balcony window - 5th floor	
☑	Remove internal doors		11/11/2020	21/11/2020	Sets->Various	
☑	Remove external doors		22/11/2020	27/11/2020	Sets->Beck project->5th floor->External doors - 5th floor	
☑	Prepare wall surfaces		14/11/2020	14/12/2020	Sets->Various	
☑	**4th Floor**		21/11/2020	24/02/2021		
☑	Remove internal windows		28/11/2020	18/12/2020	Sets->Beck project->4th floor->Room windows - 4th floor	
☑	Remove external windows		19/12/2020	24/12/2020	Sets->Beck project->4th floor->Balcony window - 4th floor	
☑	Remove internal doors		21/11/2020	18/12/2020	Sets->Various	
☑	Remove external doors		18/12/2020	23/12/2020	Sets->Beck project->4th floor->External doors - 4th floor	
☑	Prepare wall surfaces		24/01/2021	24/02/2021	Sets->Various	
☑	**3rd Floor**		10/01/2021	26/02/2021		
☑	Remove internal windows		10/01/2021	20/01/2021	Sets->Beck project->3rd floor->Room windows - 3rd floor	
☑	Remove external windows		21/01/2021	26/01/2021	Sets->Beck project->3rd floor->Balcony window - 3rd floor	
☑	Remove internal doors		11/01/2021	20/01/2021	Sets->Various	
☑	Remove external doors		20/01/2021	25/01/2021	Sets->Beck project->3rd floor->External doors - 3rd floor	
☑	Prepare wall surfaces		26/01/2021	26/02/2021	Sets->Various	
☑	**2nd Floor**		25/01/2021	10/03/2021		
☑	Remove internal windows		25/01/2021	05/02/2021	Sets->Beck project->2nd floor->Room windows - 2nd floor	
☑	Remove external windows		05/02/2021	10/02/2021	Sets->Beck project->2nd floor->Balcony window - 2nd floor	
☑	Remove internal doors		26/01/2021	05/02/2021	Sets->Various	
☑	Remove external doors		06/02/2021	11/02/2021	Sets->Beck project->2nd floor->External doors - 2nd floor	
☑	Prepare wall surfaces		11/02/2021	10/03/2021	Sets->Various	
☑	**1st Floor**		11/02/2021	26/03/2021		
☑	Remove internal windows		11/02/2021	21/02/2021	Sets->Beck project->1st floor->Room windows - 1st floor	
☑	Remove external windows		21/02/2021	26/02/2021	Sets->Beck project->1st floor->Balcony window - 1st floor	
☑	Remove internal doors		11/02/2021	21/02/2021	Sets->Various	
☑	Remove external doors		22/02/2021	27/02/2021	Sets->Beck project->1st floor->External doors - grd floor	
☑	Prepare wall surfaces		27/02/2021	26/03/2021	Sets->Various	
☑	**NEW WORKS**		26/03/2021	05/08/2021		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Tasks
Data Sources
Configure
Simulate
Add
Delete
Appearance Definitions...
Name
Start Appearance
End Appearance
Early Appearance
Late Appearance
Simulation Start Appearance
Construct
Green (90% Transparent)
Model Appearance
None
None
None
Demolish
Red (90% Transparent)
Yellow (90% Transparent)
None
None
Model Appearance
Temporary
Yellow (90% Transparent)
Hide
None
None
None

PROJECT CASH FLOW
(Excerpt for illustration only)

TIME			COST		"REVENUE"	CASH FLOW CALCULATIONS		
			Cost of	Cost of	Energy			Discounted
Year	Month	Month #	Renovation	Heating	Saving	cash flow	Present Value	cumulative
						(month only)		cash flow
		0				0,00	0,00	0,00
0,08	Dec-20	1	15 084,40	2 090,00		-15 084,40	-15 035,18	-15 035,18
0,17	Jan-21	2	15 084,00	2 090,00		-15 084,00	-14 985,72	-30 020,90
0,25	Feb-21	3	9 784,00	2 090,00		-9 784,00	-9 688,53	-39 709,43
0,33	Mar-21	4	14 612,00	2 090,00		-14 612,00	-14 422,21	-54 131,65
0,42	Apr-21	5	15 084,00	2 090,00		-15 084,00	-14 839,50	-68 971,15
0,50	May-21	6	44 222,45	2 090,00		-44 222,45	-43 363,68	-112 334,83
0,58	Jun-21	7	58 960,90	2 090,00		-58 960,90	-57 627,26	-169 962,09
0,67	Jul-21	8	117 921,80	2 090,00		-117 921,80	-114 878,44	-284 840,53
0,75	Aug-21	9	88 441,35	2 090,00		-88 441,35	-85 877,69	-370 718,22
0,83	Sep-21	10	58 960,90	2 090,00		-58 960,90	-57 064,98	-427 783,20
0,92	Oct-21	11	20 510,45	2 090,00		-20 510,45	-19 786,15	-447 569,35
1,00	Nov-21	12		2 090,00	1 045,00	1 045,00	1 004,81	-446 564,54
1,08	Dec-21	13		2 131,80	1 065,90	1 065,90	1 021,56	-445 542,98
1,17	Jan-22	14		2 131,80	1 065,90	1 065,90	1 018,23	-444 524,76
1,25	Feb-22	15		2 131,80	1 065,90	1 065,90	1 014,90	-443 509,85
1,33	Mar-22	16		2 131,80	1 065,90	1 065,90	1 011,59	-442 498,26
1,42	Apr-22	17		2 131,80	1 065,90	1 065,90	1 008,29	-441 489,97
1,50	May-22	18		2 131,80	1 065,90	1 065,90	1 005,00	-440 484,97
1,58	Jun-22	19		2 131,80	1 065,90	1 065,90	1 001,72	-439 483,25
1,67	Jul-22	20		2 131,80	1 065,90	1 065,90	998,45	-438 484,80
1,75	Aug-22	21		2 131,80	1 065,90	1 065,90	995,19	-437 489,60
1,83	Sep-22	22		2 131,80	1 065,90	1 065,90	991,95	-436 497,65
1,92	Oct-22	23		2 131,80	1 065,90	1 065,90	988,71	-435 508,94
2,00	Nov-22	24		2 131,80	1 065,90	1 065,90	985,48	-434 523,46