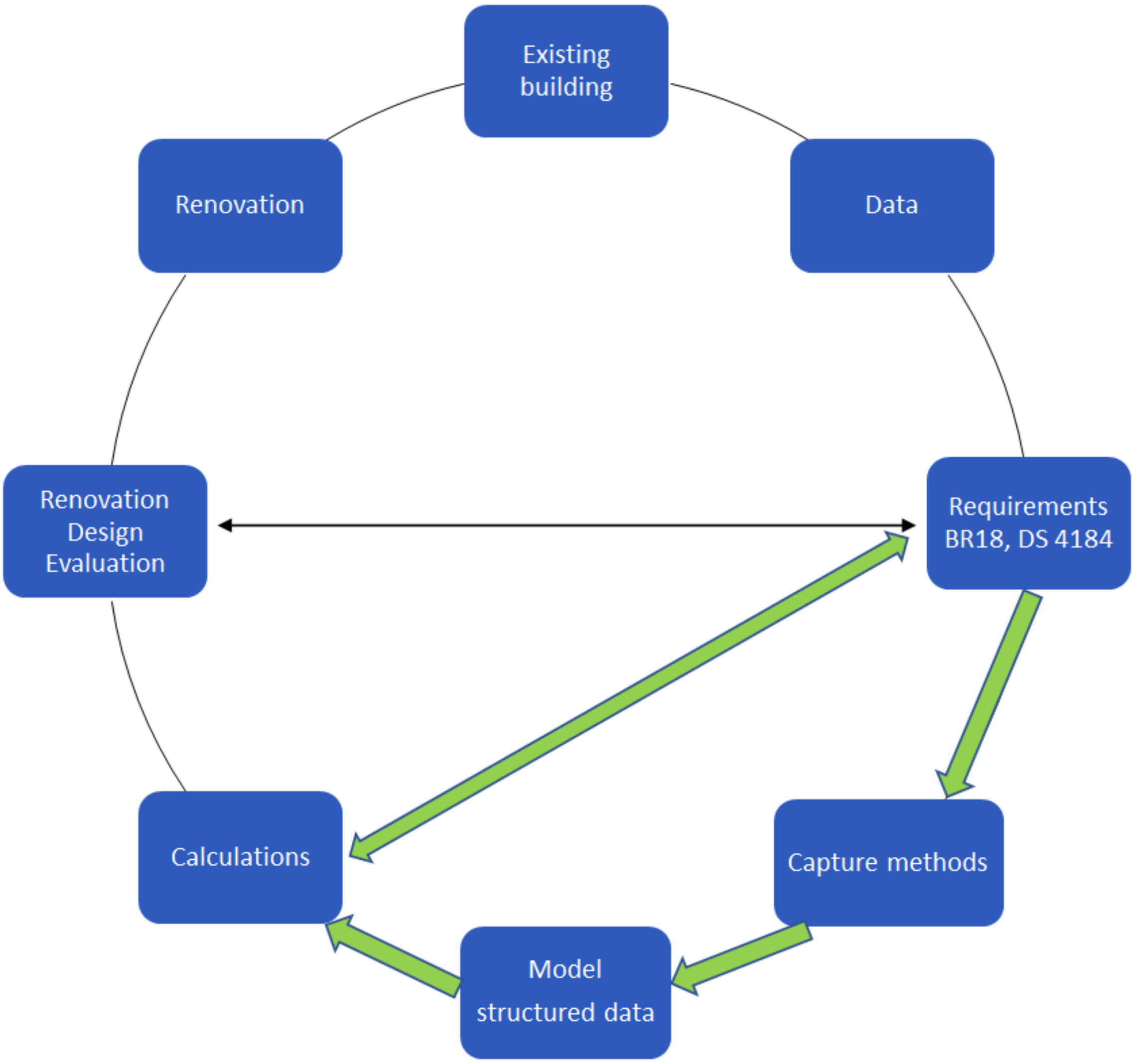


Data requirements and workflow for energy efficient renovation

23d April 2020

Aalborg University

Master of Science in Construction Management and Building Informatics

AALBORG UNIVERSITET
STUDENTERRAPPORT

Title:
Data requirements and workflow for energy-efficiency renovation

Project:
Master thesis
MSc. Construction Management and Building Informatics

Project period:
September 1st, 2019 to April 23d, 2020

ECTS:
Master's thesis
30 ECTS

Supervisors:

Kjeld Svidt
(Associate Professor,
Department of Civil Engineering,
Aalborg University)

Ekaterina Petrova
(PhD Fellow,
Department of Civil Engineering,
Aalborg University)

Author:

Reinis Petersons
(rpeter18@student.aau.dk)

Signature

Reinis Petersons

Synopsis:

In renovation projects, as-built documentation might exist, but inspection of current conditions must be made to evaluate renovation options. This information must be captured to enable performance-oriented evaluation. As a result, new Building Information Models can be created to enable contemporary design workflows.

In Architectural, Engineering and Construction industry, BIM aims to increase productivity and efficiency by supporting data for all phases of the project.\Identification of required information for energy redesign and BIM software capabilities set rules of how the geometrical models need to be enriched with semantic information and help choosing the registration methods.

To enable BIM-based energy-efficient renovation, this master thesis investigates building capture methods, BIM capabilities, building standard requirements and data flow between these processes. A workflow for energy efficiency calculation for renovation of residential buildings is proposed and discussed.

Number of pages:
48

Number of appendix pages:
32

Department of civil engineering
Thomas Manns Vej 23,
9220 Aalborg Øst

Summary

This report is written as master's thesis in Construction Management and Building Informatics, Aalborg University, Denmark, between September 2019 and April 2020.

Contents of the chapters is shown in Figure 1.

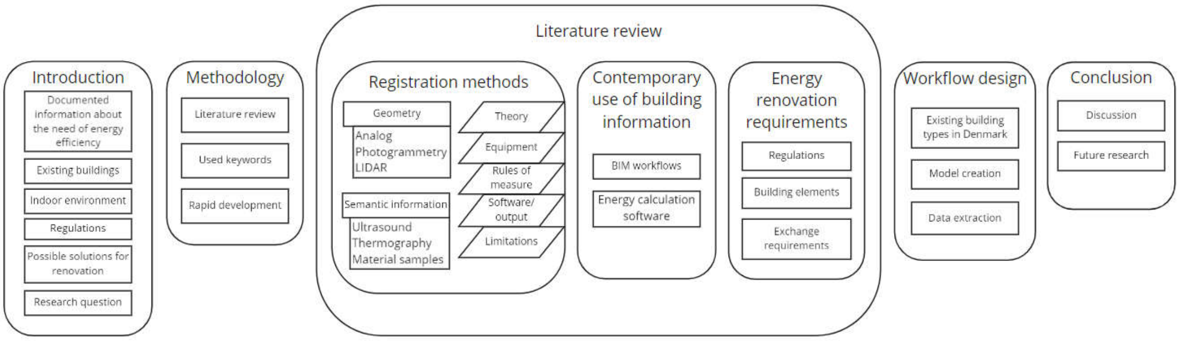


Figure 1: Chapter contents overview

In this report an investigation of workflow for building energy renovation is made. In Introduction the concepts involved are indicated and the research question is formulated. Methodology chapter describes the system of data gathering for the report. The distinction between geometric and semantic data and available methods of capturing them from existing buildings are described in Registry of buildings chapter. The benefit of storing data in a BIM model and the different use of is described in Contemporary use of building information chapter, along with description of energy calculation software used in Denmark. The energy calculation standards are explored for connection between input data and the final value of heat transmittance for separate building elements in Energy renovation requirements chapter. Here the registration protocols are introduced as exchange requirements between the building capture and model creation. The capabilities to extract data from Revit model, using Dynamo scripting, to supply the data for the heat transmission calculations are demonstrated in Workflow design chapter. Conclusion chapter summarizes the report and presents discussion and future research in energy renovation workflow development. Bibliography, Table of Figures and **Error! Reference source not found.** with images of created relation graphs, protocols and Dynamo scripts supplement and conclude the report.

Acknowledgments

This thesis is the final project of master’s course in Construction Management and Building Informatics at Aalborg University. In Architectural, Engineering and Architectural science education as in field application no substantial project can be completed by one person, and I would like to express my gratitude to people that have contributed to the creation of this report.

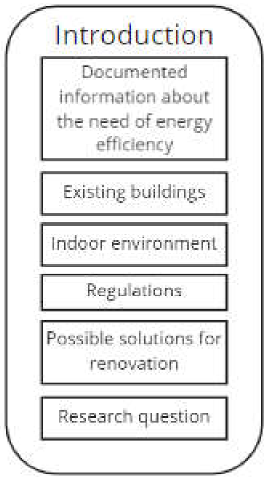
First and foremost, I thank both of my supervisors from Aalborg University: Kjeld Svidt and Ekaterina Petrova. They have encouraged me to explore the different pathways that this education and thesis open, and, in times of confusion, have helped me to focus on essential efforts.

For fruitful discussions and comradery, I thank my fellow students. Especially Adam Piaskowski and Mindaugas Mikalainis for consulting me with expertise and inspiring with confidence.

Lastly, I would like to thank my family that have always supported me in the time of need.

Contents

1 Introduction



In this chapter the argument for thesis selection and the problem statement are made. A brief description of the current situation in the residential building market in Denmark is presented. The need for and the different parts of a building renovation are mentioned in a correlation to the building standards and the data that is required to meet them. The data creation and handling using the Building Information Modelling (BIM) is presented as a workflow that enables the modern design processes but requires the knowledge of the data structure.

1.1 Background

In the last years the climate change and its effects are increasingly in the public focus and accepted as the reality. The overuse of the building materials will speed up the climate change and will rise the prices for commonly used materials, e.g. sand (Ludacer, 2018). Concurrently, increased ground water level, intensity of storms and unpredictable weather influence precautions made in the building structure (*Climate change impact on buildings and constructions*, 2019). Differentiating the used materials and recycling of the existing buildings is required.

“Resource scarcity, sustainability challenges and stricter decrees for recycling and resource efficiency in buildings [1] motivate the Architecture, Engineering, Construction, Facility Management (FM) and Deconstruction communities to manage resources efficiently [2].” (Volk et al., 2014)

The regulations aim to increase the energy efficiency of buildings, since 30% - 60% of all energy is used in heating of spaces (Danish Energy Agency, 2018)(The Ministry of Climate, 2014)(International Energy Agency, 2013), and decrease the individual use of fossil fuels through requiring the use of established grids of district heating and natural gas supply, that are controlled by the municipalities and the government. In the areas where these grids are available, the individual heating solutions require the use of renewable energy. In the time of writing this thesis, the Executive order on building regulations 2018 (BR18) with its supplementary literature in Danish Standards (DS) and instructions of the Danish Building Research Institute (SBi) is in effect in Denmark. The energy framework is the allowed energy consumption including heating, domestic hot water, cooling, ventilation and lighting, for building to be exploitable. The BR18 states this framework, the minimum thermal requirements for the building elements, and simple rules of calculation and documentation, that are further explored in SBis and DSs.

“For residential units, halls of residence, hotels, etc. the total energy supply demand of the building for heating, ventilation, cooling and domestic hot water per sq. metre heated floor area may not exceed 30.0 kWh/sq. metre per year plus 1,000 kWh per year divided by the heated floor area.” (Ministry of Transport Building and Housing, 2018)

Thus, the climate change effects the Architectural, Engineering and Construction (AEC) industry in all phases from material production, environmental and regulatory factors for design, construction and demolishing of the buildings, and the design of the workflows encompassing these phases.

1.2 Renovation

Renovation is the process of repairing and improving an existing building. In contrast with restoration that is aimed to conserve the building in its historical state, renovation implies addition of new elements. Decision to change the use of a building, add new or replace parts of it, all have special requirements in BR18. In this thesis the focus is on renovation with purpose of increasing energy efficiency of the building with replacement of building parts. This includes two main parts - building envelope, i.e. outer building elements, and ventilation and heating network inside of the building. The renovation design requires a financial viability check (Danish Knowledge Center for Energy Savings in Buildings, 2018), the construction material and detail selection according to allowed heat transfer coefficients (U-values) and transmission losses, and avoiding moisture damage.

If the design is not viable, the conversion must be scaled down and an insulation of cavities (e.g. attic) must be investigated. While making the building envelope more insulated and air-tight, it is forbidden to decrease the indoor climate (Danish Knowledge Center for Energy Savings in Buildings, 2018), since people spend around 90% of their time indoors, and the indoor climate is tied to health and productivity (Klepeis et al., 2001). Another factor to consider is the architectural value of the existing façade, where preserved façade will limit the possible solutions for increase in energy efficiency (Odgaard et al., 2015). Based on the above, renovation can be seen as a balancing act between energy efficiency, material choices, cost, architectural value and individual comfort. BIM gives possibility to compare the data more efficiently, thus allowing to substantiate the design choices.

The existing building stock in Denmark is divided in three groups (Figure 2), based on time of building and the construction details/methods used in them. This information can be used to make standard solutions.

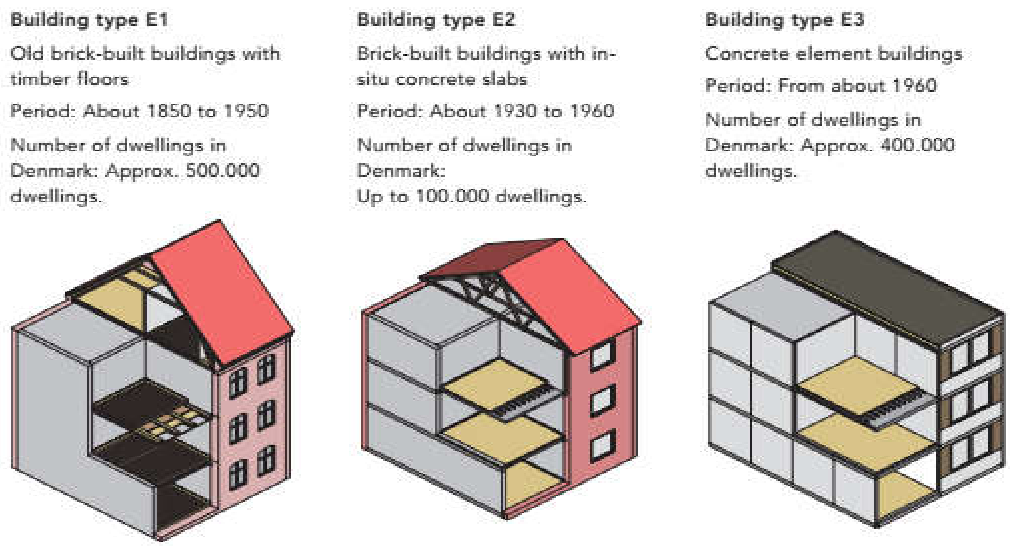


Figure 2: Building types in Denmark

Source: (Rasmussen & Petersen, 2014)

To start a renovation design, extensive data of the existing situation is needed. For the building envelope, thermal imaging is required, to evaluate the inefficiencies and locate the critical areas, the fan pressurization method (blow-door test) is used to register an air leakage through inefficiencies in airtightness. The data on geometry, materials currently used and structural system is needed to evaluate the possible solutions. For the building networks, the geometry data is the prime constraint on the available space for the systems, if it is not sufficient, the information on materials and structural system is required to expand it. Buildings have a long life cycle, often hundred years or more (The Ministry of Climate, 2014), that means that the documentation of buildings are in two-dimensional drawings. The precision of existing records depends on the effectiveness of the file management system, if all the changes are recorded in the as-built drawings, and the quality and frequency of monitoring of the building.

"In Europe, more than 80% of residential buildings are built before 1990 [38] and mainly do not have a building documentation in BIM format [19,39–41]. Therefore if implemented in practice, costly and mainly manual reverse engineering processes ('points-to-BIM', 'scan-to-BIM') (case III) help recapturing building information [42,43]. " (Volk et al., 2014)

To ensure the data is up to date, new inspections must be made, and to enable the contemporary design processes, this information must be turned into a BIM model (Volk et al., 2014)(Eastman et al., 2016)(Gerrish et al., 2017). To recreate the three-dimensional geometry with high precision and time-efficiently, registration methods like photogrammetry and LIDAR can be used for the inspection. After registry, the data must be manipulated through software that can turn it into a 3D model. Another set of registration methods focus on the materials and the performance of building elements, this data must be combined with 3D geometry model to create a BIM model. To select the proper combination of methods or workflow, the result must be defined, to find the meaningful data sets. In this thesis it is energy efficiency increase.

The lowest acceptable objective for an energy efficient renovation are dictated by the building standards. In Denmark the buildings are divided in two renovation classes:

Building type/ improvements	Renovation class 1	Renovation class 2
Residential buildings	52.5kWh/m^2/year+1650kWh/year/heated floor area	110kWh/m^2/year+3200kWh/year/heated floor area
Energy efficiency	Minimum reduction 30 kWh/m^2/year Energy efficient lighting	Minimum reduction 30 kWh/m^2/year
Ventilation	Minimum 0.3 l/s/m^2 of heated floor area outdoor air injection in residential rooms Extraction in bathrooms (min 20 l/s), toilets (min 15l/s) and kitchens Range hood over cooker of minimum 20 l/s extraction Heat recovery system Basement ventilation according to size and use	
Public buildings	71.3 kWh/m^2/year+1650 kWh/year/heated floor area	135kWh/m^2/year+3200kWh/year/heated floor area
Energy efficiency	Minimum reduction 30 kWh/m^2/year Energy efficient lighting	Minimum reduction 30 kWh/m^2/year
Ventilation	Minimum 5 l/s/adult + 3 l/s/child + 3 l/s/m^2 per floor area in day-care Minimum 5l/s/person + 3 l/s/m^2 per floor area in teaching rooms CO_2 max 1000ppm	

Table 1: Minimum energy efficiency increase and ventilation requirements for renovation projects

Source: (Ministry of Transport Building and Housing, 2018)

Regulations not only specify the properties of materials and installations, but also limit the design through prohibited solutions and requirements for the whole building.

1.3 Research question

To increase the effectiveness and efficiency of the design process (that connects the existing situation to the goals), ease the communication between the stakeholders (that concerns cost evaluation and construction phase), and support the facility management, BIM processes and software should be used (Volk et al., 2014)(Eastman et al., 2016)(Gerrish et al., 2017).

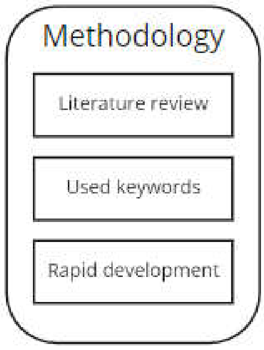
The foundation for these processes is a BIM model, with the correct geometry, properties and values. In energy renovation projects the required geometric and semantic information is dictated by the formulas in heat loss calculations. Based on the data of the existing situation, heat loss analysis can be made for separate building elements and different renovation scenarios can be modelled, thus allowing flexibility in solution selection. However, the relations between geometric and semantic information, their registration, recreation in BIM model and communication for energy analysis is not clear.

The research question for this thesis is:

How can the data from registration methods be semantically enriched to create BIM models for energy renovation?

The purpose of the report is to set up an effective and efficient workflow for the creation and handling of the semantically enriched data in renovation projects. This is done through the inquiry into building regulations of energy efficiency and indoor climate, building registration products/methods, data handling between different AEC industry specialities/software.

2 Methodology



In this chapter the breakdown of research question in separate domains and methods of investigation are explained.

2.1 Literature review

To answer the research question "*How can the data from registration methods be semantically enriched to create BIM models for energy renovation?"* it is separated in components, that will make up the research chapters in this report. Registration methods describe the different capabilities of modern technology in measuring existing buildings, contemporary building information use lays out the processes BIM model enables, Energy renovation investigates the calculations presented in (Dansk Standard, 2011) and measurements required in them. As these are broad concepts, they are constrained by the focus on energy renovation. Literature review methodology is selected, to gather existing information in these domains. To enable information search, separate research questions are formulated for each chapter.

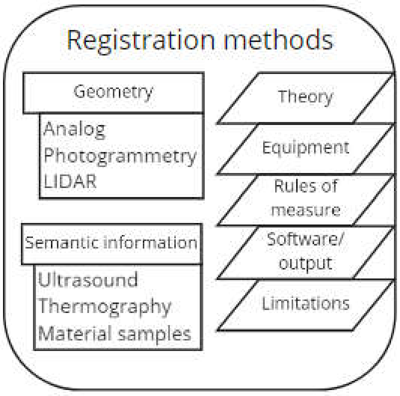
In chapter Registry of buildings, the research questions *"What methods are currently used for building registration?"* and *"What data is provided by the registration methods?"* were formed. Quantitative resource gathering was started with six theses on Scan to BIM process. From these the reference lists were inspected for relevant articles and scientific papers. Additional search of online research sources like Google Scholar, Science Direct and Research Gate was made with keywords "Scan to BIM", "Building Laser Scanning", "Photogrammetry", etc. Together around sixty articles, both primary and secondary source (literature reviews), were found and inspected for relevance to thesis topic, outdatedness and, in case of literature reviews, duplication of information. This research helped identifying the main registration methods. To understand the operation of these methods, theory articles were combined with research papers, opinion sources in online forums and information from equipment manufacturers. Opinion sources were used to identify the favourite workflows but are unusable as sources. In this chapter the limitation of energy-renovation meant excluding material testing methods used for other purposes, like welding tests for vacuum-vessels.

Contemporary use of building information chapter is based on questions *"What benefits does the BIM provide to AEC industry?"*, *"What data is contained in a BIM model?"*. Here the theoretical background was provided by BIM handbook (Eastman et al., 2016), literature reviews, case studies and national and international government agency publications. Additionally, databases were searched for keywords *"BIM"*, *"Energy-renovation"*, *"Exchange requirements"*. Flow models and Business Process Model and Notation (BPMN) are used to explain the processes in AEC industry specialities.

Energy renovation requirements chapter examines questions: *"What are the requirements for a BIM model, used in energy-renovation?"* "How can the registered data be turned into a BIM model?".

In Workflow design chapter rapid prototyping was used to develop prototype tools to document and extract data, for calculations required by (Dansk Standard, 2011). Future research in conclusion is based on findings in prototype testing.

3 Registry of buildings



"In many existing buildings, incomplete, obsolete or fragmented building information is predominating [11,23]. Missing or obsolete building information might result in ineffective project management, uncertain process results and time loss or cost increases in maintenance, retrofit or remediation processes."(Volk et al., 2014)

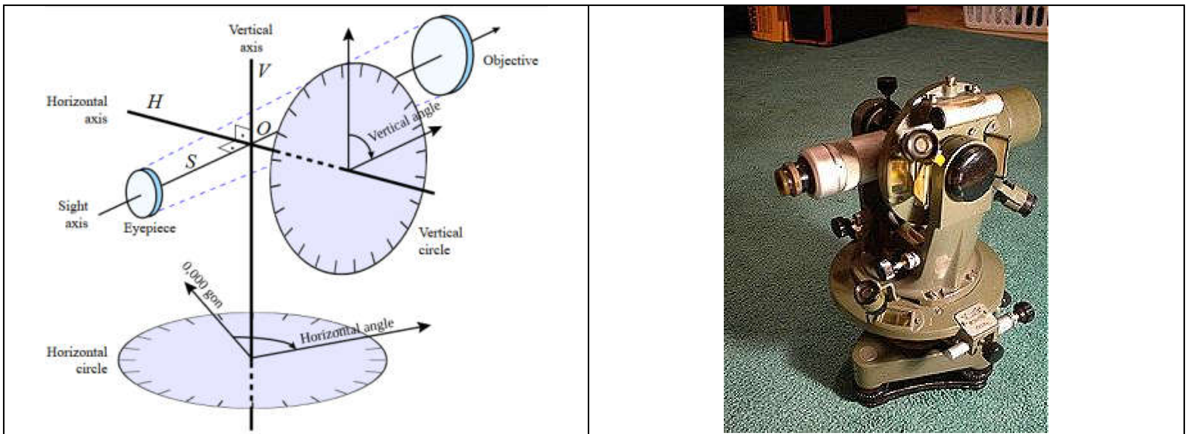
To register existing buildings and create a BIM model containing various data required for energy frame assessment several methods can be used. In this chapter the overview of the building registry equipment, theory, process and the resulting raw data will be presented. Registered information is divided in two groups – geometry data and semantic data.

3.1 Geometry registration

Geometrical data is the graphical representation of the building objects in a defined coordinate system and is made with combinations of two-dimensional surfaces, that can have textures applied on them. For energy renovation this will give the external dimensions of the building elements. Distinction is made between a manual registry, resulting in data that needs to be remodelled in software, and methods, that give digitalized results, that need to be manipulated to become a BIM model.

3.1.1 Analog/Manual registry

Theodolites (Figure 3) are optical measuring instruments that are used in land surveying and construction. It consists of a telescope that is mounted between the horizontal and vertical dial discs, this structure is then mounted on a levelling plane that can be attached to the support, like a tripod. When the telescope is aimed at the measuring point, angular readouts of the dial discs are recorded. A pair of surveyors is required – one takes the measurements, other indicates the points with a target marker. Theodolites have been in use since the sixteenth century, in the twentieth century they have been updated with electronics to digital theodolites and total stations. These modern tools, like Sokkia DTx40, eliminate the more complicated parts of setting up the instrument and gives the result on a display. Total stations also have the capabilities to measure distances, coordinates of the measuring point and even work on a remote control, eliminating the need for a second surveyor. Some models allow digital creation of the surveyed map by connecting to a proprietary software, like Trimble C5 HP with connection to Trimble Access.



a) Axes and circles of theodolite
Source: en.wikipedia.org

b) Non-digital theodolite
Source: en.wikipedia.org

 c) Digital theodolite DTx40 / DTx40L Source: https://eu.sokkia.com/products/optical-instruments/theodolites/dtx40-dtx40l-series	 d) Mechanical total station Trimble C5 HP Source: https://geospatial.trimble.com/products-and-solutions/trimble-c5-hp

Figure 3: Theodolites

For small scale dimensions the measuring tape is still widely used. This method is prone to errors and is highly dependent on the surveyor's experience, since it lacks the levelling and precision. This means that the measurements will need to be adjusted when the object is recreated digitally. Through the advancement in technology, measuring tape is being replaced by the handheld distance laser meters. As the name indicates, this device shoots a laser beam to the surface and measures the distance, thus giving a precise measurement, moreover, these devices have an in-built level indicator. Current models, like Leica DISTO X3, enable the measurements to be transferred to Excel®, Word®, AutoCAD® or to other programs through Bluetooth (Leica Geosystems AG, 2010). To eliminate the errors in these transfers, care must be taken with a software on computer and the unbroken wireless connection. Software like Leica DISTO Plan App allows to make sketch plans on smartphones, that can later be transferred to CAD software (Leica Geosystems AG, 2010). File formats like DWG and DXF can then be imported in to BIM software such as Autodesk Revit, still a recreation of the model is required.

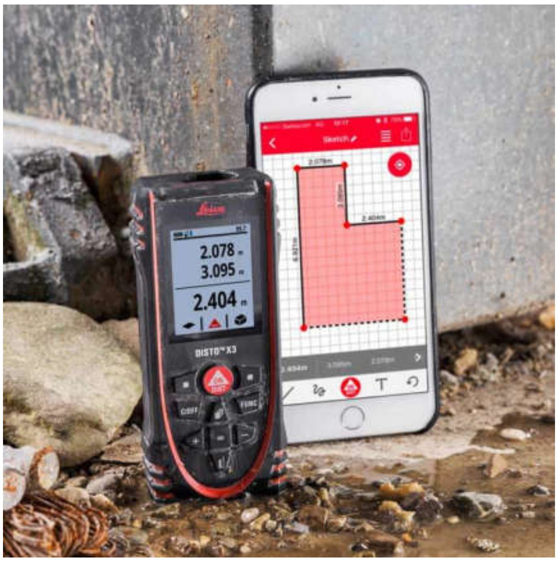


Figure 4: Laser distance meter Leica DISTO X3 and DISTO Plan App on a smartphone.

Source: (Leica Geosystems AG, 2010)

3.1.2 Photogrammetry

Photogrammetry is a method of virtually measuring and recreating objects based on one or more photos. It includes three main processes: image acquisition, image measurement and object recreation. As shown in Figure 5, each has a governing system and it defines the quality of the results. For images it is the photo camera, for measurement – the mathematical calculations and for processing – the software that visualises the object model.

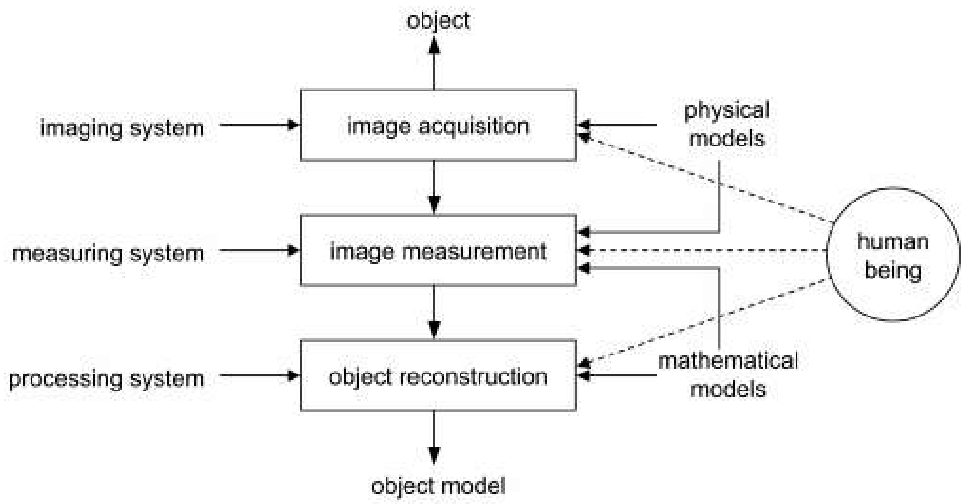


Figure 5 The photogrammetric process: from object to model

Source: (Luhman et al., 2006)

3.1.2.1 Theory

The main problem of the process is the re-creation of a three-dimensional digital or graphical model from a two-dimensional image.

"The reduction of a three-dimensional object to a two-dimensional image implies a loss of information. Object areas which are not visible in the image cannot be reconstructed from it. […] Whereas the position in space of each point on the object may be defined by three coordinates, there are only two coordinates available to define the position of its image. There are geometric changes caused by the shape of the object, the relative positioning of camera and object, perspective imaging and optical lens defects." (Luhman et al., 2006)

To measure the object, the central projection imaging is used, illustrated in Figure 6. The significant points on the object, denoted as "P", are selected and various amount of images are taken of the same object from separate and defined positions in three dimensions, called the perspective centres, denoted as "O' ". The projection of "P" on the images is denoted as "P' ". Casting rays from each images O' through P' allows to define (triangulate) the position of P in three-dimensional space where the appropriate rays meet. To allow triangulation of single point at least two images are required, further on the interior orientation of the camera needs to be known.

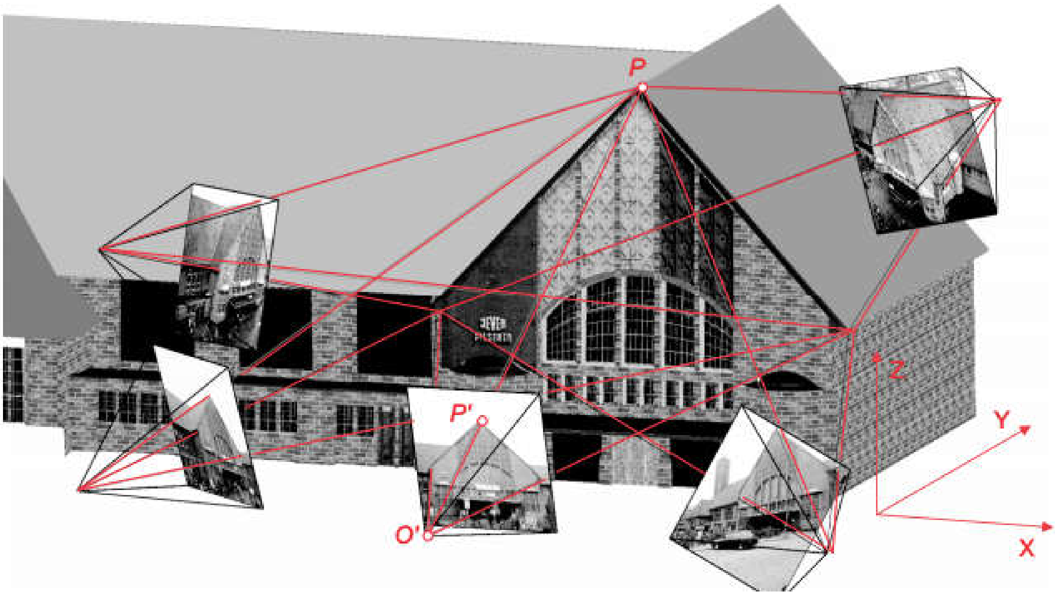


Figure 6 Principle of photogrammetric measurement

Source: (Luhman et al., 2006)

The methods of measuring and recreating the objects require a certain quality of the radiometric and geometric data contained in the images. Photo camera is the primary equipment used in the photogrammetry and its design defines the measures used in further process, seen in Figure 7. The distance between the perspective centre to the plane of the image is the principal distance ”c”; the internal orientation parameters shows the angular orientation of the image plane. The photo-scale factor ”m” is a division of the object distance ”h” with the principal distance ”c”, this will multiply any measurement error, that can arise from lens defects.

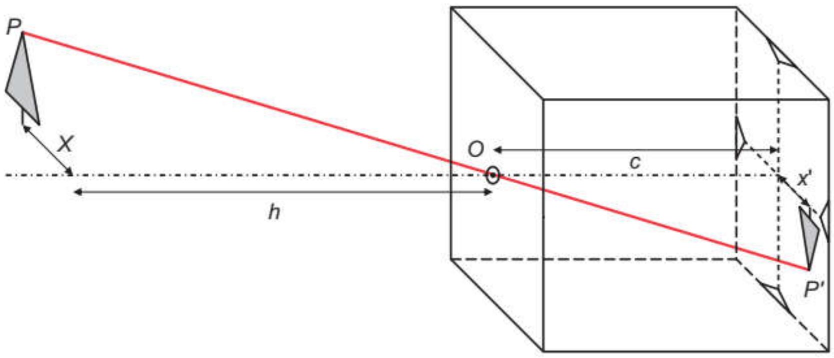


Figure 7 Pinhole camera model

Source: (Luhman et al., 2006)

“If the used camera is calibrated, interior image orientation may be done by transforming the measured coordinates into a calibration system, defined by fiducial marks or residual crosses. If a non-calibrated camera has been used, an independent set of parameters of the interior orientation is necessary for each image. In frame cameras independent parameters of the interior orientation are only required if the zoom factor or the focus of the camera has been changed during the image acquisition.” (Sužiedelyte-Visockiene & Bručas, 2009)

The dimensional accuracy is dependent on the quality and quantity of the images. Control points are points measured and marked in geodetic coordinates, that are established for the building projects. If they are captured in the images, the local coordinates of the object can be translated to other established geodetic systems.

In (Kraus et al., 2007), authors argue that high accuracy photogrammetry will be performed with light-sensitive film in metric cameras, however the advancements in photoelectronic image recording (digital photography) and digital software, combined with the ease of use (compared to photochemical processes in analogue imaging) have made the digital cameras the main equipment for photogrammetry (PhotoModeler Technologies, 2018c). The camera selection criteria is summarised in Table 2.

Factor	Why and what to look for
High resolution	Most high-quality cameras support resolutions of 8 mega pixels or better
High quality non-zoom lenses	Almost all digital consumer cameras will come with a zoom lens, so this is difficult to avoid. If using a zoom lens, you should set the optical zoom to one setting for all your PhotoModeler projects. Avoid using the digital zoom settings – digital zoom manipulates the photo without actually adjusting the focal length. DSLRs on the other hand let you choose your lens and we recommend a wide-angle non-zoom lens (called a prime lens). Do not use vibration reduction or image stabilization lenses.
Control over settings	If your camera has automatic features such as image stabilization or orientation detection ensure there are menu settings for turning these features off. Other good controls are for manual focus and sharpening (and in some cases aperture and shutter speed). When doing projects with high contrast targets we recommend using cameras with an anti-aliasing filter (most cameras have one) and turn off or reduce the sharpening setting.
Easy, fast image download to PC	The best methods are through Flash card (SDCard with SDCard reader for the PC), or a USB interface cable.
Frame size – aps-c vs full frame	The cameras listed below are the APS-C frame size as they are less expensive. A full frame (35mm across) camera can have better image quality (less noise, better in low light) and this might be important in some situations.
Focus range	What range can the camera or lens focus? If you are doing close-up work with very small objects, a macro focus capability can be useful.
Manual focus	Can you manually focus the lens? This can be useful for higher accuracy projects when you want the focus to be constant. This can be very important for macro photography.
Aperture – max and control	The amount of light that hits the sensor is controlled by the aperture and the exposure time. If you are working in lower light conditions and/or indoors, having a faster lens (smaller f-number) can help. Also, do you have manual control over aperture and exposure time? This can help in some tricky depth-of-field situations.
Remote control	Will the camera be mounted remotely or on a ceiling? Or will it be at the end of a pole for high shots? If so, you might want to remotely control the camera – take photos, download pictures. Some allow this through USB, some WiFi, and some Bluetooth. Also, can the camera be plugged into power if it is mounted in a difficult location to access.
Size/weight	If the camera is going to be hand-held in awkward positions, put on the end of a pole, or lifted by a drone/uav, then you will need to find a light camera. Compare the weights of your options.

Table 2: Factors in camera choice

Source: (PhotoModeler Technologies, 2018a)(PhotoModeler Technologies, 2018d)

3.1.2.2 Process/training

When starting the photogrammetric survey, the established control points must be identified and recorded. The purpose of the photogrammetric survey must be defined, so that the appropriate points on the object can be chosen. This must be included in a survey plan, that should be accurate, consistent, efficient and easy to execute (PhotoModeler Technologies, 2018b). To ensure the quality of an image, the scene must be properly lighted, so an artificial light source might be required. Good praxis indicates that the overall object (building) should be captured around the perimeter to establish a base model. If there are areas that require higher detail, like sculptured façade elements around entrance, they should have a separate plan of capture with more pictures, to increase the precision. The resulting separate model can be later merged with the overall building model.

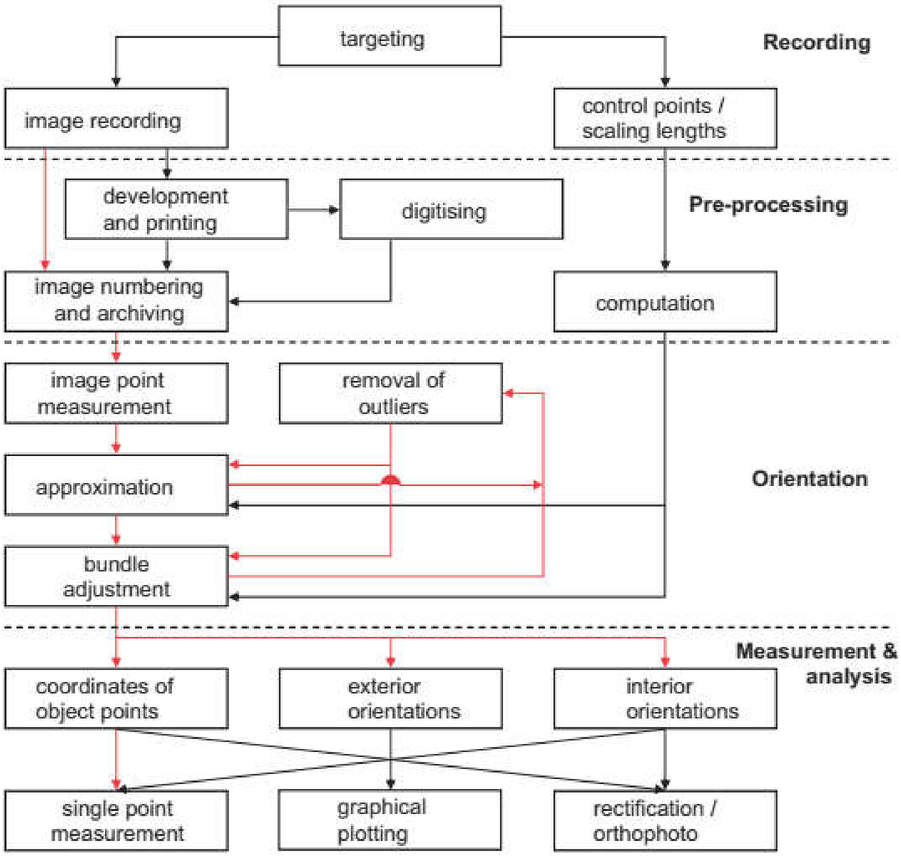


Figure 8 Recording and analysis procedures

Source: (Luhman et al., 2006)

If an analogue camera is used, different process must be implemented, however it is error-prone and time-consuming, due to the technological development, this is deemed obsolete in this thesis (Sužiedelyte-Visockiene & Bručas, 2009).

3.1.2.3 Products

There are a multitude of software and hardware in the market that uses the photogrammetry to streamline the object surveying. To select the product, surveyor must inspect the geometrical complexity of the building, the desired output and budget for solutions. While rectangular shapes can be managed by manual input, curved shapes require software to calculate the surface geometry. Software like PhotoModeler offer solutions for both cases. In the manual method, the user selects the significant points, corners and edges on a multitude of images and a wireframe connecting these features is made. In the coded target detection, the software assigns 3D coordinates for the user-selected targets and can identify these points in other photos. (Photogrammetry | 3D Measurements from Photos | PhotoModeler, 2019).

As mentioned in previous subchapter, the selection of camera requires consideration, however some companies supply hardware that is supported by their software, like Leica BLK3D (Figure 9), that is a separate hand-held device that uses two calibrated cameras, taking stereo pictures. These stereo pictures are then fed through an edge detection software, that detects objects and automatically snaps them together. In the software the users are allowed to make corrections in object snapping and text comments, then the plan drawings can be exported in JPG or PDF formats. The device works without requiring connection to external clouds or computers. To create BIM model, redrawing of the model is required, also the tying to coordinate systems are left to the user.

Figure 9: Leica BLK3D

Source: (Leica Geosystems AG, 2017)

Above mentioned products require relatively high investment (150USD/month for PhotoModeler software, 4800 USD for Leica BLK3D hardware and up to 593 USD/year for the software). Meshroom is a free, open-source photogrammetry software for object recreation, and it is written in Python programming language, that has similar user interface as visual programming software Dynamo and Grasshopper. As a free-ware, Meshroom support and help is dependent on user tutorials on the internet.

3.1.3 Light detection and ranging (LIDAR)

Light detection and ranging is a non-destructive registration method that uses laser to measure distance to objects and re-creates the 3D environment as a cluster of measured points, called point cloud. In addition to measuring the location of points most hardware also registers the visual surface. Depending on hardware mount this method divides in terrestrial laser scanning (TLS) and airborne LIDAR (S. & Pande, 2011)(Ergn, 2011)(Luis et al., 2011).

3.1.3.1 Theory

To measure distance to a point, laser is shot at it, then sensor picks up the reflection, time between these two actions is measured and multiplied by the speed of light. The in-built GPS tracker and angular measurement system allows the equipment to give each point local and global coordinates (S. & Pande, 2011).

"By compiling a series of adjacent 2D digital images captured at different heights in the specimen, constructed 3D images provide 3D surface and volume information by a non-contacting and un-intrusive method (Sheppard and Shotton, 1997; Pawley, 1995). Using specialised software, surface measurements can be readily performed on variations in pixel intensity and spatial locations contained in 3D images (Brown and Newton, 1994; Yuan et al., 2005)." (Tomovich et al., 2011)

3.1.3.2 Equipment

Large producers as Leica, Sokkia and Trimble offer their solutions for 3D laser scanning. These products combine total station measurements, point cloud creation and high-resolution imaging. The main difference in specifications is the optimal working range, accuracy and reflectivity. There is also a minimum distance that device can work with. This stems from the power of the laser used in the device and is measured from the diameter of laser dot in the distance, identifying the size of a point in the result. Other notable differences are the amount of scanned points per second, time for 360° scan, data storage capacity, battery life, image quality, supported software and requirement for additional accessories. Accessories include on-site laptops/tablets, tripods and target marks for meaningful points. The current products also offer internet connectivity for easy data transfer.

3.1.3.3 Process/training

As the laser cannot penetrate objects, a survey plan must be made, considering what needs to be seen in the result. The necessary objects for capture are defined in project exchange requirements, in case of energy renovation, it is the building envelope. TLS equipment is set up on the survey plan points and scans are performed, generating a point cloud. The data is uploaded to software environment where it is possible to combine scans from the separate survey points (Figure 10), clean up erroneous points, simplify the data cloud, to decrease the data size and do mark-up. The model is created on "top" of the point cloud. (Leica Geosystems AG, 2019)

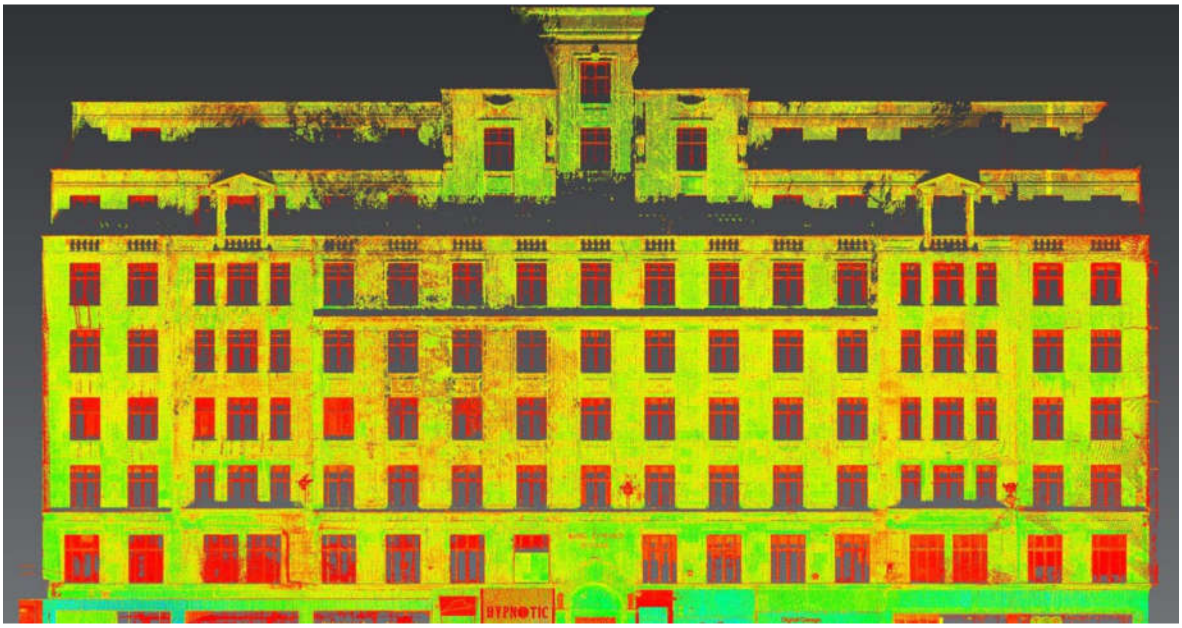


Figure 10: Point cloud of facade of a building

Source: (How Hollis captures, processes, manages and delivers reality capture data | Leica Geosystems, 2019)

Drone mounted measuring equipment can be used for capture of external geometry of a building, comparison between the methods are shown in Figure 11.

	Photogrammetry	LIDAR
Cost	$20K-$30K for a professional drone + high resolution camera system	$50K and up for just the sensor - survey-quality complete systems in the $150K-$300K range
Operational complexity	No additional sensors required, indirect georeferencing requires longer processing but is resistant to potential workflow errors	LIDAR uses direct georeferencing, which means that multiple components and sensors must work perfectly together in order to gather usable data
Outputs	2D orthomosaic maps 3D models, point clouds, surface models with visual information as part of the 3D model	3D point clouds, intensity maps with multiple returns and full-waveform information for classification
Accuracy	1 cm horizontal, 2-3 cm elevation (vertical) over hard surfaces	1-2 cm elevation (vertical) over soft and hard surfaces
Best for	Mapping, surveys, mining, broad-coverage combined with high horizontal and vertical accuracy.	Terrain models below dense vegetation, forestry, 3D modeling of power lines or cables, 3D modeling of complex structures

Figure 11: Comparison of photogrammetry and LIDAR

Source: (Drone photogrammetry vs. LIDAR: what sensor to choose for a given application | Wingtra, 2019)

3.2 Semantic information registration

Semantic information in BIM is data identifying specific properties of the building object. These parameters include spatial areas (coordinates in model space), functions, material types and custom defined properties, thus enabling the full visualization of 3D geometry and supply the data used by specialized software for the different purposes, mentioned in the chapter 4. Semantic information also includes rules between the data and objects, thus defining the data structure. These rules allow for semi-automation for design, like snapping a new wall between the floor and the ceiling or parametric design. Furthermore, aggregation of building components can be defined, so that addition of hanging balcony will add the load for structural calculations and thermal bridge for connection to a wall element. In energy renovation the material data is used to calculate the transmission heat loss.

3.2.1 Ultrasound

For the inspection of internal structure of building elements, ultrasound scanning can be used. This method requires access to element surface, where a transducer is attached, that emits ultrasonic signal. The ultrasonic wave permeates the element and reflects from different materials, generating echo that is recorded by the transducer and transformed into electrical signal that is displayed, thus allowing to locate the inconsistencies in material.

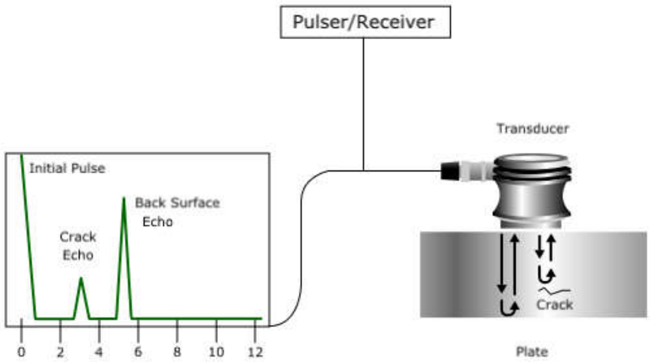


Figure 12: Scheme of Ultrasound test.

Source: (Nde-ed.org, 2019a)

"Goals range from the determination of fundamental microstructural characteristics such as grain size, porosity, and texture (preferred grain orientation), to material properties related to such failure mechanisms as fatigue, creep, and fracture toughness" (Nde-ed.org, 2019b)

Testing equipment operates with three main physical values – wavelength, velocity and frequency. Velocity is constant and surveyor adjusts frequency to change the wavelength. Smaller wavelength increase the sensitivity (ability to detect small defects) and resolution (ability to distinguish between separate, closely located inconsistencies), but scatter in coarse materials, like concrete (Nde-ed.org, 2019a).

Material	Inspections
Concrete	Crack and void detection/location; reinforcement placement/corrosion; cable and pipe location; element thickness
Steel	Welding consistency; paint thickness; corrosion mapping; element thickness
Timber	Element thickness; cavity/damage/rot detection
Masonry	Internal structure, adhesive connection of reinforcement and grout

Table 3: Ultrasonic inspections in different building materials

Source: (Nde-ed.org, 2019a), (Zielińska & Rucka, 2018), (Hasenstab et al., 2006)

3.2.2 Thermography

Objects with a temperature higher than absolute zero (-273.15ºC) radiate energy. Thermal infrared imaging (thermography) captures quantity of energy leaving a surface as radiant heat in wavelengths of 2-15 µm. Thermography uses digital cameras with specialized lenses and detectors, and can capture large surfaces, showing the differences in the surface temperature, to localize the heterogeneous areas. This makes it advantageous compared to point measurements of the temperature.

The problems in building construction, that can be detected using thermal imaging include missing or damaged insulation layer, existence of thermal bridges and moisture in the building elements. All these faults decrease the energy efficiency of a building, by allowing thermal energy to escape, and must be corrected in energy renovations to decrease the heating/cooling costs. Thermography allows for localization of issues and their cause, thus reducing the repair costs. Likewise, the insufficient insulation of heating, ventilation and air conditioning (HVAC) systems can be detected and localised.

When performing thermography, the surveyor must be aware of the factors that can decrease the accuracy of the thermography. Ambient temperature effect on camera is mostly compensated by the equipment, there is required difference of at least 11ºC between internal and external object surfaces, when measuring buildings. When dealing with moisture in elements, like water accumulation under the roof felt, inspection must be done when the surface is not heated (during sunny day, there will be no difference visible). Atmospheric particles like gas, vapour, water and dust can absorb and scatter emitted heat. Wind speed increases the heat transfer through convection, thus the surfaces exposed to wind will radiate less, however indoors this will increase the temperature difference on surfaces. It is recommended to perform outdoor thermographic survey when wind is lower than 5m/s, or the effects can obscure the problems in the resulting images. Increased distance to the inspection object will increase all distortion from atmospheric phenomena. Polished metals are not measurable by thermography without altering their surfaces (painting, adding targets). Glass materials reflect the infrared spectrum, requiring positioning of heating elements (also surveyor) to be considered during the analysis of results. Lastly, the angle of capture influences the amount of data each pixel needs to represent, thus viewing from right angles presents maximum detail (Balaras & Argiriou, 2002)(Taylor et al., 2014).

3.2.3 Other

Material samples can be acquired and tested for the material properties, like thermal conductivity. However, sample collection damages the elements and represents only localized property values. To solve this issue, (Dansk Standard, 2011) states applicable thermal conductivity values for construction materials in annex F and values in connection with renovation in annex G.

4 Contemporary use of building information

Contemporary use of building information

BIM workflows

Energy calculation software

"Building Information Modelling (BIM) is an intelligent 3D model-based process that gives architecture, engineering, and construction professionals the insight and tools to more efficiently plan, design, construct, and manage buildings and infrastructure." (© Autodesk Inc, 2019)

There are international, national and private incentives in using BIM, as it is seen as major component in digitalization of building sector, aimed to increase the low labour productivity growth (1.0% compared to 3.6% in manufacturing sector). BIM facilitates collaboration between the different stakeholders and phases of a project (Figure 13), increasing efficiency, lowering costs, miscommunication and inaccuracies. (European Commission, 2019b)

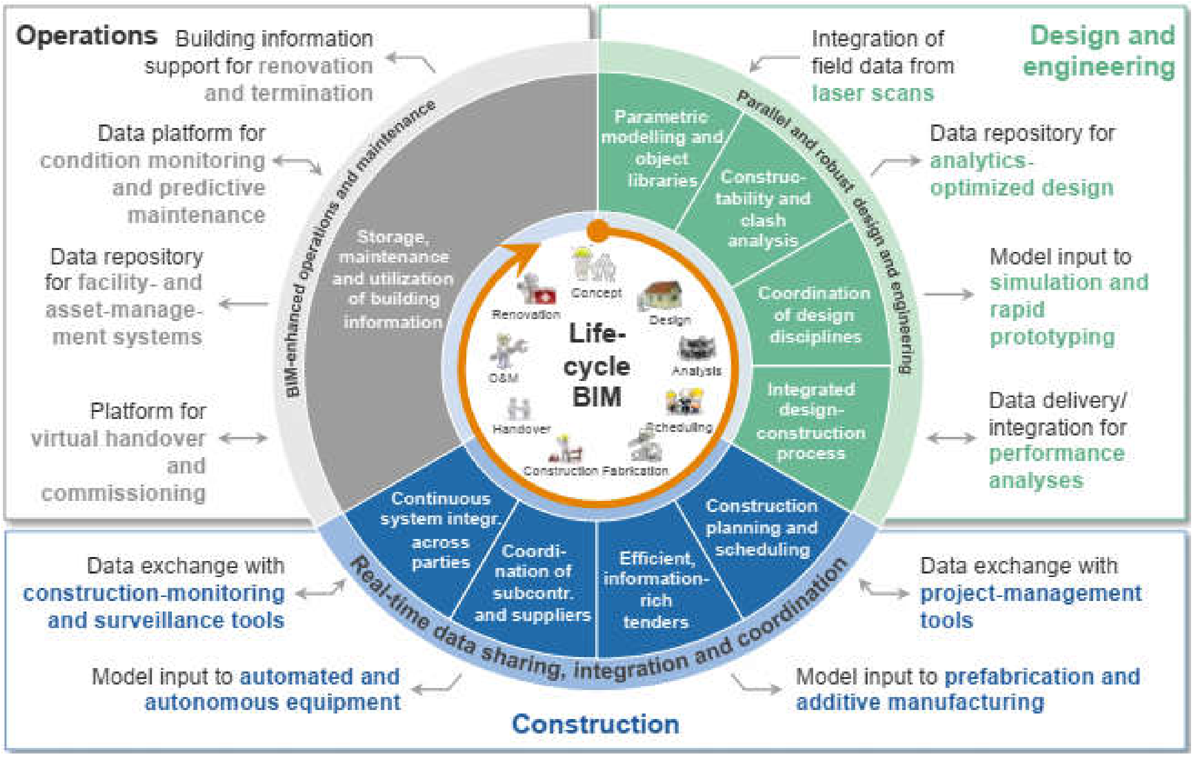


Figure 13: Applications of BIM along the construction value chain

Source: (Philipp Gerbert, 2016)

Effective communication of purposes and requirements for the BIM model between stakeholders in a project lead to concept of Integrated Project Delivery that aims to decrease time and cost. In this chapter the existing BIM workflows, software and related data requirements in an energy renovation project will be described.

4.1 BIM workflows

The purpose of BIM is creation of a model that contains the required information, that can be modified and extracted for further analysis in speciality software, since there is no one software that can perform all tasks needed for complete building design. In order to set up the model correctly, separate uses must be investigated, to define what data is needed and where it must be stored. The results of separate analyses and resulting design choices must be documented from each software, so the information can be tracked. The information, created by separate specialities in AEC industry, is placed back into a federated model.

4.1.1 Renovation design

During the lifetime of a building factors like vibrations, weather and inappropriate use can damage building and degrade its structural, architectural and mechanical, electrical and plumbing (MEP) system quality. The building renovation project starts with client's need for a new or improved facility. The design of the project (Figure 14) is a balance between satisfaction of client's needs and expenditure of available resources. In feasibility analysis the requirements for the project are defined in terms of facility functions, operational equipment and financial plan of funding the project and earning back the investment. Simplified engineering calculations can be attached to model to illustrate the impact on construction time and cost by construction material and system. When calculations of the structural elements are done, BIM supports detailing and connection to fabrication software that is linked to numerical control machinery, that automates the precise production of steel, precast concrete, fenestration and glass elements (Eastman et al., 2016). Different MEP systems can be compared for their impact on operations. Connection of separate specialization designs helps to demonstrate the impact of changes, allowing for generation of reconfiguration choices, thus facilitating concept feasibility analysis.

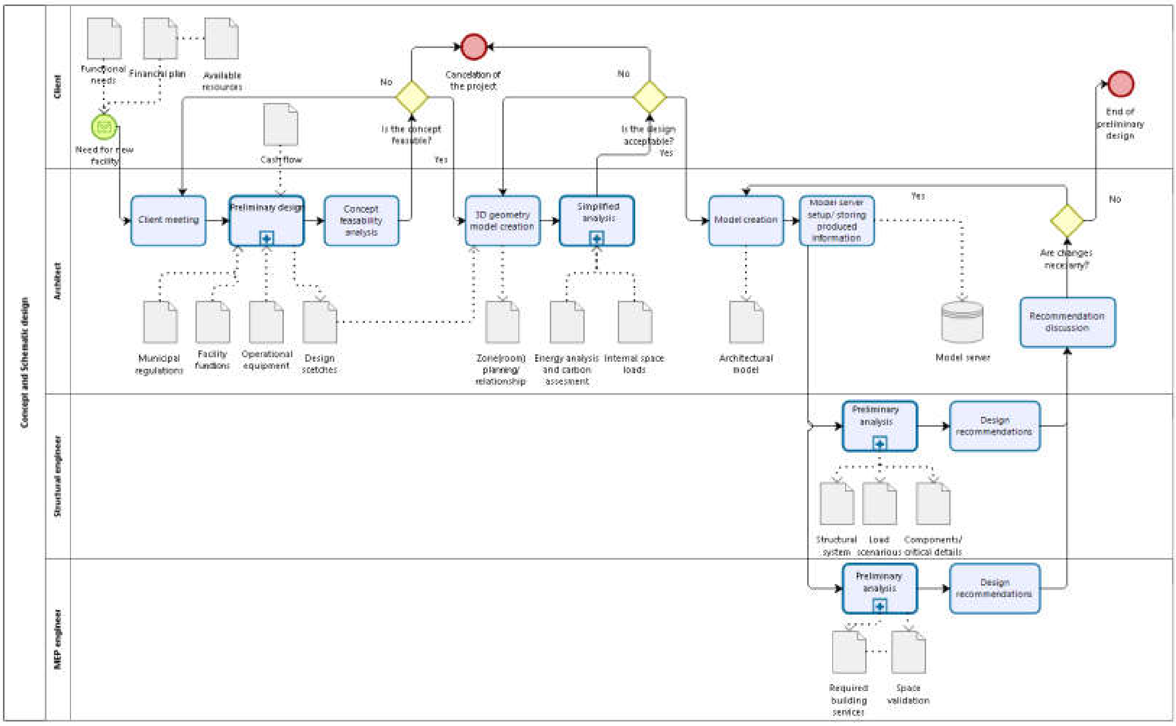


Figure 14: Preliminary design phase diagram

MEP engineering design aims to increase the sustainability of buildings, while offering the best indoor climate for the occupants. Buildings account for 35%-40% of total energy consumption in developed countries (Danish Energy Agency, 2013), thus the ever increasing energy costs and climate impact drive more demanding legislative requirements. In Denmark, the maximum allowed energy demand for square meter per year have constantly decreased (Figure 15). European Commission also incentivizes creating databases for existing building energy efficiency and increasing the regulations for renovation projects (European Commission, 2019c).

MEP uses Building energy performance simulation (BEPS) software and the calculations or Energy Performance Assessment (EPA) using thermal properties and arrangement of building elements, supply of energy and networks of heating, ventilation and plumbing. The commonly used software in Denmark – Be18, IV20 and BSim is described in the chapter 4.2.

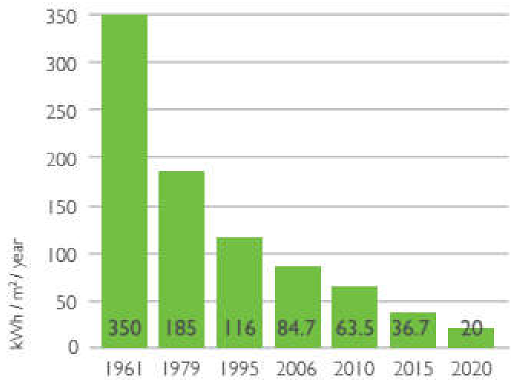


Figure 15: Danish building codes from 1961 to present: Maximum allowed energy demand per year and m2 heated floor space in a new 150 m2 residential building. The limit is on the total amount of supplied energy for heating, ventilation, cooling and domestic hot water

Source: (Danish Energy Agency, 2013).

There are two types of BEPS: conventional – data are fed into sequential functions, that give the result; and advanced simulation – object information is linked to equations, thus allowing faster simulation (Pinheiro et al., 2018) (Wetter et al., 2016). BIM supports precise quantity take-off and communication during the design phase, that can be imported in calculation software. Common BIM models include around 70% of the information required for EPA(Choi et al., 2016). The source data is the architectural model with indications of intended space use, that allows for design of indoor climate. It concerns the supply and loss of air, heat and light. Passive solutions require thermal insulation and airtightness to minimize heat transfer through building envelope, and sunlight analysis to optimize the heat and light gain by correct building positioning and façade glazing. Active solutions, like heating, ventilation, air conditioning and artificial lightning can be controlled to ensure the correct indoor climate at any time of the building operation. Regulated amount and specification of sanitation installations are allocated, based on the intended use of the building. Electrical system is designed to distribute power to the active systems and to required power sources for the operation of the building. This process is illustrated in Figure 16. Network design in the BIM model allows for allocating the necessary space and access. Automation of active systems can be linked to sensors and information in model to simplify their operation. Collaboration capabilities allow the complete design to avoid element crossings.

Structural calculations ensure stability, strength and rigidity of buildings during intended operations with a safety factor for accidental loading. The architectural design model identifies the intended geometry and material choices, allows gathering of internal and external loads and approximation of structural system (Figure 17), i.e. load paths from the building to the ground. This information is imported in structural design software, like Autodesk Robot and Tekla Structures where calculations are made, and elements detailed. Considerations for element constructability, in terms of worker and equipment access, are alleviated by using spacing rules in BIM models, compared to two-dimensional drawing workflow, that requires high attention and “know-how” on all the details from the engineer.

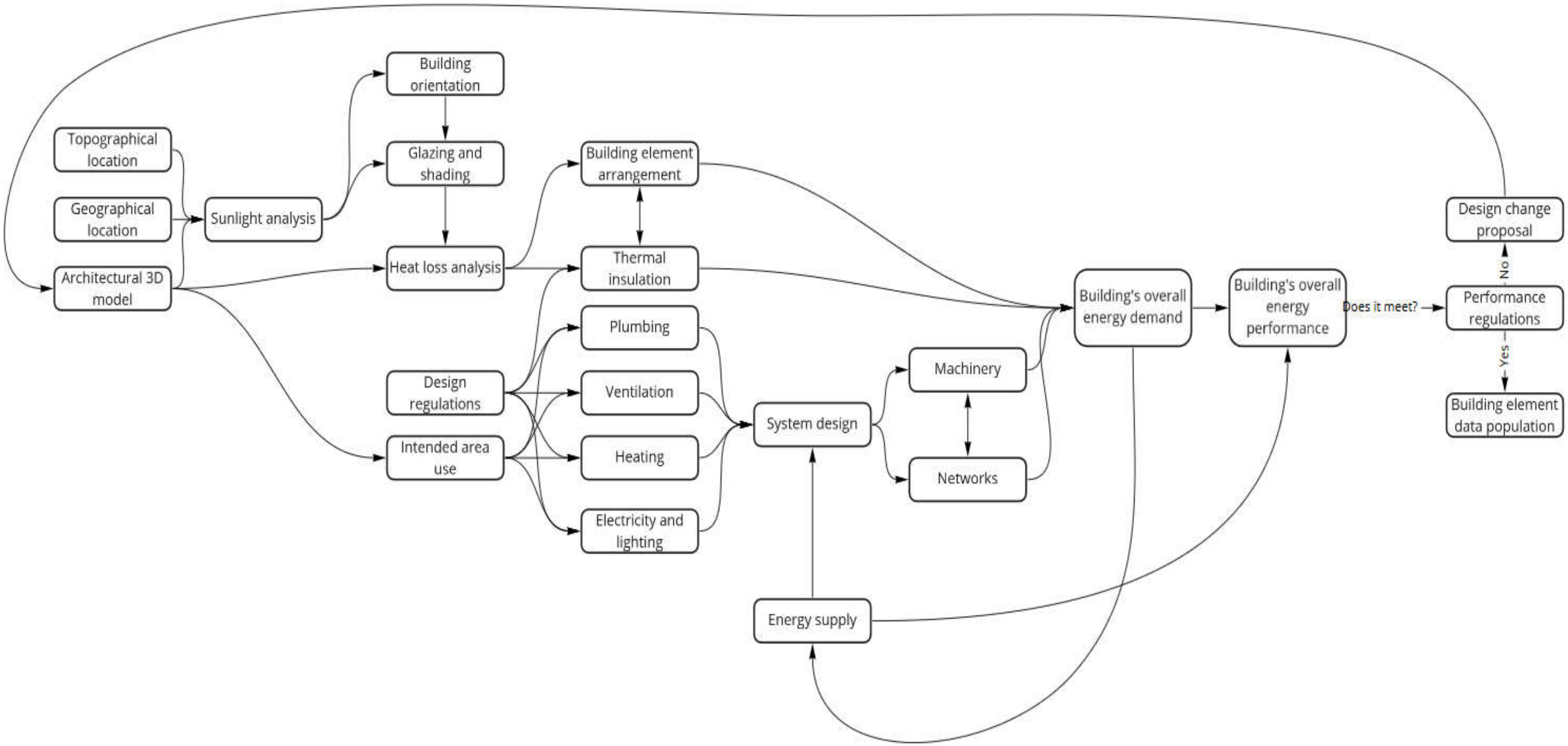


Figure 16: MEP design considerations

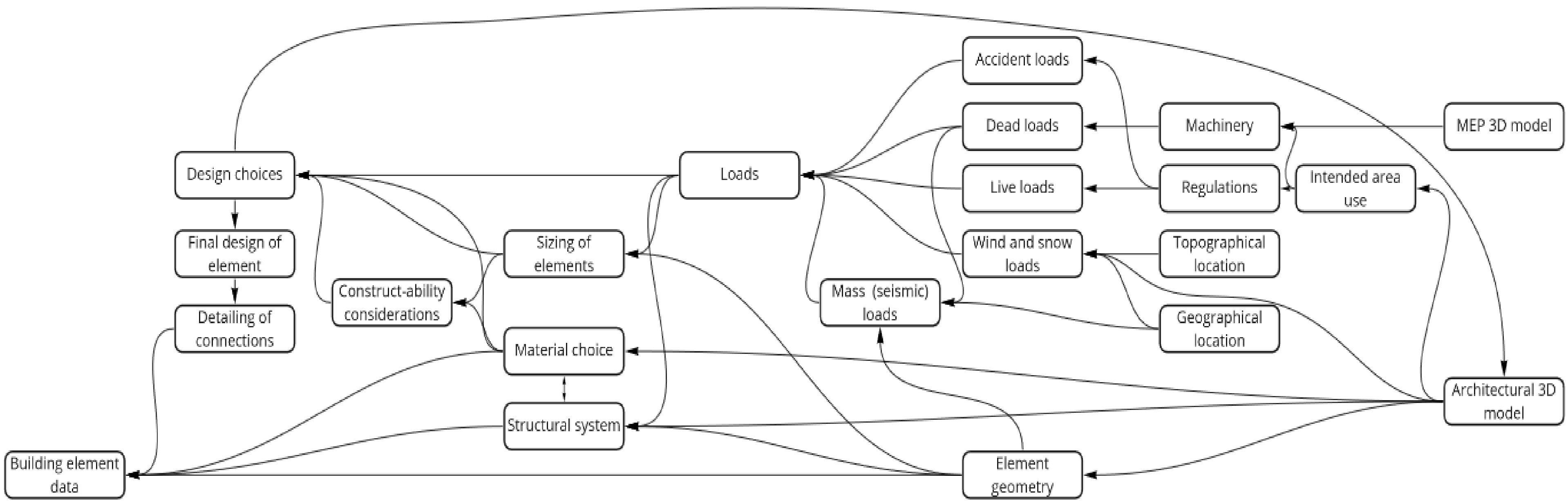


Figure 17: Structural design considerations

Model checking (Figure 18) is performed constantly throughout the design phase to check for combability of separate system, clearance adequacy and correct construction modelling. Software like Solibri Model Checker allows user to combine models and develop rulesets for the checking process (Solibri, 2018). Discrepancies can be visually marked and communicated back to designers, thus reducing errors and time consumption for remodelling during construction process.

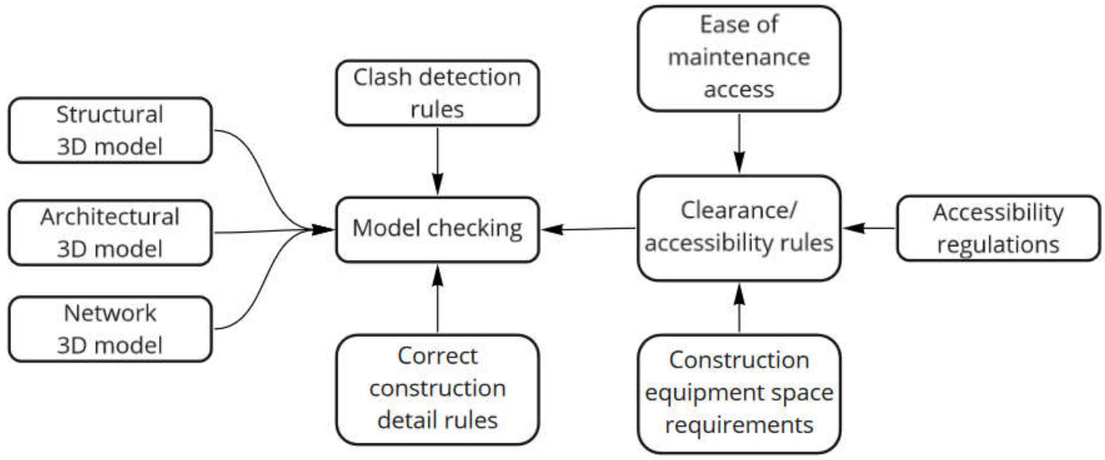


Figure 18: Model clash detection considerations

With building element information, supplied by separate specializations, and comprehensible visualisation of the whole building, the adherence to regulations can be explicitly demonstrated, thus cutting time for approvals.

Complete BIM model facilitates detailed tendering, as the building elements are modelled separately, their quantities and specifications can be easily accessed, validated and valuated, allowing for efficient cost management throughout the design phase. Consequently, it also enables the architectural heritage preservation. Denmark has around three hundred thousand building deemed worthy of preservation (ROSS, 2010). In preservation the recognition and use of historical materials and building techniques are crucial, since using differing chemical components and modern building solutions can damage the structure and the architectural value. Moreover, detailed BIM model can facilitate the reconstruction after an earthquake or fire, in more authentic manner than if only visual evidence is used (CyArk, 2020).

Excluding BIM from renovation can lead to loss of building monitoring and modification information, thus requiring meticulous inspections before each cycle of renovation. Creating BIM model of existing building gives overview of used materials, construction techniques and problem areas that need special monitoring.

4.1.2 Construction and operational phase

In scheduling of construction work, BIM has the advantage of containing all separate designs in one model, that can be filtered for specific professional works while not losing the oversight of the complete building. Accessibility of the elements in the model allow for scheduling of procurement and mobilization of the required materials, equipment and machinery. It also allows for location-based scheduling that ties place and task, thus pushing for more detailed planning and faster overall execution. In addition, rules can be attached to elements to ensure space and safety for work execution.

With this information added to BIM model, visualisations of planned progress can be generated, and errors can be averted in scheduling phase. This workflow also decreases need for on-site material storages and improves collaboration between contractors. (Eastman et al., 2016)

During the operation of a building, depending on its technological sophistication and lifespan, the running costs will overtake the initial investment in design and construction, thus the facility management must be optimized and controlled. Operation and maintenance of a building can be improved by use of BIM, through precise information on installed materials, systems and machinery. Facility management includes processes as operation/emergency simulation, cleaning, MEP system control, accident control and functional repair. When BIM model is complemented with controls and sensors, the localization and specification of any malfunction or need for maintenance can be completed effectively and efficiently.

Life cycle analysis gives overview of costs, performance and material data of a building through all phases from conception until refurbishment or demolition. As the public opinion moves toward more sustainable projects, it is essential that data influencing design decisions can be gathered and compared to performance of the completed building.

These data sets are also used to back the certification process for buildings. Building certification systems are impactful selling point for a design, since they aim to ensure quality of design, construction and operation. Popular certification systems in Denmark include Active House, BREEAM, DGNB, HQE, et al. These certification systems are based on environmental, economic and social dimensions (Figure 19) in the whole project (there are also less complicated systems that look on single and multiple product attributes). The three dimensions are subdivided in thirteen aspects and each certification system different valuation of these aspects. (3XN/GXN, 2012)

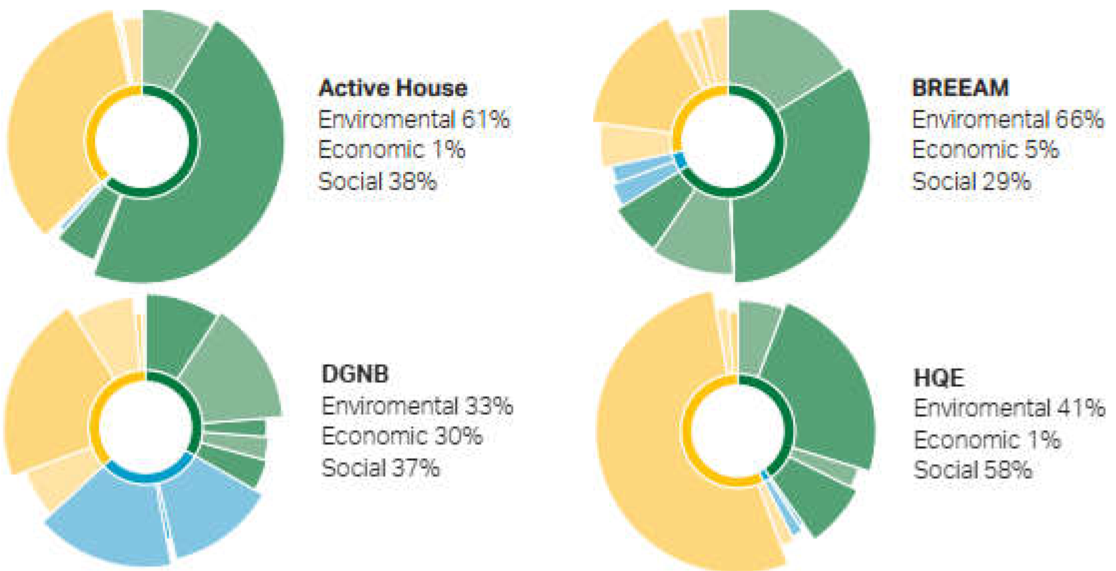


Figure 19: Sustainability dimensions of different certification systems

Source: (3XN/GXN, 2012)

BIM model also can be viewed as a catalogue of used products, that could be filtered for recyclable, reusable and hazardous materials. In the event of deconstruction or demolition, efficient and safe planning, scheduling and implementation will depend on this data.

"Construction and demolition waste (CDW) is one of the heaviest and most voluminous waste streams generated in the EU. It accounts for approximately 25% - 30% of all waste generated in the EU and

consists of numerous materials, including concrete, bricks, gypsum, wood, glass, metals, plastic, solvents, asbestos and excavated soil, many of which can be recycled." (European Commission, 2019a)

4.2 Energy calculation software

4.2.1 Be18

BE18 is a certification program that calculates energy frame of buildings for new constructions and renovations. The program uses data of building envelope and thermal losses related to it, ventilation, occupation and other similar inputs which directly correlate to heating, cooling and hot domestic water demand. The program is developed by Statens Byggeforskningsinstitut.

The BE18 software uses Extensible Markup Language (XML) format to read and write data. This allows to easily integrate the program into the workflow, as the advantage of the XML encoding is its understandable readability by users and computers. By knowing the set of rules, import modules can be extracted from such programs as Revit and with additional simple tools as Dynamo code, the data can be encoded to format that BE18 reads. This allows to minimize the amount of manual work needed and can quickly show current energy framework of the project building as well as effects of planned renovation improvements. In addition, output of BE18 is also in XML format, which allows to use the program as an intermediate as the data can be transferred to other software.

Be18 is used to document and prove the energy frame of a building. And the use is described in SBi213 (Energy needs of buildings, 2018).

4.2.2 BSim

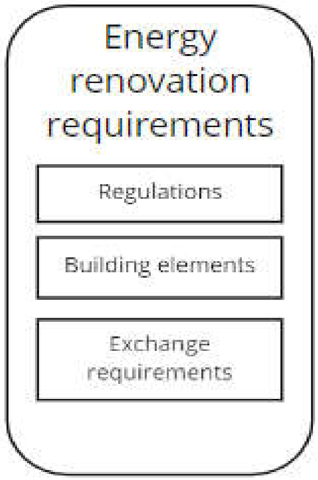
BSim is a building simulation program that performs dynamic simulations of building environment and yearly thermal conditions. Program uses geometrical and material data, occupational information and geographical positioning to estimate thermal conditions and estimate energy gains and losses due to such factors as internal energy loads or solar influence. This software is also developed by Statens Byggeforskningsinstitut.

Similarly, to BE18, BSim software stores model information in XML format. However, software itself uses its own coordinate system and constructs the geometry of the building using vertices, which makes the process of exporting data from Revit rather complicated as number of rules for encoding such model must be implemented. To alleviate this, a SimDXF file format is used to import CAD drawings. In addition, the software itself requires user input as some settings must be changed manually prior simulations are executed. The output of the software can be saved into TXT file format, but due to extensive saving options (data filtering), user input is required as well. Overall, implementation of BSim requires extensive work of implementation into the workflow. (Danish Building Research Institute, 2002)

4.2.3 IV20

IV20 is indoor environmental and energy simulation program that closely follows DNGB certification criteria. Program is developed by Aalborg University. IV20 is one of the newest available programs. However, currently it is built as a concept and written as an excel file with executable macros. For this reason, data import is limited. One of the solutions is the data extraction from Revit and import to excel, using Dynamo. Similar workflow is described in the chapter 6.

5 Energy renovation requirements



5.1 Regulations

The energy requirements for the buildings are stated in BR18 (Ministry of Transport Building and Housing, 2018) and address the whole building, to understand the calculations of separate building parts, Danish Standards must be investigated. The transmittance of thermal energy through the building envelope is covered in DS418 – Calculation of heat loss from buildings (Dansk Standard, 2011). Calculation input data dictates what information must be extracted from the BIM model. In this subchapter the overall calculation principles are presented.

In energy calculations, there are two means of heat leaving through the building envelope - transmission loss and linear loss. Transmission loss represents the amount of heat that flows through elements and is dependent on thicknesses and thermal properties of different layers of materials (Dansk Standard, 2011).

$$\varphi_t = U\,A(\theta i - \theta e)$$

where

φ_t	is transmission loss in W
U	is the transmission coefficient in W/m^{2}K
A	is the area of the plane in m^2
θi	is the design indoor temperature in °C
θe	is the design outdoor temperature in °C

Figure 20: Transmission loss calculation

Source : (Dansk Standard, 2011)

Transmission area is the element area that is exposed to the environment, specific cases are mentioned in section 3.6 (Dansk Standard, 2011). Indoor temperature for residential rooms is set to +20ºC and outdoor to -12ºC, for basement walls and floors below the depth of two meters, the outside soil temperature is set to +10ºC (Dansk Standard, 2011). Additionally, the influence of radiators and floor heating must be taken into account by changing the indoor temperature to +50ºC and +30ºC respectively.

U-value describes the heat transmission through the material layers, if the layer consists of different materials (inhomogeneous layer), the separate areas and thermal conductivities are added and divided by the area of the layer. This value then is adjusted with the correction due to the interruptions in insulation layer. These corrections represent are related to state of wear and tear of insulation material, the amount of wall ties between the structural leaves of walls and “upside down” roofs, where the waterproof membrane is below the insulation layer. These corrections are found in Annex A (Dansk Standard, 2011).

$U = U' + \Delta U$

where

U' is the uncorrected transmission coefficient in W/m^2 K

ΔU is the correction, estimated according to Annex A (normative).

Resulting U-values are indicated to 2 decimals.

$$\frac{1}{U'} = R_{si} + R_{se} + \sum R_h + \sum \frac{d}{\lambda'}$$

where

$$\lambda' = \frac{A_a\lambda_a + A_b\lambda_b + ..}{A_a + A_b ..}$$

R_{si} is the inner surface resistance in m^2 K/W

R_{se} is the outer surface resistance in m^2 K/W

R_h is the resistance of homogeneous layer in m^2 K/W

d is the thickness of inhomogeneous layer in m

λ' is the estimated average thermal conductivity of the inhomogeneous layer in W/mK

A_a, A_b is the area of inhomogeneous layer sections in m2

λ_a, λ_b is the applicable thermal conductivity in W/mK

The resistance for an unbroken homogenous material layer is

$$R = \frac{d}{\lambda}$$

where

d is the thickness of the material layer in m.

λ is the design thermal conductivity for material or product in W/mK (see chapter 7).

Figure 21: Calculation of the transmission coefficient (U-value) and heat flow resistance

Source: (Dansk Standard, 2011)

Surface resistances (Rsi and Rse) are given by the product manufacturer or read from table 6.2.1 (Dansk Standard, 2011) and are influenced by direction that heat transmits through them. As in Figure 20 and Figure 21, thickness and construction homogeneity of layers, area and material thermal conductivity are required to do the calculations for transmission loss.

Linear loss is heat loss due to linear cold bridges – parts of construction that have significantly smaller heat flow resistance than the rest of the construction (Dansk Standard, 2011), this also applies for the construction joints around openings.

$$\varphi t = \Psi_{sa}\, l_{sa}\, (\theta i - \theta e)$$

where

ψ_{sa} is the linear loss for the joint in W/m K, referring to chapter 6.12

l_{sa} is the total length of the joint, referring to chapter 3.7

Figure 22: Linear heat loss calculation

Source : (Dansk Standard, 2011)

Linear loss ψ_{sa} is dependent on the wall construction and the window/door frame material and placement.

Construction elements like beams above or brick ribs around windows, brick columns in walls form cold bridges, requiring the dimensions of areas, to calculate the heat loss.

$$U' = \frac{\sum_{i=1}^{n} A_i \cdot U_i + \sum_{k=1}^{m} l_k \Psi_k + \Sigma \chi_j}{A}$$

$$A = \sum_{i=1}^{n} A_i$$

where

A	is the total transmission area in m^2 of the construction, see chapter 3.6
A_i	is the sub area in m^2
U_i	is the transmission coefficient of the sub area with a one-dimensional heat flow in W/m^2 K
l_k	is the length of the individual linear thermal bridge in m, see chapter 3.7
Ψ_k	is the linear heat loss for the individual linear thermal bridge in W/mK
χ_j	is the point heat loss for the individual spot thermal bridge in W/K
n	is the number of sub areas
m	is the number of linear thermal bridges

Figure 23: U-value calculation for constructions with cold bridges

Source: (Dansk Standard, 2011)

Heat is also lost through ventilation. If the building has natural ventilation, the value is dependent on heated floor area.

$$\Phi_V = \rho c \frac{q_a}{1000} (\theta_i - \theta_e) \approx 1.21\, q\, A (\theta_i - \theta_e)$$

where

q_a	is the fresh air amount in l/s per m^2 heated floor area
A	is the heated floor area in m_2.

Figure 24: Natural ventilation heat loss calculation

Source: (Dansk Standard, 2011)

The value q_a is set to 0.3 l/s for residential buildings per room, however if the wind proofing of doors and windows is not documented, this value is increased by multiplying air intake with joint length. For exposed buildings in terrain categories 0, I, II (Fonden Dansk Standard, 2007), air intake is 0.8 l/s per meter, otherwise 0.5 l/s per meter of a joint.

If a mechanical or a hybrid ventilation system is used, loss is dependent on the design of the system and requires HVAC engineer to calculate.

Total heat loss from a building combines transmission losses and ventilation loss.

5.2 Building elements

For each building element there are special calculations and exceptions for transmission losses, that are presented in this chapter. The (Dansk Standard, 2011) is inspected for connections and different cases for each element, to draw a relationship graphs that can be seen in appendix 10.1. The rules of measurement and relations are explained in this chapter. Based on input data for these calculations, requirements for building inspection/registry survey, BIM model and data extraction from model is made and structured in protocols, that are presented in 5.3 Exchange requirements.

5.2.1 Walls

As seen in Figure 21, the main data required for transmission loss of a building element is their planar and cross sectional dimensions, and material properties. In Figure 25, the limits of height measurements for walls are indicated.

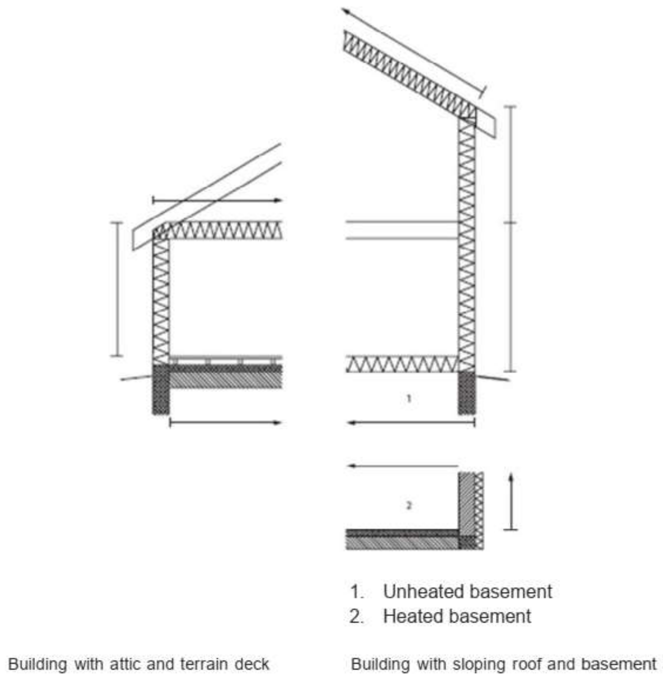


Figure 25: Measurements of transmission heights

Source : (Dansk Standard, 2011)

As a structural element that comprises largest volume of a building and defines the geometry, walls have complex construction with many details that vary in their thermal transmittance. Measurements start with dimensions of wall and openings. In absence of as-built drawings, the cross-section of wall must be investigated by use of intrusive methods, to inspect the materials and thicknesses of different layers of wall. For precise calculations inhomogeneous layers (e.g. timber frame and insulation) must be inspected, with uncovering the layer or using ultrasound. Additionally, the number of brick-ties, concrete anchors, cracks in insulation layers and air-filled cavities must be evaluated and recorded. After the planar values, the local linear losses are investigated. These include structural elements as pillars (thickness changes require to calculate average value), ribs around openings and penetrations of walls, here each change of insulation layer thickness adds linear loss. For areas with lower insulation thickness additional transmission area is calculated, disregarding insulation, according to section 6.7 (Dansk Standard, 2011). Further, linear losses are present in joints with change in plane of insulation, like connection between outer wall and basement wall, where existence of overlap of insulation layers must be investigated. Linear loss values are based on measurements and read from tables in (Dansk Standard, 2011). A thermographic survey can give the actual measurement of transmission loss.

5.2.2 Windows and doors

"The transmission coefficient for windows and outer doors, including gates, glass walls, hatches, skylights, dormer windows towards the free, towards unheated rooms and between spaces heated to different temperature, are decided and declared (by the producer) like pointed out in the harmonized product standards DS/EN 1873, DS/EN 14351-1 and DS/EN 14963" (Dansk Standard, 2011).

For products that are in the building and are missing the data it can be calculated manually.

U-values are calculated from the basic formula:

$$U = \frac{A_g U_g + l_g \Psi_g + A_p U_p + A_f U_f + l_k \Psi_k}{A_g + A_p + A_f}$$

where

A_g	is the glass area in m^2 (by glass can be understood other corresponding materials)
L_g	is the circumference of the glass area in m
A_p	is the panel area in m^2
A_f	is the frame/casing area[1)] in m^2
L_k	is the length of other linear cold bridges in m
U_g	is the transmission coefficient in the middle of the pane in W/m^2K
ψ_g	is the linear loss for the pane's distance profile in W/mK
U_p	is the transmission coefficient for the panel in W/m^2K
U_f	is the transmission coefficient for frame/casing[1)] in W/m^2K
ψ_k	is the linear loss for other cold bridges in W/mK

[1)] "frame/casing" also includes bars and posts.

Figure 26: U-value calculation for window

Source: (Dansk Standard, 2011)

For transmission loss, the dimensions of opening, frame and panel (window or door) are combined with structure of panel and its material properties. The same properties will also enable calculating linear loss between panel and frame. For linear losses between frame and wall, the construction of wall and placement of the opening need to be investigated and the values can be read from tables in the chapter 6.12 (Dansk Standard, 2011).Windows and doors in renovation projects can have non-standard solutions that require making separate calculation model according to annex C (Dansk Standard, 2011).

Skylights and roof windows transmission loss is calculated as for windows – frame and panel. Linear loss requires the measurements of joint height and joint insulation thickness, according to Figure 27, and then can be read from table 6.12.4 (Dansk Standard, 2011).

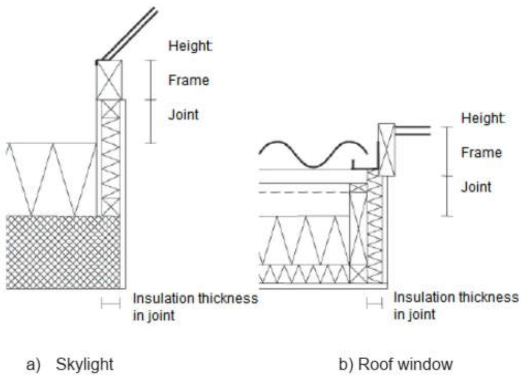


Figure 27: Skylight measurements

Source : (Dansk Standard, 2011)

5.2.3 Foundations

Foundations contribute to linear losses and are differentiated considering their depth, connection to floor and materials and construction of the supported element (wall or door/window). For this thesis, foundations under basement outer and partition walls are investigated.

5.2.4 Roof, ceiling and slabs

For roof, ceilings and slabs, the dimensions and materials need to be recorded. A special case is an "upside-down" roof, where waterproof membrane is below the insulation layer. This calculation is described in Annex A (Dansk Standard, 2011) and requires meteorological data about rainfall.

5.3 Exchange requirements

Exchange requirements for the registration of the building and model creation for energy renovation project are based on standards, that are used to create registration and calculation protocols. At the top of a protocol, the element category and identification number is recorded, then tables consisting of measurement titles, values, units and locations in (Dansk Standard, 2011) are made. The required values are colour coded. Revit input shows the values that are used in model, but are not extracted, thus require manual input in calculations. Revit extract indicates the registered values that are placed in Revit model and later extracted for calculations with Dynamo script (6.3 Data extraction from Revit model using Dynamo). The manual input is for values used in calculations, but not recorded in Revit model. Values without colour code are calculated in the Excel spreadsheets.

In Figure 28, the first page of wall protocol demonstrates the necessary measurements for calculation of transmission loss – areas of walls and material conductivities. Also visible are the comments on the left side of tables that indicate relations. Values of #DIV/0 show cells with calculations that include division by zero, since the related values are not filed in. The total transmission loss includes the adjustments for cold bridges and linear losses, that are calculated in next pages.

				Section/ Table/ Figure
Element	Wall			
Identification no				
Colour codes	Measurement	Value	Units	
Revit input	Length		[m]	
Revit extract	Height		[m]	
Manual input	Area of openings		[m^2]	
	Area of the whole wall	0	[m^2]	
	Depth below terrain deck (influences the temperatures)		[m]	
* heating elements	Inner temperature θi	20	[°C]	F- 2.1
	Outer temperature θe	-12	[°C]	F- 2.1
* change for basement	Inner surface resistance	0,13	[m^{2}K/W]	T- 6.2.1
* change for basement	Outer surface resistance	0,04	[m^{2}K/W]	T- 6.2.1
T- 6.9.1				
Composition				
	No material - λ=1			
Inner leaf	Material	Concrete	N/A	
	Thickness d		[m]	
	Thermal conductivity λ		[W/mK]	Annex F/G
Insulation leaf	Material	Rockwool	N/A	
	Thickness d		[m]	
	Thermal conductivity λ		[W/mK]	Annex F/G
Middle leaf	Material		N/A	
	Thickness d		[m]	
	Thermal conductivity λ		[W/mK]	Annex F/G
Outer leaf	Material	Concrete	N/A	
	Thickness d		[m]	
	Thermal conductivity λ		[W/mK]	Annex F/G
	Component for uncorrected transmission coefficient U'	#DIV/0!	[W/m^{2}K]	
Adjust for cavities	Combined U value for the wall	#DIV/0!	[W/m^{2}K]	
	Transmission loss ϕ_t for the whole wall	#DIV/0!	[W]	

Figure 28: Wall protocol title page

The next page Figure 29 shows the calculations of cold bridges, according to Annex A (Dansk Standard, 2011). Also, requirements of use case are placed before the table.

Cold bridges	Annex A			
Insulation				
	Level of air cracks in insulation layer	1		S- A.2.3
	Correction for air-cracks in the insulation ΔU''		[W/m²K]	T- A.1
	Heat flow resistance of the insulation layer R_i	#DIV/0!	N/A	
	Heat flow resistance of the construction R_T	#DIV/0!	N/A	
	Correction for air-cracks in the insulation ΔU_g	#DIV/0!	[W/m²K]	
Bric ties/ concrete anchors				
Neglect if:	1 Non-insulated cavity			
	2 Ties between brick and timber frame			
	3 Heat flow resistance of a tie < 1W/m K			
	4 Correction < 0.005 W/m² K			
Cannot apply if:	1 Both ends of the tie is in contact with metallic cover material, then use DS/EN ISO 10211			
Common ties				
	Material of fixing			
	Number of ties per m² n_f		[No/m²]	
	Diameter of ties		[mm]	
	Thickness of insulation layer, that contains ties d_1		[m]	
	Tie correction ΔU_f for common ties		[W/m²K]	T- A.2
Uncommon ties				
	Coefficient α	0,8		S- A.3
	Thermal conductivity for the wall-tie λ		[W/mK]	
	Cross sectional area of the tie A_f	0	[m²]	
Set to insulation leaf	Heat flow resistance of the insulation layer with ties R_1	#DIV/0!	[m²K/W]	
	Construction's total heat flow resistance R_T	#DIV/0!	[m²K/W]	
	Tie correction ΔU_f	#DIV/0!	[W/m²K]	
	Total wall correction ΔU	#DIV/0!	[W/m²K]	

Figure 29: Cold bridge calculation regarding insulation and ties

Next the adjustments for pillars and ribs are recorded and calculated Figure 30. The calculations are made for linear loss on each side of the thinner insulation zone and area of thinner zone is considered as having no insulation.

Pillars and ribs				
Linear loss				
	For buildings with change in pillar/rib thickness - average thickness			
Requirements:	1 Cold bridge insulation thermal conductivity λ < 0,04 W/m K			
	2 Pillars and ribs made of the same material as the connected wall			
	3 Materials according to tablle 6.7.1 requirements			
	Count of insulation changes			
	Cold bridge insulation thermal conductivity λ		[W/m K]	
	If λ>0,04, assume cold bridge interruption thickness = 0			
	Cold bridge interruption thickness		[m]	
	Inner leaf material			
	Outer leaf material			
	Linnear loss Ψ_k		[W/m K]	T- 6.7.1
Transmission loss	Cold bridge interruption width		[m]	
	Cold bridge length (heigth of pillar/rib) l_k		[m]	
	Cold bridge sub area A_i	0	[m²]	
	Transmission coefficient of the sub area U_i	#DIV/0!	[W/m²K]	
	Area of the whole wall	0	[m²]	
	Component for uncorrected transmission coefficient U'	#DIV/0!	[W/m²K]	

Figure 30: Losses due to pillars and ribs

Other considerations for wall elements include calculations for change in plane of insulation, air filed cavities, penetrations and ingoing and outgoing corners.

For window elements, the transmission loss calculations require measurements of openings, frame and glass areas and structure. For linear losses the construction of wall element and placement of the frame needs to be recorded (Figure 31).

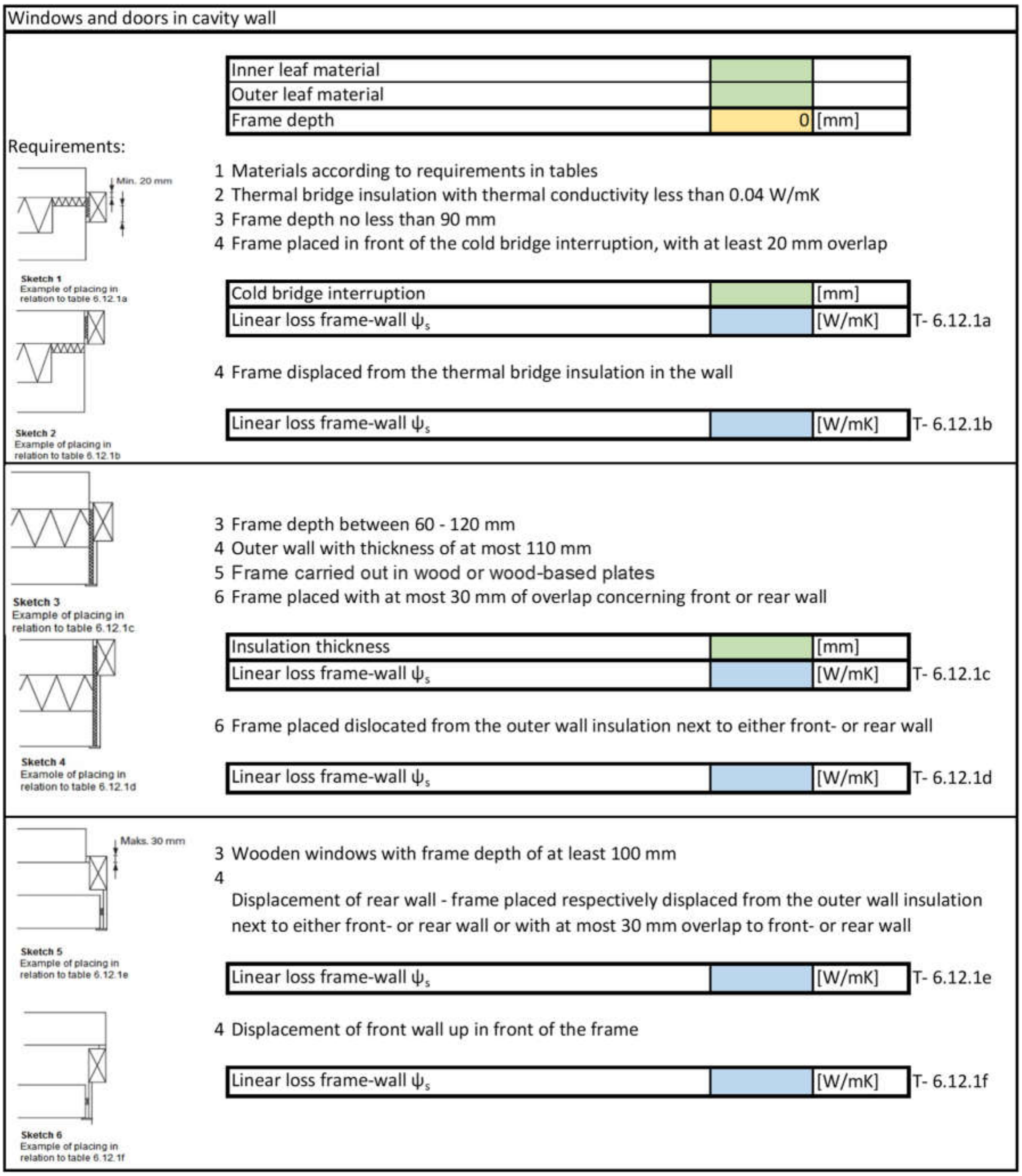


Figure 31: Window-wall linear loss registration

Drawing source: (Dansk Standard, 2011)

Protocols for the other elements can be found in appendix 10.2 Survey/calculation protocols.

In Figure 32 the means of acquiring required measures from existing buildings are shown. As mentioned in the chapter 3.2.3, it is advised to collect the individual material properties from (Dansk Standard, 2011).

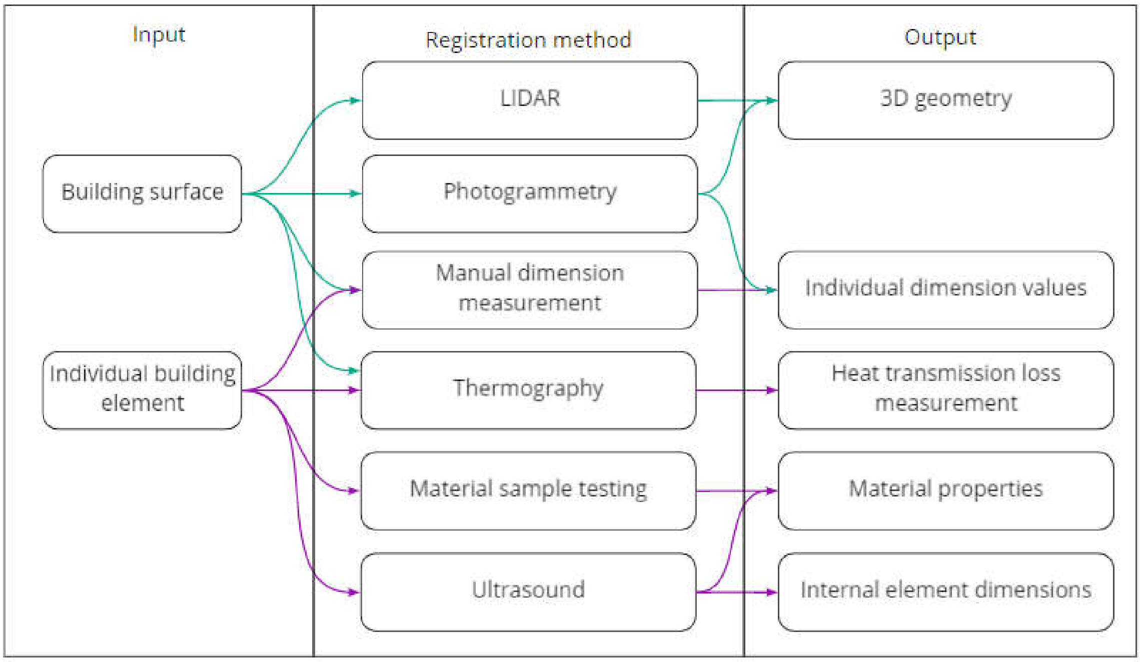
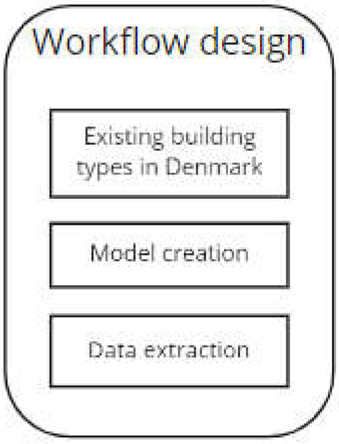


Figure 32: Registration method inputs and outputs

6 Workflow design



This chapter describes the Revit model creation and Dynamo scripting to extract the values required for energy calculations. Revit 2020 and Dynamo 2.3.0.6270 with Clockwork, Rhythm, archilab and GeniusLoci node packages are used.

6.1 Existing building types in Denmark

As mentioned in chapter 1.2 and Figure 2, the existing residential buildings in Denmark can be grouped in three types. For the design of workflow one apartment of two storey residential building of Type E3 is chosen and modelled according to descriptions in (Rasmussen & Petersen, 2014). This type is characterized by use of prefabricated concrete – sandwich elements for the walls and hollow core slabs for storey partitions. Gable walls are supported by columns, while façade walls are supported by the columns and transverse walls that are used as room partition walls. The columns are disrupting the external wall insulation layer.

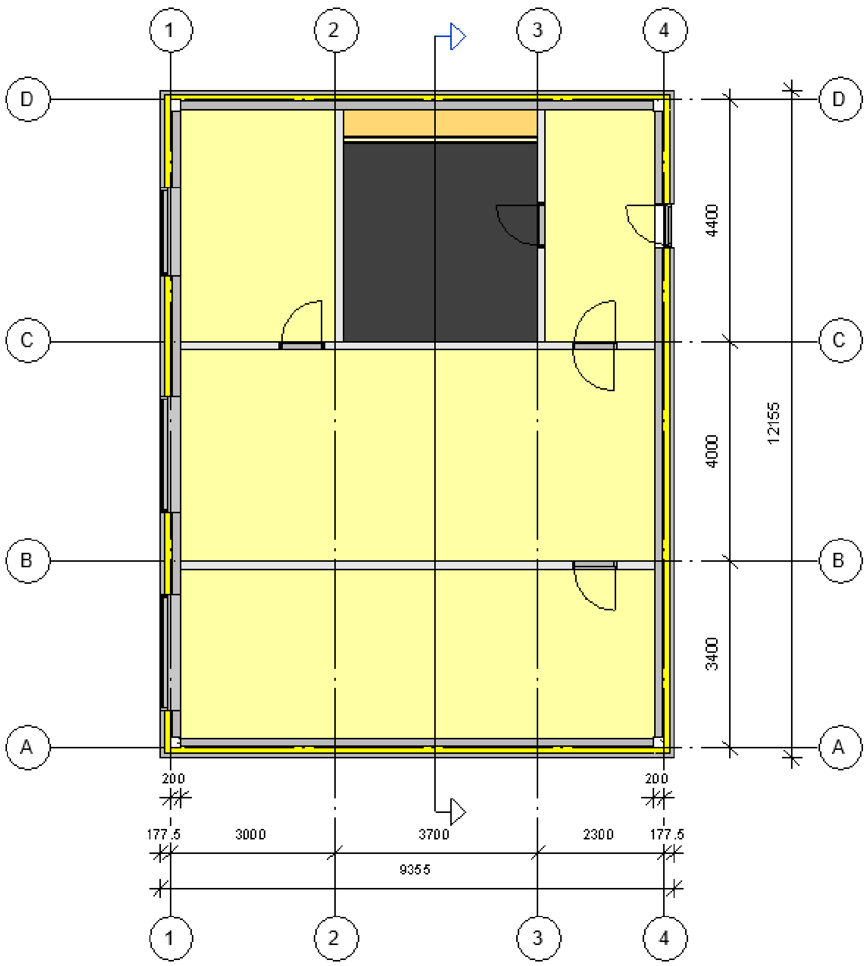


Figure 33: ground floor plan of the building

The basement walls are made cast-in-situ concrete with polystyrene insulation on exterior face. Basement floors are made of concrete, that rests on insulation layers. The foundations are made for the walls and columns and penetrate the insulation layer of basement floor. The building has flat roof of precast concrete elements with insulation and roofing felt on top.

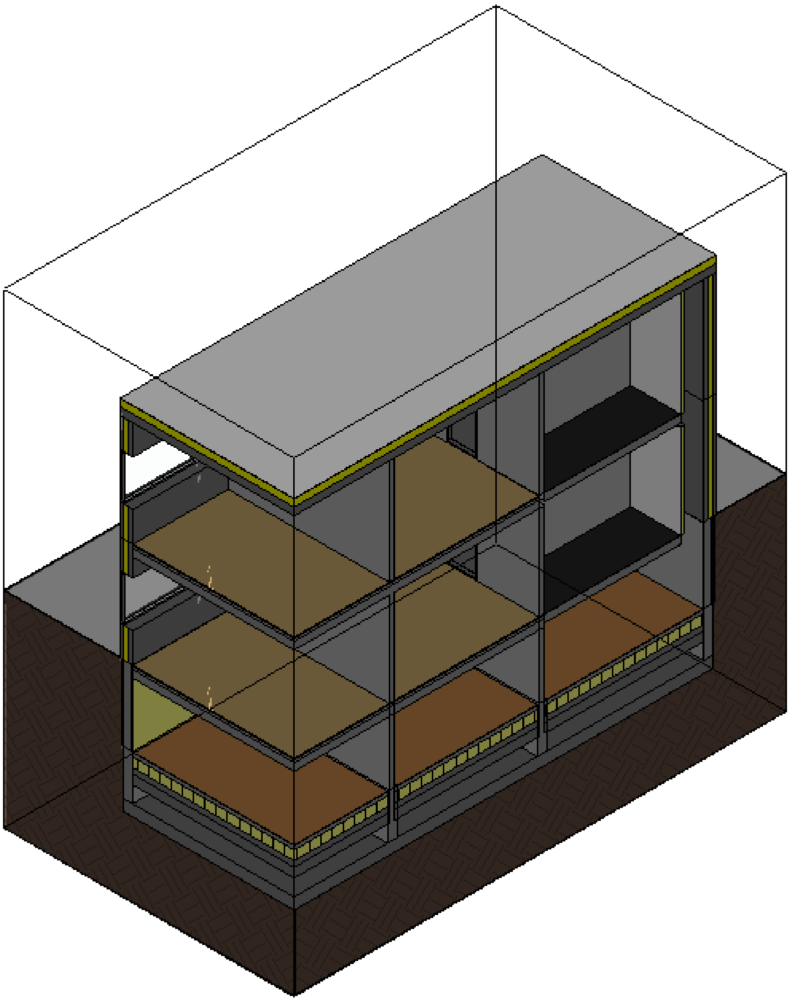


Figure 34: 3D cross section of the building

There is no staircase designed, since unheated spaces do not add to energy calculations.

6.2 Data in model

Geometry in the model is created to represent different building elements and give values for calculation, so it does not represent structural details. Restrictions on geometry apply to element cross-sections, to allow calculations to be made according to (Dansk Standard, 2011)

Semantic information consists of element types, material dimensions and thermal properties, that are filled according to (Dansk Standard, 2011), to represent existing building with unknown product data. This required custom material creation. In real life application this data comes from the registration methods and protocols.

Two custom parameters are created – Revit_GUID (Figure 35) to display the in-built element identification for elements of interest and tie correction for amount of connectors per m2 between leaves. Parameters are set to instance, so that each element can have a different one and the data type is set to text.

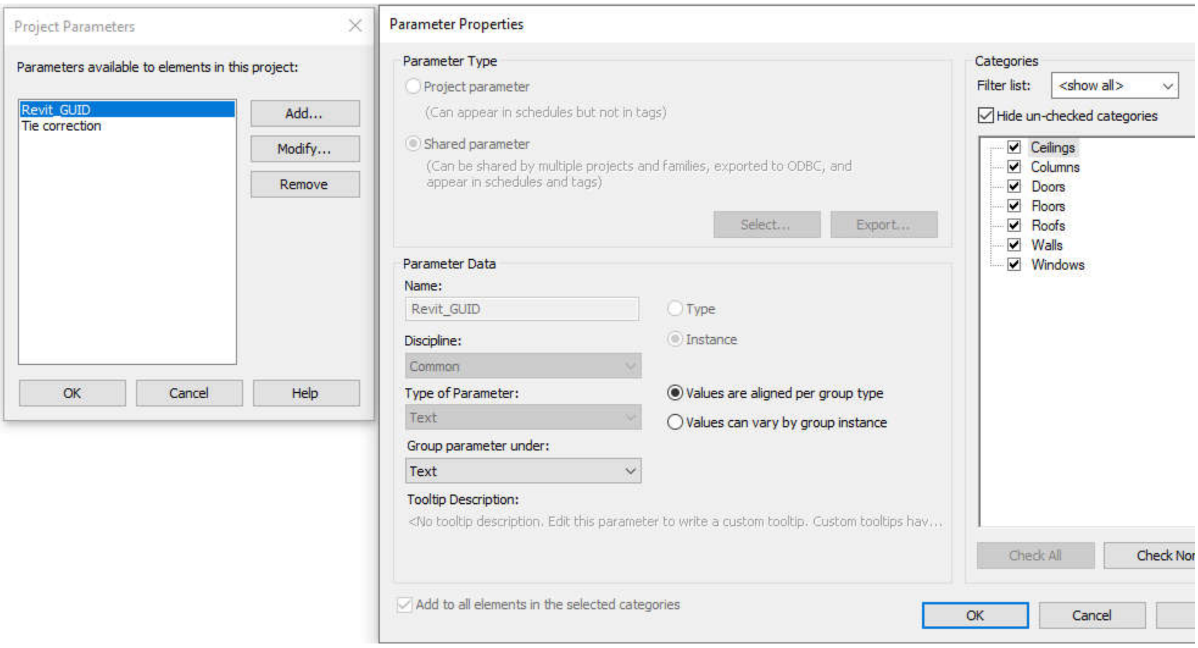


Figure 35: Creating project parameter

External walls have concrete with 2% reinforcement, with thermal conductivity λ=2,64 W/mK for internal leaf and λ=2,76 W/mK for external leaf. Insulation layer in sandwich elements is set for mineral wool for renovation above ground with λ=0,05 W/mK. Elements are modelled separate for each wall on each floor to enable different renovation changes for each of them. Elements are defined with eight ties per square meter. Since only external walls are of interest in residential buildings it is important to set the function – external for the appropriate elements.

Windows have set opening width, height and frame width, from which other dimensions can be calculated. Revit has one U-value for glass and frame combined, so in has to be calculated by hand according to tables in (Dansk Standard, 2011). The glass is set for three layers with 3 mm distance between, filled with air, giving U_g=2,7 W/m^{2}K and cased in an oak frame with U_f=2,4 W/m^{2}K. Doors have the same calculation formulas, except the U-value comes from the material of doors, which is set to wood panel with U=3,804 W/m^{2}K. Doors function also has to be set to external.

6.3 Data extraction from Revit model using Dynamo

The necessary data for energy calculations can be extracted from Revit model using Dynamo visual programming tool and exported to a database of choice. Dynamo script consists of connected nodes that represent functions with defined input and output. As the registration protocols are made in Excel, in this project the data is exported to a Excel spreadsheet, that can be linked to calculations.

For each element the code starts with selecting category and selecting all elements of the category (Figure 36).

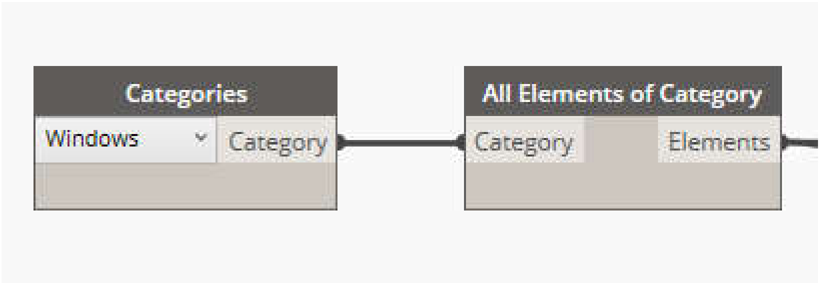


Figure 36: Selection of all elements of category

The full scripts for each element category can be found in appendix 10.3 Dynamo scripts.

6.3.1 Walls

Since only external walls are of interest, they are filtered by detecting the function recorded in element. In Figure 37 the input comes from all elements, the filter is made by accessing element type and function, defining the mask (filter) as function value of "Exterior" (the correct syntax with upper and lowercase letters is paramount), and applying this to all elements.

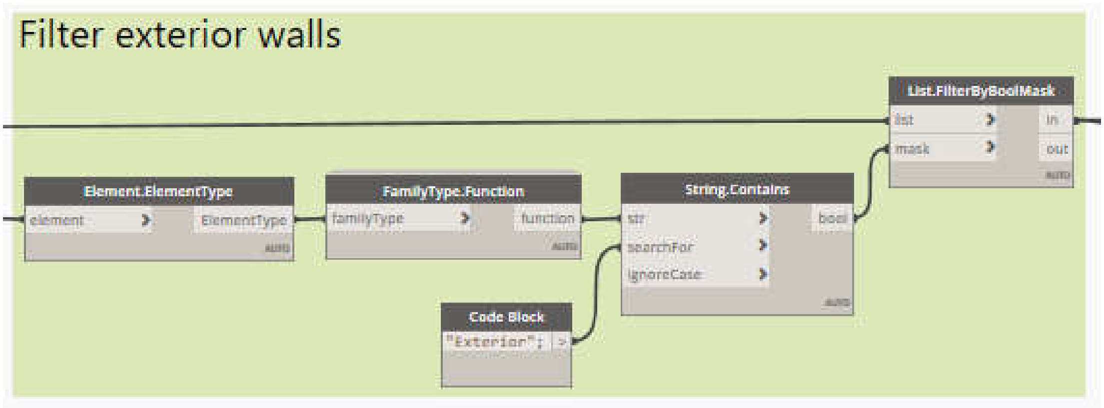


Figure 37: Filtering exterior walls

In Figure 38, the value of in-built Revit element ID is extracted and applied to the external walls in the custom parameter (as mentioned in 6.2Data in model) , so it can be inspected both in Revit schedules and extracted data.

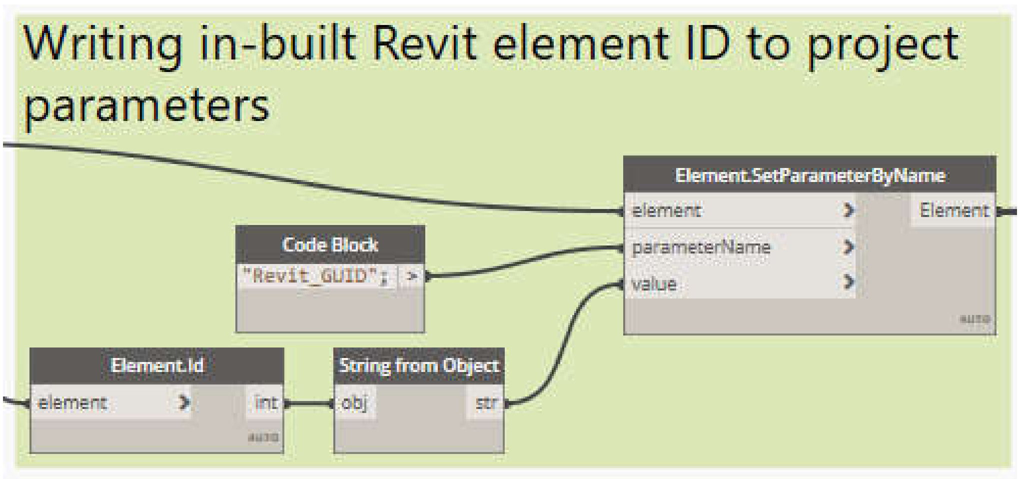


Figure 38: Writing element ID in parameter "Revit_GUID"

Now the manipulated elements are ready for parameter extraction for ID, Type, Area, U-value and Tie correction figure. It is done with the same nodes, just changing the name of the parameter. Revit automatically excludes the openings from the wall area, so this information is not required. However given U-value is based only on wall construction thus relating to uncorrected U' in (Dansk Standard, 2011).

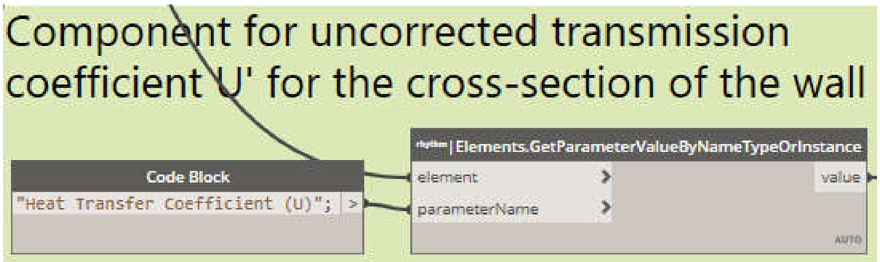


Figure 39: Parameter extraction

A list is created that contains all these properties, and the columns and rows are transposed to represent each element with all properties in one row Figure 40.

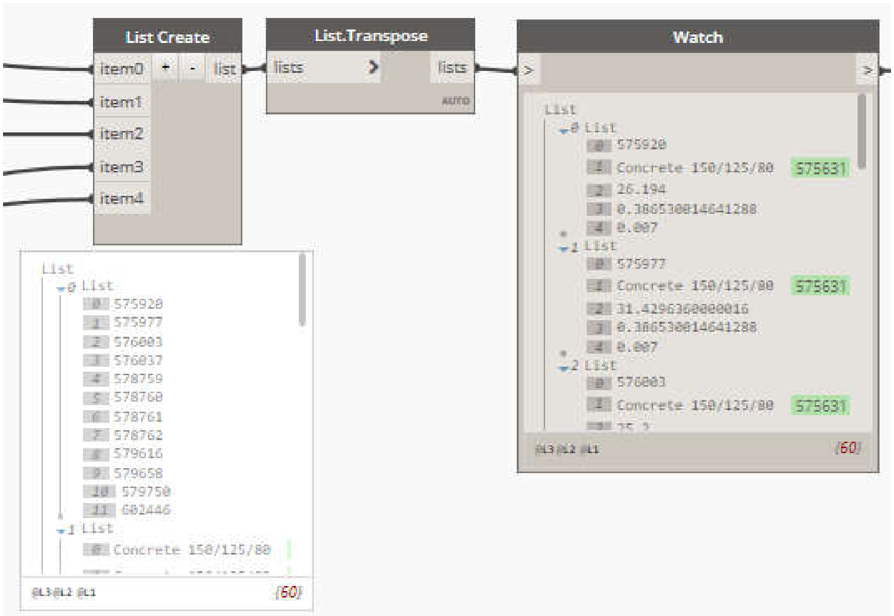
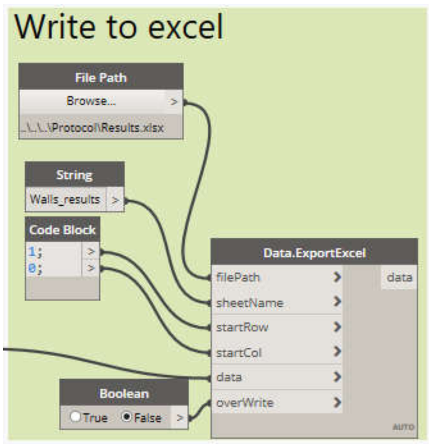


Figure 40: Creation of a list

In the end, the list is exported to Excel (Figure 41). Here the sheet and cell locations are defined, to systematize data.



ID	Type	Area	Uncorrected U'	Tie correction
575920	Concrete 150/125/80	26,194	0,386530015	0,007
575977	Concrete 150/125/80	31,42964	0,386530015	0,007
576003	Concrete 150/125/80	25,2	0,386530015	0,007
576037	Concrete 150/125/80	24,97277	0,386530015	0,007
578759	Concrete 150/125/80	26,194	0,386530015	0,007
578760	Concrete 150/125/80	31,42964	0,386530015	0,007
578761	Concrete 150/125/80	25,2	0,386530015	0,007
578762	Concrete 150/125/80	24,97277	0,386530015	0,007
579616	Basement wall 250/50	24,065	1,6	
579658	Basement wall 250/50	17,915	1,6	
579750	Basement wall 250/50	17,915	1,6	
602446	Basement wall 250/50	22,865	1,6	

Figure 41: List export to Excel

6.3.2 Openings (Windows and doors)

For windows the script follows the same steps as for walls, except there is no need for sorting by external elements. The parameters extracted from model are ID, Type, Rough Width and Height, Frame Width and Depth. Dimensions are linked to code block, that transforms the millimetres from the model to meters and calculates the Frame Area, Glass Width, Height and Area (Figure 42).

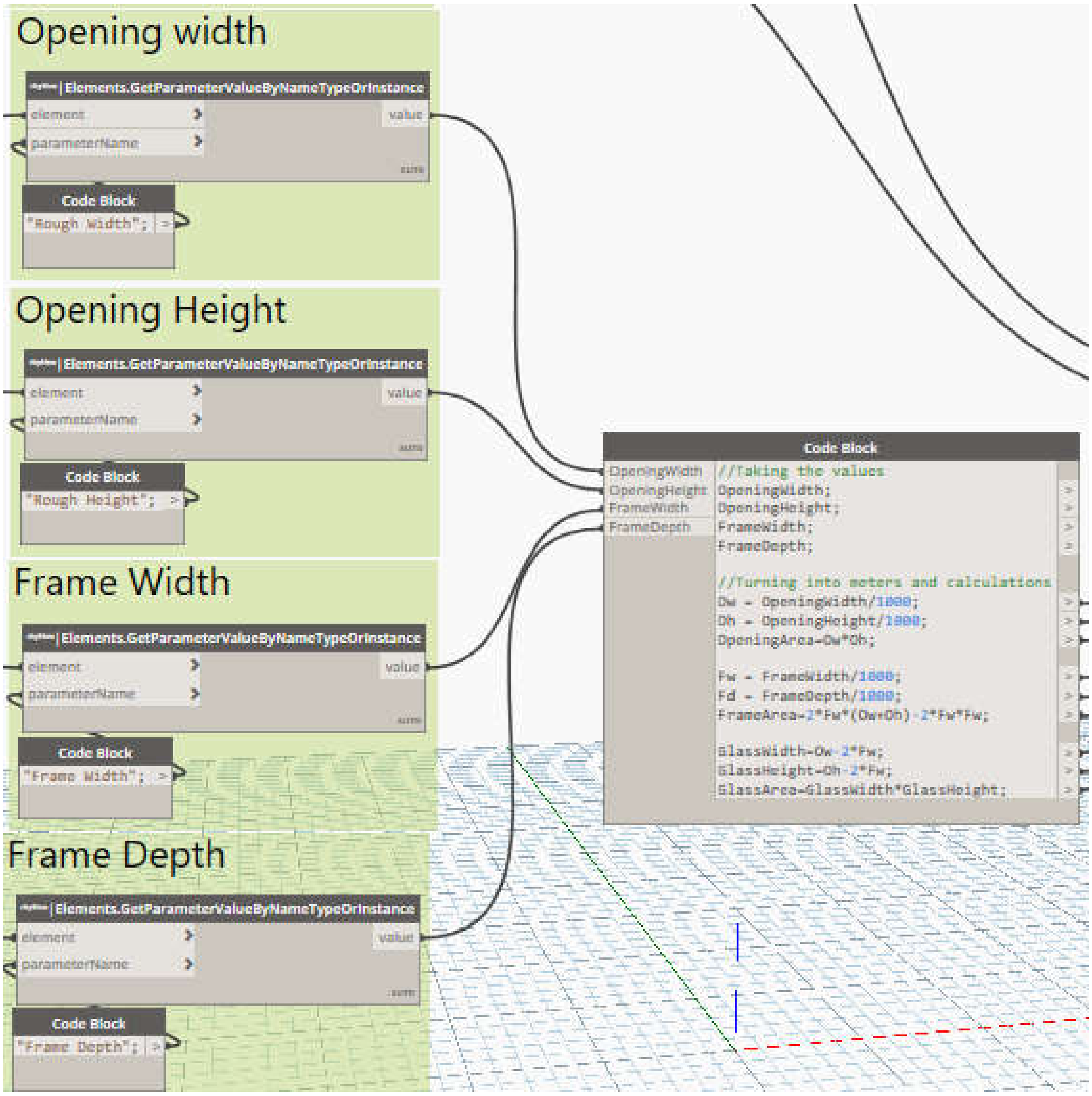


Figure 42: Window dimension calculation

ID	Type	Opening Width	Opening Height	Opening Area	Frame Width	Frame Depth	Frame Area	Glass Width	Glass Height	Glass Area
589390	Family Type: 1612x1212 mm concrete wall, Family: Fixed	1,612	1,212	1,953744	0,045	0,12	0,25011	1,522	1,122	1,7077
591240	Family Type: 1612x1212 mm concrete wall, Family: Fixed	1,612	1,212	1,953744	0,045	0,12	0,25011	1,522	1,122	1,7077
591748	Family Type: 2112x1212 mm concrete wall, Family: Fixed	2,112	1,212	2,559744	0,045	0,12	0,29511	2,022	1,122	2,2687
591807	Family Type: 2112x1212 mm concrete wall, Family: Fixed	2,112	1,212	2,559744	0,045	0,12	0,29511	2,022	1,122	2,2687
591831	Family Type: 2112x1212 mm concrete wall, Family: Fixed	2,112	1,212	2,559744	0,045	0,12	0,29511	2,022	1,122	2,2687
591877	Family Type: 2112x1212 mm concrete wall, Family: Fixed	2,112	1,212	2,559744	0,045	0,12	0,29511	2,022	1,122	2,2687

Figure 43: Windows results in Excel

Door elements need to be filtered for exterior elements and parameters change from of glass dimensions to door dimensions.

6.3.3 Other

Roof and external slab elements are extracted for ID, Type, Area and U-value properties. For foundations the ID, Type and Length of elements are extracted.

6.3.4 Protocol filling with results

In Figure 44 the results for the cavity wall containing windows on the ground floor are shown.

Element	Wall			Section/ Table/ Figure
Identification no	576037			
Colour codes	Measurement	Value	Units	
Revit input	Length	11,8	[m]	
Revit extract	Height	2,800	[m]	
Manual input	Area of openings	7,073232	[m^2]	
	Area of the whole wall	24,972768	[m^2]	
	Depth below terrain deck (influences the temperatures)		[m]	
* heating elements	Inner temperature θi	20	[°C]	F- 2.1
	Outer temperature θe	-12	[°C]	F- 2.1
* change for basement	Inner surface resistance	0,13	[m^{2}K/W]	T- 6.2.1
* change for basement	Outer surface resistance	0,04	[m^{2}K/W]	T- 6.2.1
T- 6.9.1				
Composition				
	No material - λ=1			
Inner leaf	Material	Concrete	N/A	
	Thickness d	0,15	[m]	
	Thermal conductivity λ	2,64	[W/mK]	Annex F
Insulation leaf	Material	Mineral woo	N/A	
	Thickness d	0,125	[m]	
	Thermal conductivity λ	0,05	[W/mK]	Annex G
Middle leaf	Material		N/A	
	Thickness d		[m]	
	Thermal conductivity λ	1	[W/mK]	Annex F
Outer leaf	Material	Concrete	N/A	
	Thickness d	0,08	[m]	
	Thermal conductivity λ	2,75	[W/mK]	Annex F
	Component for uncorrected transmission coefficient U'	0,387	[W/m^{2}K]	
Adjust for cavities	Combined U value for the wall	0,737	[W/m^{2}K]	
	Transmission loss ϕ_t for the whole wall	588,67364	[W]	

Figure 44: Results for the wall 576037

Although the wall itself has U-value of 0,387 W/m^{2}K, the contributions from column and foundation are is 0,185 W/m^{2}K and 0,179 W/m^{2}K respectivley. Foundations contribute with having no overlap in planes of insulation. Column has a large transmission coefficient U_i because the insulation thermal conductivity value is taken for renovation and according to standard, the cold bridge interruption is ignored:

"The transmission coefficient Ui for the sub areas is to be calculated, as if only one dimensional heat flow occur. For continuing storey partitions, beams and columns for instance of concrete or steel, the transmission Ui for the sub area is to be estimated as if the storey partition, the beam or the column are in the same level as the actual construction surface, for instance the surface of the walls." (Dansk Standard, 2011)

In Figure 45, the results for the smaller window are shown. The main contribution to overall U-value comes from the construction of the window – three layers seperated by three milimeters and filled with air.

				Section/ Table/ Figure
Element	Opening for doors and windows			
Identification no	589390			

Transmission loss

Colour codes
Revit input
Revit extract
Manual input

Measurement	Value	Units	
Inner temperature θ_i	20	[°C]	F- 2.1
Outer temperature θ_e	-12	[°C]	F- 2.1
Opening height	1,212	[m]	
Opening width	1,612	[m]	
Opening area	1,954	[m^2]	
Frame thickness	0,045	[m]	
Frame depth	0,12	[m]	
Glass/panel height	1,122	[m]	
Glass/panel width	1,522	[m]	
Glass/panel area	1,708	[m^2]	
Distance between glass panels	3	[mm]	
Layers of glass	3		
Filling between glass panels	Air		
Transmission coefficient for glass/panel - U_g/U_p	2,7	[W/m^2K]	

Double, triple glazed panes - Figure N.1-N.4
Single certical glass layer 5,9
Other glass - Annex I

Frame area	0,250	[m^2]	
Frame thickness	0,045	[m]	
Softwood/hardwood	hardwood		
Frame transmission coefficient U_f	2,4	[W/m^2K]	T- 6.8.1

Opening transmission coefficient for Revit	2,667	[W/m^2K]

Linear loss

Linear loss length glass-frame l_g	5,288	[m]
Case number from below the table	2	0,06
Linear loss glass-frame ψ_g	0,06	[W/mK]

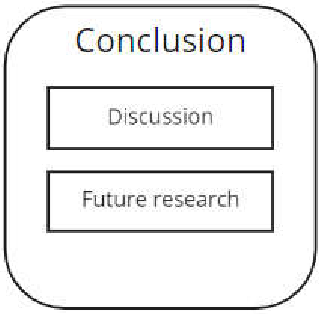
1 Metal profile frames with broken thermal bridges and with distance profiles in different materials in dependence on the pane's U- value — T- 6.8.2
2 Wood or plastic profile frames and with distance profiles in different materials in dependence on the pane's U- value — T- 6.8.3
3 Windows with single glass layer 0 [W/mK]

Linear loss length frame-wall l_k	5,648	[m]
Linear loss frame-wall ψ_k	0,13	[W/mK]

Total transmission coefficient U	3,199	[W/m^2K]
Total transmission loss ϕt	199,986	[W]

Figure 45: Results for the window 589390

7 Conclusion



The requirements for energy efficient renovation of buildings are set in (Ministry of Transport Building and Housing, 2018) and the description of energy-frame calculations and necessary measurements of the existing building are found in (Dansk Standard, 2011). The measurements make up the exchange requirements for the building envelope registration and are arranged into separate protocols for each building element. To enable data connectivity between different phases of a project and collaboration between separate specialities involved, a BIM model should be used for geometric and semantic information storage. The element external geometrical data is accessible with various registration methods, like photogrammetry and LIDAR, that enable fast recreation of this data in a model. The registration of element cross-secion geometry requires either uncovering of the element, that can damage the element, or use of methods like ultrasound. The semantic information consists of material properties that can be investigated either by testing samplesor using values stated in (Dansk Standard, 2011),since the former can damage the element, the latter is preffered. Thermographical imaging method can be used to acquire the actual value of heat transmission of elements, however this limits the options for renovation design, since the heat loss is not tied to cross-sectional geometry.

The captured geometrical data is recreated in model, while semantic data can require creation of placeholders for parameters not supported by the software (in this project Autodesk Revit was used). The values for energy-frame can be retrieved from model using developed Dynamo scripts and placed in calculation spreadsheets. With all elements combined, the existing energy frame and the requirements can be compared and the renovation design started. The seperation of individual elements increse the flexibility of design, but require more accurate data management.

7.1 Discussion

The assessment of current heat loss can be made in the registration protocols without use of Revit model. The data from the model can bet linked to calculations for evaluation of proposed renovation designs. To eliminate the mixture of values registered from the existing building and and those extracted from model, that can have changes applied to, the protocols need to be separated.

As seen in the chapter 6.3.4, the influence of elements with cold bridges can double the heat loss. For this reason the inspection of cold bridges and their insulation has to be paramount. That also means that fixing the connection to a conteporary design large energy gains can be acquired. In addition, the radiator placing can exacerbate any losses, because, for a wall, it changes the second part of formula in Figure 20 from multiplyer of 32 to 52, almost doubling the heat loss.

The data exported from Revit model has high influence on heat loss and can be placed in data visualization tool as Power BI, where the relations between values can be defined and differences between the existing and proposed energy conservation solutions can be showcased.

7.2 Further research

To enable the heat loss calculations based only on the data recorded in Revit model, all values in protocols must be recorded and extracted. This requires creation of additional project properties for the manual input values, like inside and outside temperature, that can be attached to elements. As for extraction of already existing information, like wall element thicknesses, thermal conductivities, window placement, and elements they are embedded in, it requires development of Dynamo script.

In addition to thermal losses through building envelope, further studies should include analysis of additional factors that has an impact to energy framework. In a basic form, these factors can be summarized as machinery or equipment and occupational habits of the building users and external energy gain, which can give a significant influence overall calculations of building's energy framework.

Such common equipment as lights, building service equipment or even computers and domestic appliances not only have a direct impact to power consumption, but are an indirect source of heat, that can result in higher building cooling demands and effect the performance of the building itself.

With the growth of well insulated buildings, a mayor concern is given to external heat sources and significant rise of cooling demands. Such aspects as shading due to geographical positioning of the building, preinstalled shading and type of window elements can significantly influence energy framework. Further studies should investigate methods of incorporating energy gain sources into calculation methodology to improve the quality of assumptions.

As for future prospects on improvement of the workflow, with advances in hardware and software photogrammetry is evolving into videogrammetry, meaning a survey could be done wihtout setting up the perspective centres. With advancement of devices supporting augmented reality and fast connection to a computing platform through 5G networks it seems plausible that registration of buildings and modelling separate elements in a 3D space could be done on-site. If technologies like RFID tagging, that carry the element information, are wideley implemented, the loss of model information could be recreated quickly.

There are insulation materials with excelent thermal and applicability qualities in development and production, that could facilitate easyer energy renovation. However the conservative nature of building industry means that focus needs to be on current and proven solutions.

8 Bibliography

© Autodesk Inc. (2019). *What is BIM?* https://www.autodesk.com/solutions/bim

3XN/GXN. (2012). *Sustainable Building Certifications*. 156. https://gxn.3xn.com/wp-content/uploads/sites/4/2018/08/Guide-to-Green-Building-Certifications-August-2018-weblow-res.pdf

Balaras, C. A., & Argiriou, A. A. (2002). Infrared thermography for building diagnostics. *Energy and Buildings*, *34*(2), 171–183. https://doi.org/10.1016/S0378-7788(01)00105-0

Choi, J., Shin, J., Kim, M., & Kim, I. (2016). Development of openBIM-based energy analysis software to improve the interoperability of energy performance assessment. *Automation in Construction*, *72*(July), 52–64. https://doi.org/10.1016/j.autcon.2016.07.004

Climate change impact on buildings and constructions. (2019). https://en.klimatilpasning.dk/sectors/buildings/climate-change-impact-on-buildings/

CyArk. (2020). *CyArk and RealityCapture*. https://www.capturingreality.com/Article-CyArk-and-RealityCapture

Danish Building Research Institute. (2002). *BSim The complete program package for building energy design*. http://sbi.dk/download/bsim/bsimbrochure.pdf

Danish Energy Agency. (2013). *Energy Efficiency in New Buildings - Experiences from Denmark*. 36. http://www.ens.dk/sites/ens.dk/files/climate-co2/low-carbon-transition-unit/danish-energy-policy-toolkits/energy_efficiency_in_new_buildings.pdf

Danish Energy Agency. (2018). *Denmark's Energy and Climate Outlook 2018: Baseline Scenario Projection Towards 2030 With Existing Measures (Frozen Policy)*. www.ens.dk

Danish Knowledge Center for Energy Savings in Buildings. (2018). *Energy requirements of BR18*. *April*, 95–98.

Dansk Standard. (2011). Beregning af bygningers varmetab Calculation of heat loss from buildings. *Ds 418*, 2011. https://doi.org/10.1210/jc.2007-1543

Drone photogrammetry vs. LIDAR: what sensor to choose for a given application | Wingtra. (2019). https://wingtra.com/drone-photogrammetry-vs-lidar/

Eastman, C., Sacks, R., Lee, G., & Teicholz, P. (2016). *BIM Handbook*.

Energy needs of buildings. (2018). https://sbi.dk/anvisninger/Pages/213-Bygningers-energibehov-6.aspx

Ergn, B. (2011). Terrestrial Laser Scanning Data Integration in Surveying Engineering. *Laser Scanning, Theory and Applications*. https://doi.org/10.5772/14728

European Commission. (2019a). *Construction and demolition waste - Environment*. https://ec.europa.eu/environment/waste/construction_demolition.htm

European Commission. (2019b). *European Construction Sector Observatory Building Information Modelling in the EU construction sector*. *March*, 22.

European Commission. (2019c). Regulation (EU) 2017/1369 of the European Parliament and of the Council of 4 July 2017 setting a framework for energy labelling and repealing Directive 2010/30/EU (OJ L 198. *Official Journal of the European Union*, *6*(2015), 75. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019H0786&rid=5

Fonden Dansk Standard. (2007). *Dansk standard Eurocode 1 : Last på bærende konstruktioner – Del 1-4 : Generelle laster – Vindlast Eurocode 1 : Actions on structures –*. 295. http://sd.ds.dk.zorac.aub.aau.dk/Viewer?ProjectNr=M222442&Status=60.61&Page=0

Gerrish, T., Ruikar, K., Cook, M., Johnson, M., & Phillip, M. (2017). Using BIM capabilities to improve existing building energy modelling practices. *Engineering, Construction and Architectural Management*, *24*(2), 190–208. https://doi.org/10.1108/ECAM-11-2015-0181

Hasenstab, A., Osterloh, K., & Krause, M. (2006). Testing of wooden construction elements with ultrasonic echo technique and X-ray. *Proceedings of the 9th European Conference on Non-Destructive Testing, Berlin, Germany*, 25–29.

How Hollis captures, processes, manages and delivers reality capture data | Leica Geosystems. (2019). https://leica-geosystems.com/case-studies/reality-capture/how-hollis-captures-processes-manages-and-delivers-reality-capture-data

International Energy Agency. (2013). Transition to sustainable buildings: Strategies and opportunities to 2050. In *Oecd* (Vol. 9789264202). https://doi.org/10.1787/9789264202955-en

Klepeis, N. E., Nelson, W. C., Ott, W. R., Robinson, J. P., Tsang, A. M., Switzer, P., Behar, J. V., Hern, S. C., & Engelmann, W. H. (2001). The National Human Activity Pattern Survey (NHAPS): A resource for assessing exposure to environmental pollutants. *Journal of Exposure Analysis and Environmental Epidemiology*, *11*(3), 231–252. https://doi.org/10.1038/sj.jea.7500165

Kraus, K., Harley, I., & Kyle, S. (2007). *Photogrammetry - Geometry from Images and Laser Scans*.

Leica Geosystems AG. (2010). Leica DISTO. *None*, *1*, 1.

Leica Geosystems AG. (2017). *Leica blk360 imaging scanner*. *54*(Iec 60529), 60529.

Leica Geosystems AG. (2019). *Scan 'till you drop*. https://leica-geosystems.com/case-studies/building/scan-till-you-drop

Ludacer, R. (2018). *Why the world is running out of sand - Business Insider*. https://www.businessinsider.com/world-running-out-sand-resources-concrete-2018-6?r=US&IR=T

Luhman, T., Robson, S., Kyle, S., & Harley, I. (2006). Close Range Photogrammetry: Principles, Techniques And Applications. In *The Photogrammetric Record*. https://doi.org/10.1111/j.1477-9730.2010.00574_1.x

Luis, J., Navarro, S., Cabrelles, M., Elena, A., Haddad, N., & Akasheh, T. (2011). Integration of Laser Scanning and Imagery for Photorealistic 3D Architectural Documentation. *Laser Scanning, Theory and Applications*. https://doi.org/10.5772/14534

Ministry of Transport Building and Housing. (2018). *Executive order on building regulations 2018 (BR18)*. *2017*(1615), 1–137.

Nde-ed.org. (2019a). *Basic Principles of Practical Ultrasonic Testing*. https://doi.org/10.1520/stp46808s

Nde-ed.org. (2019b). *Present State of Ultrasonics basic study*. https://www.nde-ed.org/EducationResources/CommunityCollege/Ultrasonics/Introduction/presentstate.htm

Odgaard, T., Bjarløv, S. P., Rode, C., & Vesterløkke, M. (2015). Building renovation with interior insulation on solid masonry walls in Denmark - A study of the building segment and possible solutions. *Energy Procedia*, *78*, 830–835. https://doi.org/10.1016/j.egypro.2015.11.003

Philipp Gerbert, S. C. C. R. and A. R. (2016). Shaping the Future of Construction A Breakthrough in Mindset and Technology. *World Economic Forum (WEF)*, *May*, 1–64. https://www.bcgperspectives.com/Images/Shaping_the_Future_of_Construction_may_2016.pdf

Photogrammetry | 3D Measurements from Photos | PhotoModeler. (2019). https://www.photomodeler.com/

PhotoModeler Technologies. (2018a). *Low-Cost Cameras for Photogrammetry and Measurement*.

https://www.photomodeler.com/low-cost-cameras-for-photogrammetry/

PhotoModeler Technologies. (2018b). *Low-Cost Cameras for Photogrammetry and Measurement*.

PhotoModeler Technologies. (2018c). *Which Camera to Use with Photogrammetry and PhotoModeler*. https://www.photomodeler.com/products/about_cameras/

PhotoModeler Technologies. (2018d). *Which Camera to Use with Photogrammetry and PhotoModeler*.

Pinheiro, S., Wimmer, R., O'Donnell, J., Muhic, S., Bazjanac, V., Maile, T., Frisch, J., & van Treeck, C. (2018). MVD based information exchange between BIM and building energy performance simulation. *Automation in Construction*, *90*(February), 91–103. https://doi.org/10.1016/j.autcon.2018.02.009

Rasmussen, B., & Petersen, C. M. (2014). *"Lydisolering mellem boligereksisterende byggeri" (Sound insulation between dwellings-existing housing). SBi guideline 243.*

ROSS, M. (2010). *Listed Buildings*. Planning and the Heritage. https://doi.org/10.4324/9780203362358_chapter_5

S., P., & Pande, H. (2011). LIDAR Remote Sensing Applications in Automated Urban Feature Extraction. *Laser Scanning, Theory and Applications*. https://doi.org/10.5772/14983

Solibri, I. (2018). *Getting Started with Solibri Model Checker™*. https://doi.org/10.1007/978-3-540-44397-1_3

Sužiedelyte-Visockiene, J., & Bručas, D. (2009). Digital photogrammetry for building measurements and reverse-engineering. *Geodesy and Cartography*, *35*(2), 61–65. https://doi.org/10.3846/1392-1541.2009.35.61-65

Taylor, T., Counsell, J., & Gill, S. (2014). Combining thermography and computer simulation to identify and assess insulation defects in the construction of building façades. *Energy and Buildings*, *76*, 130–142. https://doi.org/10.1016/j.enbuild.2014.02.080

The Ministry of Climate, E. and B. (2014). *Strategy for energy renovation of buildings. The route to energy-efficient buildings in tomorrow's Denmark. May*, 54. https://ec.europa.eu/energy/sites/ener/files/documents/2014_article4_en_denmark.pdf

Tomovich, S., Peng, Z., Yuan, C., & Y, X. (2011). Quantitative Surface Characterisation Using Laser Scanning Confocal Microscopy. *Laser Scanning, Theory and Applications*. https://doi.org/10.5772/15403

Volk, R., Stengel, J., & Schultmann, F. (2014). Building Information Modeling (BIM) for existing buildings - Literature review and future needs. *Automation in Construction*, *38*(March), 109–127. https://doi.org/10.1016/j.autcon.2013.10.023

Wetter, M., Bonvini, M., & Nouidui, T. S. (2016). Equation-based languages - A new paradigm for building energy modeling, simulation and optimization. *Energy and Buildings*, *117*, 290–300. https://doi.org/10.1016/j.enbuild.2015.10.017

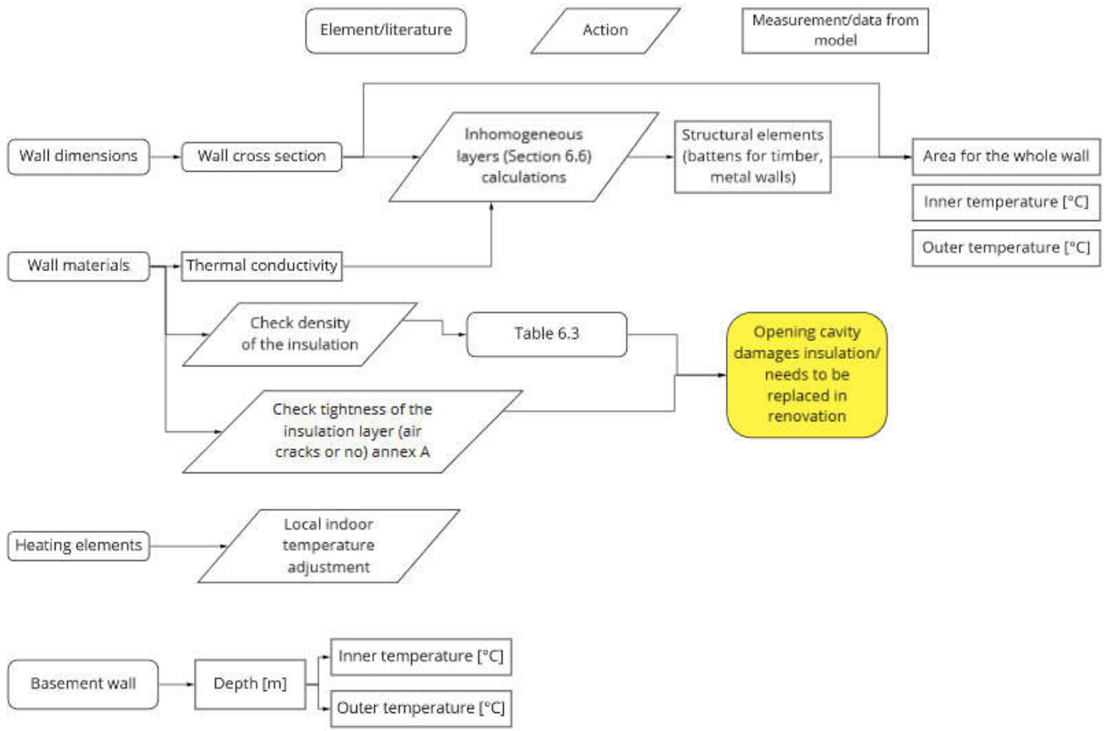
Zielińska, M., & Rucka, M. (2018). Non-destructive assessment of masonry pillars using ultrasonic tomography. *Materials*, *11*(12), 1–17. https://doi.org/10.3390/ma11122543

9 Table of Figures

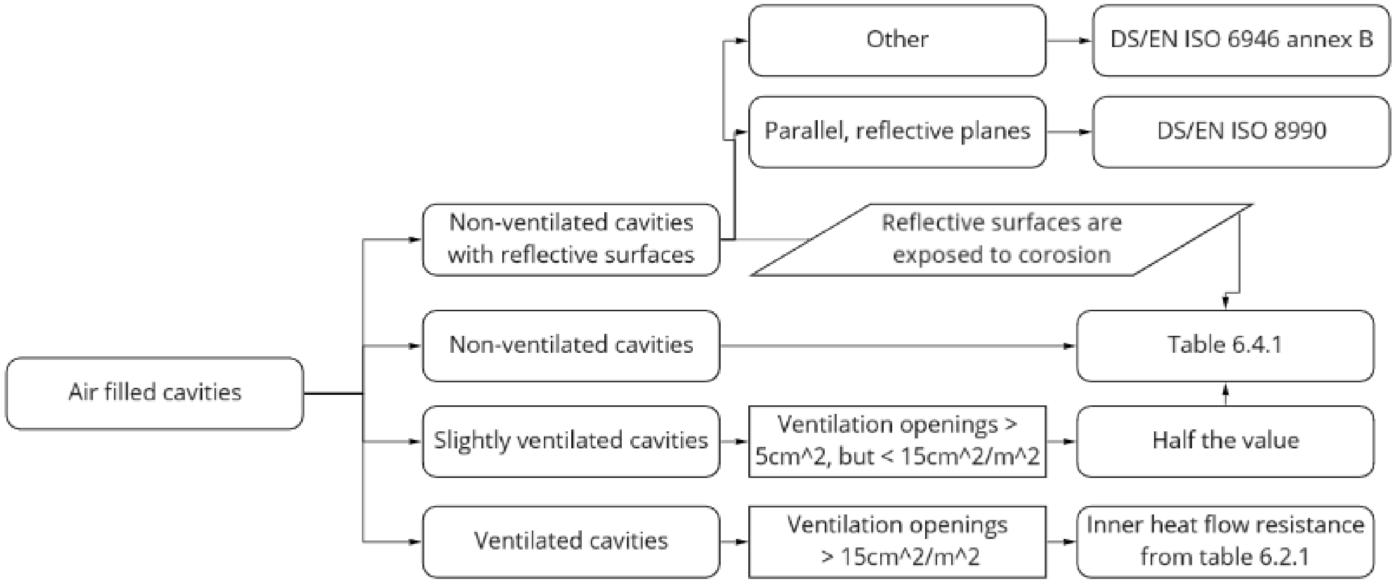
10 Appendices

10.1 Heat loss calculation relations to measurements based on DS418

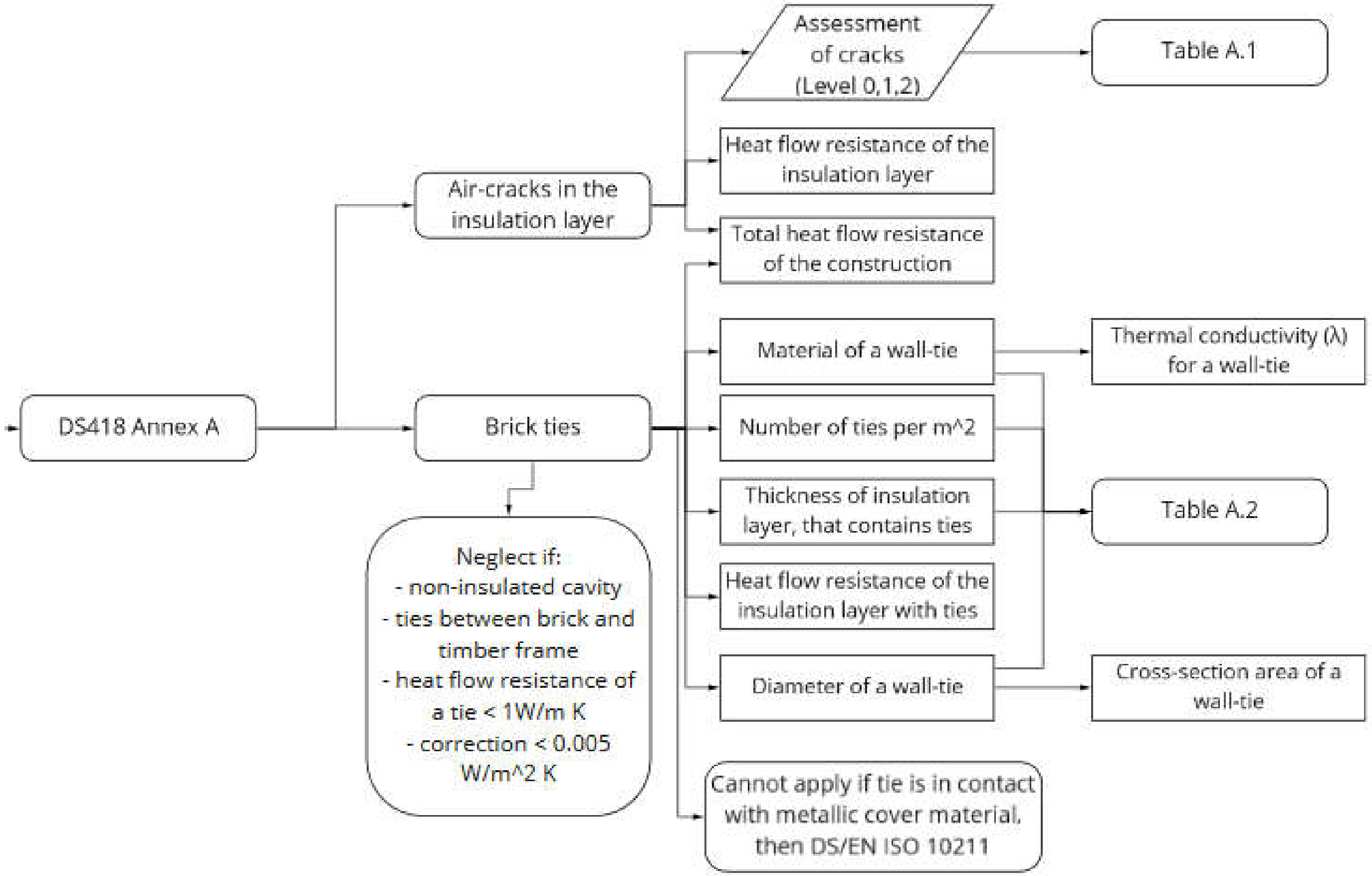
10.1.1 Walls



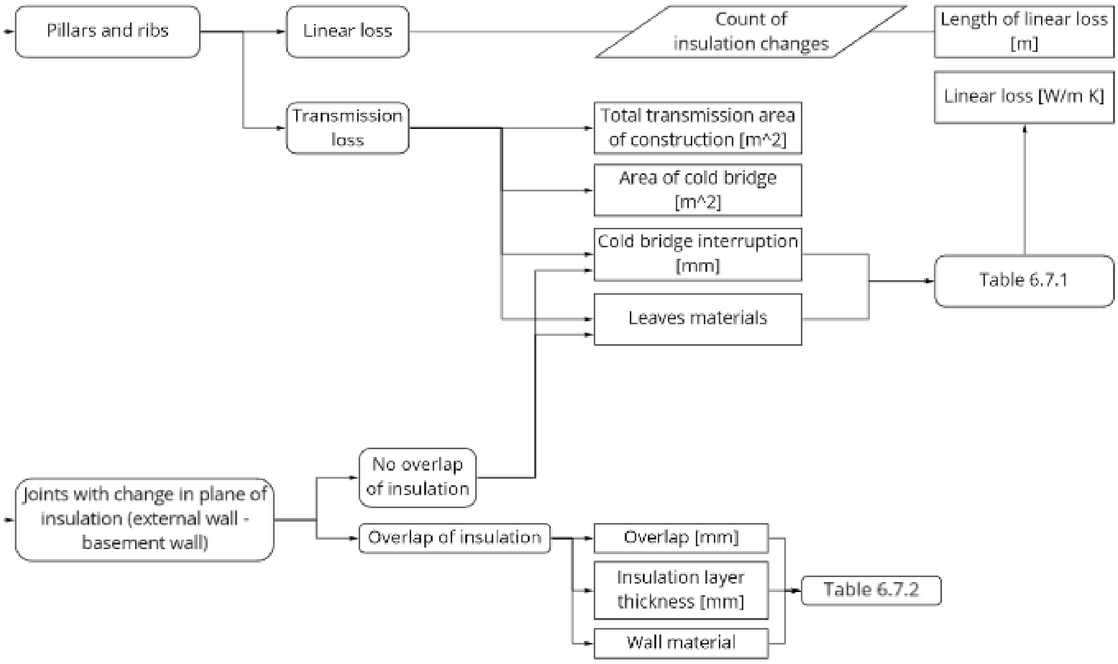
General data - walls



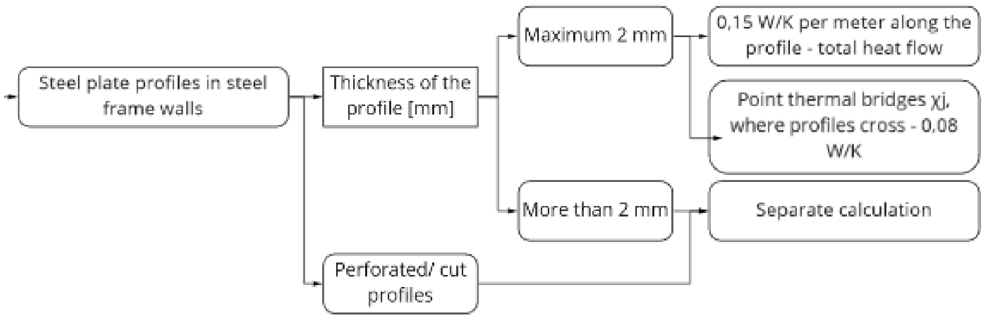
Air filled cavities



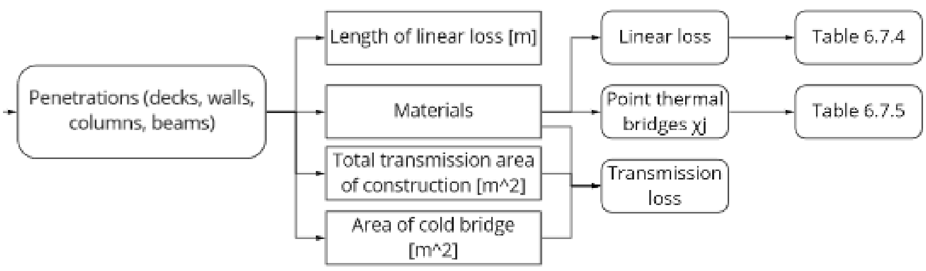
Insulation cracks and wall ties



Pillars, ribs and change in insulation plane

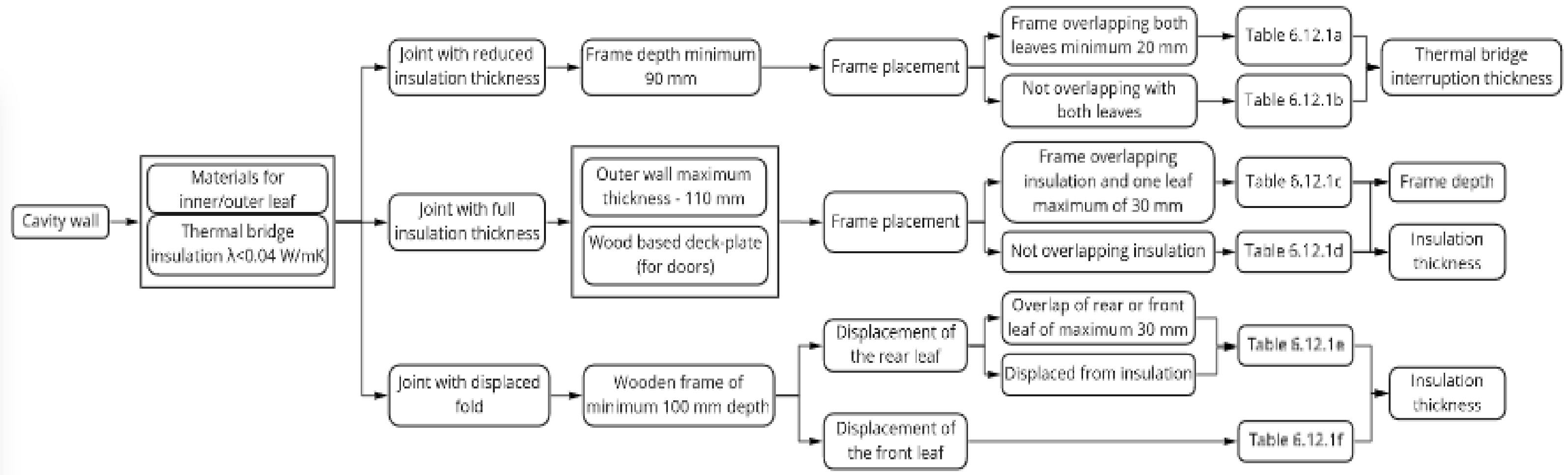


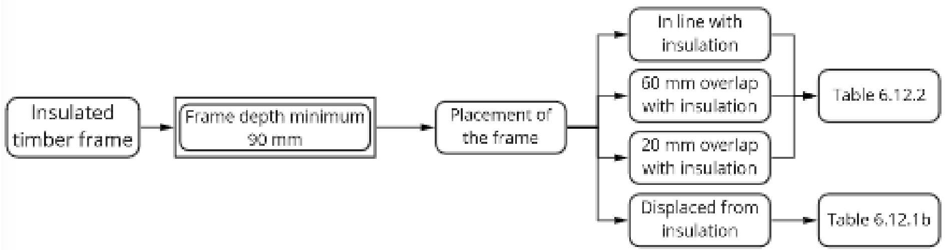
Steel plate walls

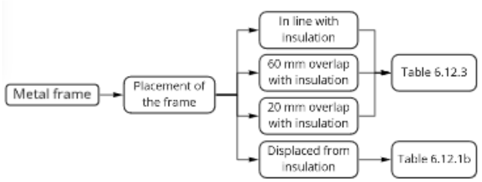


Penetrations of walls

10.1.2 Openings (doors and windows)

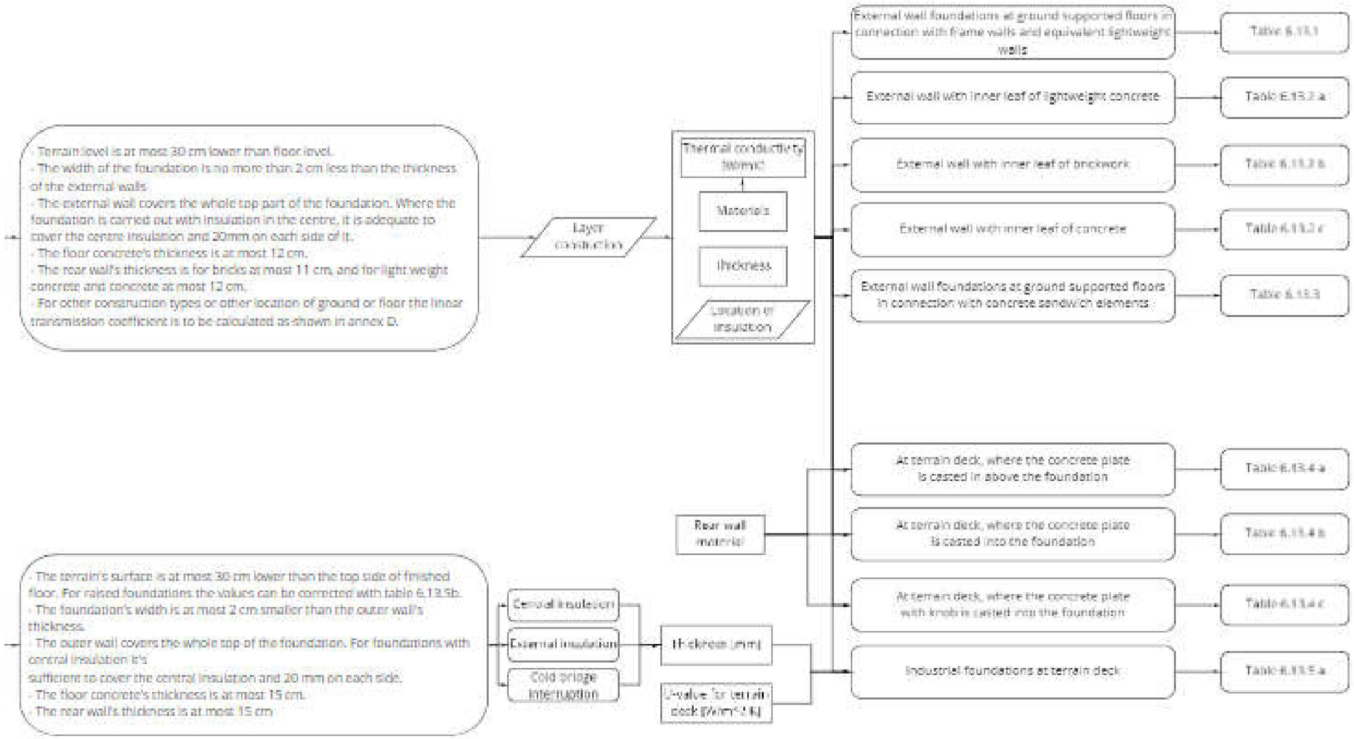




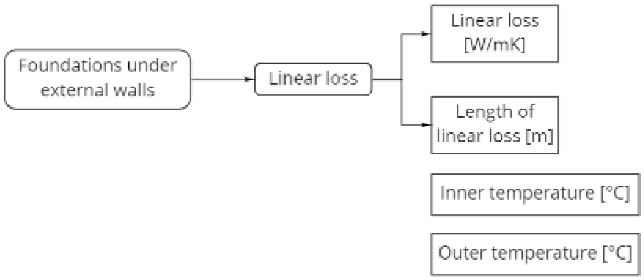


Linear loss around openings in walls Source: (Dansk Standard, 2011)

10.1.3 Foundation

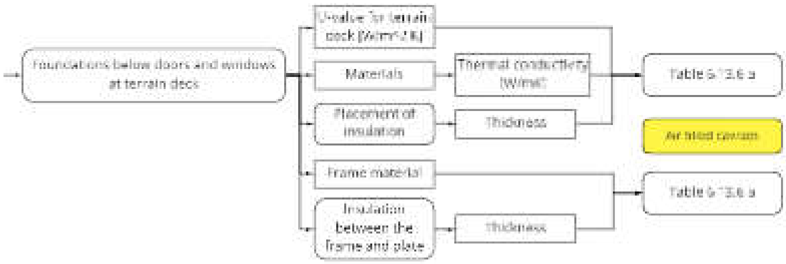


Foundations by placement

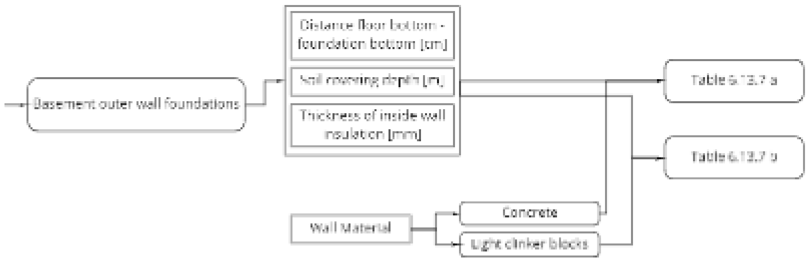


Foundation general calculation

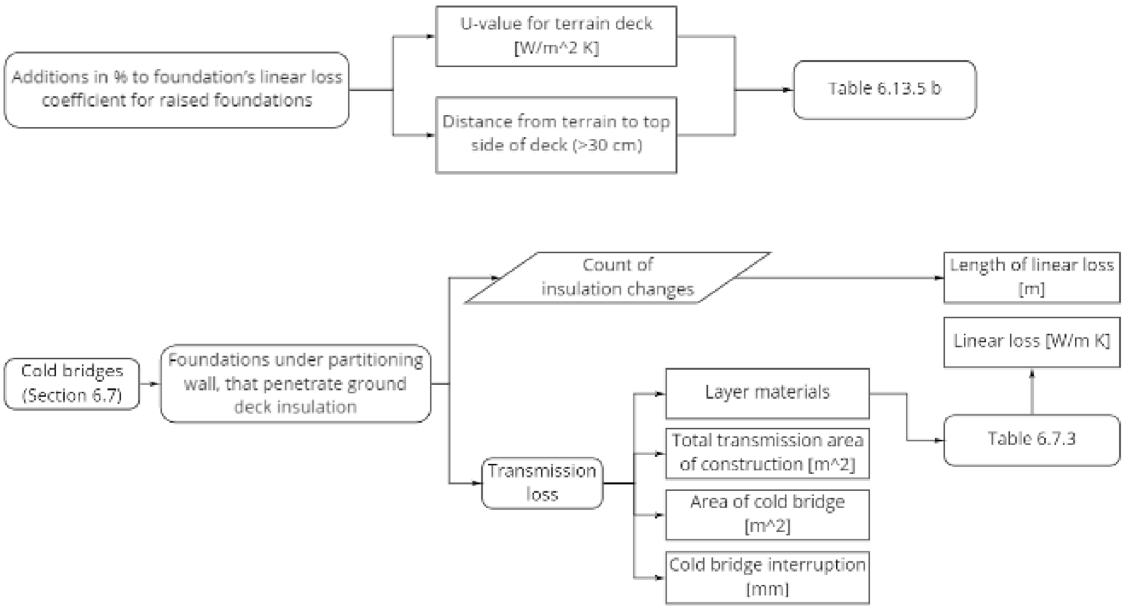
Source : *(Dansk Standard, 2011)*



Foundations by placement

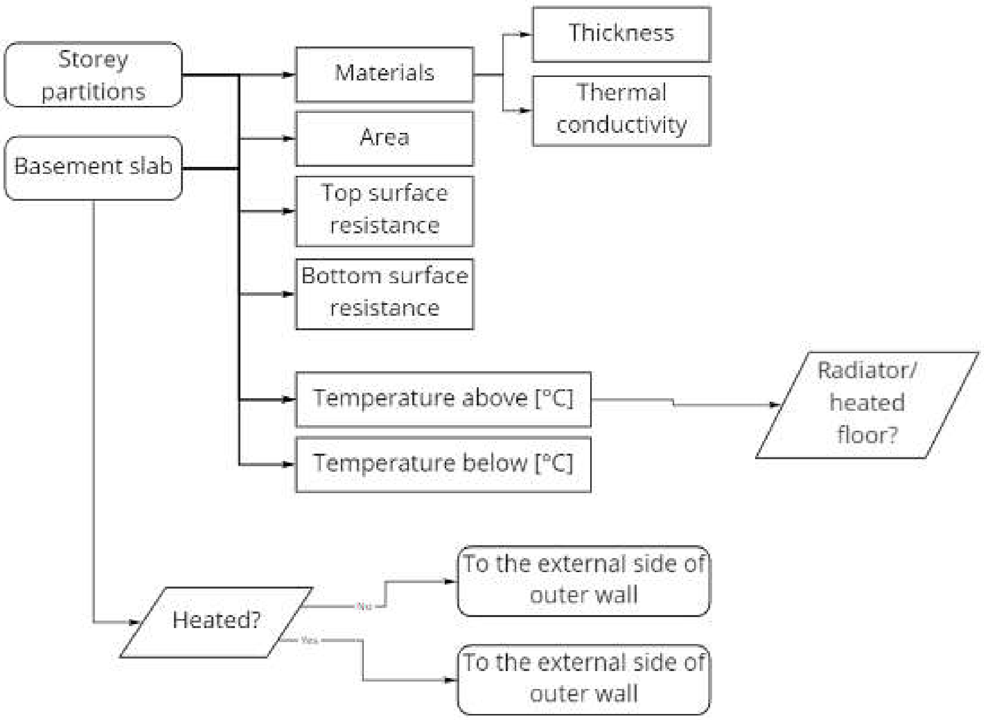


Foundations by placement

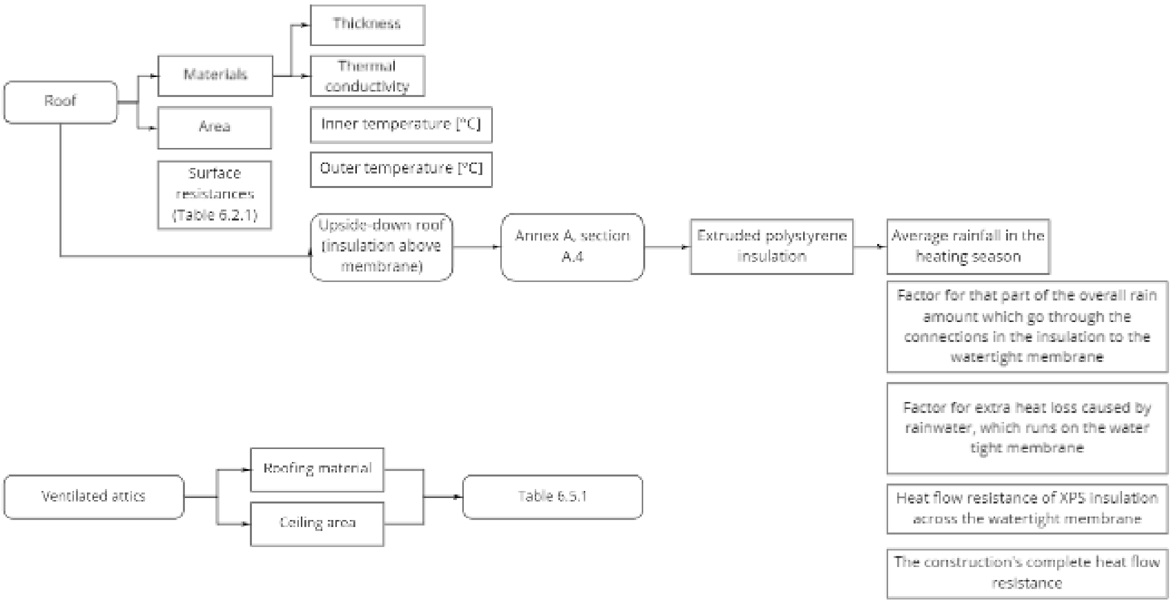


Foundations linear loss

10.1.4 Slabs



10.1.5Ceiling/Roof



10.2 Survey/calculation protocols

10.2.1 Walls

				Section/ Table/ Figure
Element	Wall			
Identification no				
Colour codes	Measurement	Value	Units	
Revit input	Length		[m]	
Revit extract	Height		[m]	
Manual input	Area of openings		[m^2]	
	Area of the whole wall	0	[m^2]	
	Depth below terrain deck (influences the temperatures)		[m]	
* heating elements	Inner temperature θi	20	[°C]	F- 2.1
	Outer temperature θe	-12	[°C]	F- 2.1
* change for basement	Inner surface resistance	0,13	[m^2K/W]	T- 6.2.1
* change for basement	Outer surface resistance	0,04	[m^2K/W]	T- 6.2.1
T- 6.9.1				
Inhomogeneous layer				
	Material 1	Concrete	N/A	
	Thermal conductivity λ		[W/mK]	Annex F/G
	Area		[m^2]	
	Material 2	Concrete	N/A	
	Thermal conductivity λ		[W/mK]	Annex F/G
	Area		[m^2]	
	Material 3	Concrete	N/A	
	Thermal conductivity λ		[W/mK]	Annex F/G
	Area		[m^2]	
	Layer thermal conductivity λ'	#DIV/0!	[W/mK]	
Composition				
	No material - λ=1			
Inner leaf	Material	Concrete	N/A	
	Thickness d		[m]	
	Thermal conductivity λ		[W/mK]	Annex F/G
Insulation leaf	Material	Rockwool	N/A	
	Thickness d		[m]	
	Thermal conductivity λ		[W/mK]	Annex F/G
Middle leaf	Material		N/A	
	Thickness d		[m]	
	Thermal conductivity λ		[W/mK]	Annex F/G
Outer leaf	Material	Concrete	N/A	
	Thickness d		[m]	
	Thermal conductivity λ		[W/mK]	Annex F/G
	Component for uncorrected transmission coefficient U'	#DIV/0!	[W/m^2K]	
Adjust for cavities	Combined U value for the wall	#DIV/0!	[W/m^2K]	
	Transmission loss ϕ_t for the whole wall	#DIV/0!	[W]	

Cold bridges	Annex A			
Insulation				

Level of air cracks in insulation layer	1		S- A.2.3
Correction for air-cracks in the insulation ΔU''		[W/m^{2}K]	T- A.1
Heat flow resistance of the insulation layer R_i	#DIV/0!	N/A	
Heat flow resistance of the construction R_T	#DIV/0!	N/A	
Correction for air-cracks in the insulation $ΔU_g$	#DIV/0!	[W/m^{2}K]	

Bric ties/ concrete anchors

Neglect if:

1. Non-insulated cavity
2. Ties between brick and timber frame
3. Heat flow resistance of a tie < 1W/m K
4. Correction < 0.005 W/m^2 K

Cannot apply if: 1 Both ends of the tie is in contact with metallic cover material, then use DS/EN ISO 10211

Common ties

Material of fixing			
Number of ties per m^2 n_f		[No/m^2]	
Diameter of ties		[mm]	
Thickness of insulation layer, that contains ties d_1		[m]	
Tie correction $ΔU_f$ for common ties		[W/m^{2}K]	T- A.2

Uncommon ties

	Coefficient α	0,8		S- A.3
	Thermal conductivity for the wall-tie λ		[W/mK]	
	Cross sectional area of the tie A_f	0	[m^2]	
Set to insulation leaf	Heat flow resistance of the insulation layer with ties R_1	#DIV/0!	[m^{2}K/W]	
	Construction's total heat flow resistance R_T	#DIV/0!	[m^{2}K/W]	
	Tie correction $ΔU_f$	#DIV/0!	[W/m^{2}K]	

Total wall correction ΔU	#DIV/0!	[W/m^{2}K]

Pillars and ribs
Linear loss

For buildings with change in pillar/rib thickness - average thickness

Requirements:

1. Cold bridge insulation thermal conductivity λ < 0,04 W/m K
2. Pillars and ribs made of the same material as the connected wall
3. Materials according to tablle 6.7.1 requirements

Count of insulation changes			
Cold bridge insulation thermal conductivity λ		[W/m K]	
If λ>0,04, assume cold bridge interruption thickness = 0			
Cold bridge interruption thickness		[m]	
Inner leaf material			
Outer leaf material			
Linnear loss $Ψ_k$		[W/m K]	T- 6.7.1

Transmission loss	Cold bridge interruption width		[m]
	Cold bridge length (heigth of pillar/rib) l_k		[m]
	Cold bridge sub area A_i	0	[m^2]
	Transmission coefficient of the sub area U_i	#DIV/0!	[W/m^{2}K]
	Area of the whole wall	0	[m^2]
	Component for uncorrected transmission coefficient U'	#DIV/0!	[W/m^{2}K]

Change in plane of insulation

Overlap between two planes of insulation (e.g. joints between external wall and basement wall)

Requirements:
1 Sidepiece between layers of insulation up to 0,12m
2 Materials according to table 6.7.2 requirements

Material between the planes of insulation	Concrete		
Overlap length (rounded to lower value in table)	0	[mm]	
Thickness of the internal insulation	0	[mm]	
Linear loss Ψ_k value from table		[W/mK]	T- 6.7.2

Interpolation			
Thickness of the insulation below		[mm]	T- 6.7.2
Thickness of the insulation above		[mm]	T- 6.7.2
Linear loss Ψ_k value below		[W/mK]	T- 6.7.2
Linear loss Ψ_k value above		[W/mK]	T- 6.7.2
Linear loss Ψ_k	#DIV/0!	[W/mK]	T- 6.7.2

Replace value in previous table

Cold bridge length		[m]
Area of the whole wall	0	[m^2]
Component for uncorrected transmission coefficient U'	#DIV/0!	[W/m^2K]

No overlap between two planes of insulation

Linear loss at the edge of noninsulated area

Count of insulation changes	2		
Cold bridge interruption	0	[m]	
Inner leaf material	Concrete		
Outer leaf material	Concrete		
Linnear loss Ψ_k		[W/m K]	T- 6.7.1

Tansmission loss for noninsulated area

Inner leaf	Material	Concrete	
	Thickness d		[m]
	Thermal conductivity λ		[W/mK]
Outer leaf	Material	Concrete	
	Thickness d		[m]
	Thermal conductivity λ		[W/mK]
	Is there uninsulated area	FALSE	
	Transmission coefficient of the sub area U_i	0	[W/m^2K]
	Cold bridge interruption width	0	[m]
	Cold bridge length		[m]
	Cold bridge sub area A_i	0	[m^2]
	Area of the whole wall	0	[m^2]
	Component for uncorrected transmission coefficient U'	#DIV/0!	[W/m^2K]

Air filled cavities

Requirements:

1. Cavities limited by parallel surfaces perpendicular to the heat flow and having an emission rate larger than 0.8
2. Has a depth in direction of the heat flow of less than 0.1 times the smallest dimension of the cavities

Non-ventilated cavities

Requirements:

1. Area of openings do not exceed $5cm^2$ per m of horizontal length for vertical cavities
2. Area of openings do not exceed $5cm^2$ per m^2 of area for horizontal cavities

No interpolation			
Cavity depth		[mm]	
Heat flow direction	Horizontal		
Heat flow resistance (R)		[m^2K/W]	T- 6.4.1

Interpolation		
Cavity depth value below		[mm]
Cavity depth value above		[mm]
Heat flow resistance (R) below		[m^2K/W]
Heat flow resistance (R) above		[m^2K/W]
Heat flow resistance (R)	#DIV/0!	[m^2K/W]

Component for uncorrected transmission coefficient U'	#DIV/0!	[W/m^2K]

Sligtly ventilated cavities

Requirements:

1. Area of openings > $5cm^2$, but <15 cm^2 per m of horizontal length for vertical cavities
2. Area of openings >$5cm^2$, but <15 cm2 per m^2 of area for horizontal cavities
3. If the heat flow resistance for an external facing exceed 0.15 m2K/W, a heat flow resistance of no more than 0.15 m^2K/W must be taken to account.

Resistance of the external face	#DIV/0!	[m^2K/W]
Half of the value from table 6.4.1	#DIV/0!	[W/m^2K]
Component for uncorrected transmission coefficient U'	#DIV/0!	[W/m^2K]

Ventilated cavities

Requirements:

1. Area of openings > $15cm^2$ per m of horizontal length for vertical cavities
2. Area of openings >$15cm^2$ per m^2 of area for horizontal cavities

Heat resistance equal to the inner leaf	#DIV/0!	[m^2K/W]
Component for uncorrected transmission coefficient U'	#DIV/0!	[W/m^2K]

Penetrations (decks, walls, columns, beams)

Requirements: 1 Materials according to table 6.7.4 and 6.7.5 requirements

Linear loss at the edge of noninsulated area

Count of insulation changes			
Cold bridge interruption	0	[m]	
Thermal bridge kind			T- 6.7.4
Linnear loss Ψ_k		[W/m K]	T- 6.7.4

Tansmission loss for noninsulated area

Penetrating element

Material	Concrete	N/A
Thickness d (equal to penetrated wall thickness)		[m]
Thermal conductivity λ		[W/mK]
Transmission coefficient of the sub area U_i	#DIV/0!	[W/m^{2}K]
Cold bridge interruption height		[m]
Cold bridge length		[m]
Cold bridge sub area A_i	0	[m^2]

Continuing beams and columns

Material	Concrete	N/A	
Cross sectional height		[m]	
Cross sectional width		[m]	
Cross sectional area	0	[m^2]	
Point heat loss for the individual spot cold bridge χ_j		[W/m^{2}K]	T- 6.7.5

Area of the whole wall	0	[m^2]
Component for uncorrected transmission coefficient U'	#DIV/0!	[W/m^{2}K]

Corners - ANNEX M

Right angled corners

Requirements: 1 Materials according to tables M.1,2,3

2 If walls are not symetrical, use the greatest loss

Thickness of insulation	0,125	[m]	
No of outgoing corners	1		
Linear loss Ψ	-0,1	W/mK	T- M.1,2,3
No of ingoing corners			
Linear loss Ψ		W/mK	T- M.1,2,3
Height of the linear loss	5,6	[m]	
Area of the whole wall	0	[m^2]	
Component for uncorrected transmission coefficient U'	#DIV/0!	[W/m^{2}K]	

10.2.2 Windows

Element	Window	Section/ Table/ Figure
Identification no		

Transmission loss

Colour codes
Revit input
Revit extract
Manual input

Measurement	Value	Units	Section/ Table/ Figure
Inner temperature θ_i	20	[°C]	F- 2.1
Outer temperature θ_e	-12	[°C]	F- 2.1
Opening height		[m]	
Opening width		[m]	
Opening area		[m^2]	
Frame thickness		[m]	
Frame depth		[m]	
Glass/panel height		[m]	
Glass/panel width		[m]	
Glass/panel area		[m^2]	
Distance between glass panels	3	[mm]	
Layers of glass	3		
Filling between glass panels	Air		
Transmission coefficient for glass/panel - U_g/U_p	2,7	[W/m^2K]	
Double, triple glazed panes - Figure N.1-N.4			
Single certical glass layer	5,9		
Other glass - Annex I			

Frame area	0,000	[m^2]	
Frame thickness	0	[m]	
Softwood/hardwood			
Frame transmission coefficient U_f	2,4	[W/m^2K]	T- 6.8.1

Opening transmission coefficient for Revit	#DIV/0!	[W/m^2K]

Linear loss

Linear loss length glass-frame l_g	0	[m]	
Case number from below the table			
Linear loss glass-frame ψ_g		[W/mK]	

1 Metal profile frames with broken thermal bridges and with distance profiles in different materials in dependence on the pane's U- value — T- 6.8.2

2 Wood or plastic profile frames and with distance profiles in different materials in dependence on the pane's U- value — T- 6.8.3

3 Windows with single glass layer — 0 [W/mK]

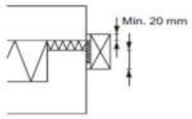
Linear loss length frame-wall l_k	0	[m]
Linear loss frame-wall ψ_k	0	[W/mK]

Total transmission coefficient U	#DIV/0!	[W/m^2K]
Total transmission loss ϕt	#DIV/0!	[W]

Windows and doors in cavity wall

Inner leaf material		
Outer leaf material		
Frame depth	0	[mm]

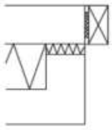
Requirements:



Sketch 1
Example of placing in relation to table 6.12.1a

1 Materials according to requirements in tables
2 Thermal bridge insulation with thermal conductivity less than 0.04 W/mK
3 Frame depth no less than 90 mm
4 Frame placed in front of the cold bridge interruption, with at least 20 mm overlap

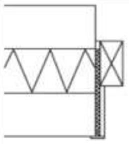
Cold bridge interruption		[mm]	
Linear loss frame-wall ψ_s		[W/mK]	T- 6.12.1a



Sketch 2
Example of placing in relation to table 6.12.1b

4 Frame displaced from the thermal bridge insulation in the wall

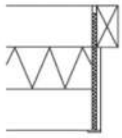
Linear loss frame-wall ψ_s		[W/mK]	T- 6.12.1b



Sketch 3
Example of placing in relation to table 6.12.1c

3 Frame depth between 60 - 120 mm
4 Outer wall with thickness of at most 110 mm
5 Frame carried out in wood or wood-based plates
6 Frame placed with at most 30 mm of overlap concerning front or rear wall

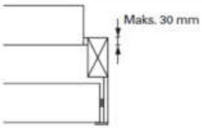
Insulation thickness		[mm]	
Linear loss frame-wall ψ_s		[W/mK]	T- 6.12.1c



Sketch 4
Examole of placing in relation to table 6.12.1d

6 Frame placed dislocated from the outer wall insulation next to either front- or rear wall

Linear loss frame-wall ψ_s		[W/mK]	T- 6.12.1d



Sketch 5
Example of placing in relation to table 6.12.1e

3 Wooden windows with frame depth of at least 100 mm
4
Displacement of rear wall - frame placed respectively displaced from the outer wall insulation next to either front- or rear wall or with at most 30 mm overlap to front- or rear wall

Linear loss frame-wall ψ_s		[W/mK]	T- 6.12.1e

Sketch 6
Example of placing in relation to table 6.12.1f

4 Displacement of front wall up in front of the frame

Linear loss frame-wall ψ_s		[W/mK]	T- 6.12.1f

10.2.3 Doors

Element	Window		Section/ Table/ Figure
Identification no			

Transmission loss

Colour codes
Revit input
Revit extract
Manual input

Measurement	Value	Units	
Inner temperature θ_i	20	[°C]	F- 2.1
Outer temperature θ_e	-12	[°C]	F- 2.1
Opening height		[m]	
Opening width		[m]	
Opening area		[m^2]	
Frame thickness		[m]	
Frame depth		[m]	
Glass/panel height		[m]	
Glass/panel width		[m]	
Glass/panel area		[m^2]	
Distance between glass panels	3	[mm]	
Layers of glass	3		
Filling between glass panels	Air		
Transmission coefficient for glass/panel - U_g/U_p	2,7	[W/m^2K]	

Double, triple glazed panes - Figure N.1-N.4
Single certical glass layer 5,9
Other glass - Annex I

Doors U-value	Material1		N/A	
	Thickness d		[m]	
	Thermal conductivity λ		[W/mK]	
	Material2		N/A	
	Thickness d		[m]	
	Thermal conductivity λ		[W/mK]	
Horizontal	Inner surface resistance	0,13	[m^2K/W]	T- 6.2.1
Horizontal	Outer surface resistance	0,04	[m^2K/W]	T- 6.2.1
Combine with glass	Transmission coefficietn for door U_p	#DIV/0!	[W/m^2K]	

Frame area	0,000	[m^2]	
Frame thickness	5,9	[m]	
Softwood/hardwood			
Frame transmission coefficient U_f	2,4	[W/m^2K]	T- 6.8.1

Opening transmission coefficient for Revit	#DIV/0!	[W/m^2K]

Linear loss

Linear loss length glass-frame l_g	0	[m]
Case number from below the table		0,06
Linear loss glass-frame ψ_g		[W/mK]

1 Metal profile frames with broken thermal bridges and with distance profiles in different materials in dependence on the pane's U- value T- 6.8.2
2 Wood or plastic profile frames and with distance profiles in different materials in dependence on the pane's U- value T- 6.8.3
3 Windows with single glass layer 0 [W/mK]

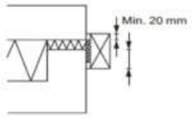
Linear loss length frame-wall l_k	0	[m]
Linear loss frame-wall ψ_k	0	[W/mK]

Total transmission coefficient U	#DIV/0!	[W/m^2K]
Total transmission loss ϕt	#DIV/0!	[W]

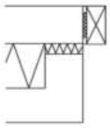
Windows and doors in cavity wall

Inner leaf material		
Outer leaf material		
Frame depth	0	[mm]

Requirements:



Sketch 1
Example of placing in relation to table 6.12.1a



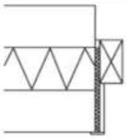
Sketch 2
Example of placing in relation to table 6.12.1b

1 Materials according to requirements in tables
2 Thermal bridge insulation with thermal conductivity less than 0.04 W/mK
3 Frame depth no less than 90 mm
4 Frame placed in front of the cold bridge interruption, with at least 20 mm overlap

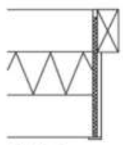
Cold bridge interruption		[mm]	
Linear loss frame-wall ψ_s		[W/mK]	T- 6.12.1a

4 Frame displaced from the thermal bridge insulation in the wall

Linear loss frame-wall ψ_s		[W/mK]	T- 6.12.1b



Sketch 3
Example of placing in relation to table 6.12.1c



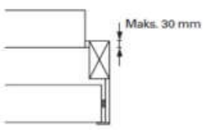
Sketch 4
Examole of placing in relation to table 6.12.1d

3 Frame depth between 60 - 120 mm
4 Outer wall with thickness of at most 110 mm
5 Frame carried out in wood or wood-based plates
6 Frame placed with at most 30 mm of overlap concerning front or rear wall

Insulation thickness		[mm]	
Linear loss frame-wall ψ_s		[W/mK]	T- 6.12.1c

6 Frame placed dislocated from the outer wall insulation next to either front- or rear wall

Linear loss frame-wall ψ_s		[W/mK]	T- 6.12.1d



Sketch 5
Example of placing in relation to table 6.12.1e

Sketch 6
Example of placing in relation to table 6.12.1f

3 Wooden windows with frame depth of at least 100 mm
4
Displacement of rear wall - frame placed respectively displaced from the outer wall insulation next to either front- or rear wall or with at most 30 mm overlap to front- or rear wall

Linear loss frame-wall ψ_s		[W/mK]	T- 6.12.1e

4 Displacement of front wall up in front of the frame

Linear loss frame-wall ψ_s		[W/mK]	T- 6.12.1f

10.2.4 Roofs

Element	Roof/ceiling			Section/ Table/ Figure
Identification no				
	Measurement	Value	Units	
Colour codes	Length		[m]	
Revit input	Width		[m]	
Revit extract	Area of openings		[m^2]	
Manual input	Area of the whole roof/ceiling	0	[m^2]	
	Inner temperature θi	20	[°C]	F- 2.1
	Outer temperature θe	-12	[°C]	F- 2.1
* change for ventilated attcis T- 6.5.1	Inner surface resistance	0,1	[m^2K/W]	T- 6.2.1
	Outer surface resistance	0,04	[m^2K/W]	T- 6.2.1
Inhomogenious layer				
	Material 1		N/A	
	Thermal conductivity λ		[W/mK]	
	Area		[m^2]	
	Material 2		N/A	
	Thermal conductivity λ		[W/mK]	
	Area		[m^2]	
	Material 3		N/A	
	Thermal conductivity λ		[W/mK]	
	Area		[m^2]	
	Layer thermal conductivity λ'	#DIV/0!	[W/mK]	
Composition				
	No material - λ=1			
Inner leaf	Material		N/A	
	Thickness d		[m]	
	Thermal conductivity λ		[W/mK]	
Insulation leaf	Material		N/A	
	Thickness d		[m]	
	Thermal conductivity λ		[W/mK]	
Middle leaf	Material		N/A	
	Thickness d		[m]	
	Thermal conductivity λ		[W/mK]	
Outer leaf	Material		N/A	
	Thickness d		[m]	
	Thermal conductivity λ		[W/mK]	
	Component transmission coefficient U' for roof/ceiling	#DIV/0!	[W/m^2K]	
	Corrected transmission coefficient U for roof/ceiling	#DIV/0!	[W/m^2K]	
	Transmission loss ϕ_t for roof/ceiling	#DIV/0!	[W]	
Cold bridges	Annex A			
Insulation				
	Level of air cracks in insulation layer	1		S- A.2.3
	Correction for air-cracks in the insulation ΔU''	0,01	[W/m^2K]	T- A.1
	Heat flow resistance of the insulation layer R_i	#DIV/0!	N/A	
	Heat flow resistance of the construction R_T	#DIV/0!	N/A	
	Correction for air-cracks in the insulation ΔU_g	#DIV/0!	[W/m^2K]	
"Upside down" roof - membrane below insulation layer		According to Annex A, S- A.4		

10.2.5 Slabs

				Section/ Table/ Figure
Element	Slab - basement and ground supported floor			
Identification no				
	Measurement	Value	Units	
Colour codes	Length		[m]	
Revit input	Width		[m]	
Revit extract	Area of openings		[m^2]	
Manual input	Area of the whole slab	0	[m^2]	
	Inner temperature θi	20	[°C]	F- 2.1
	Outer temperature θe	10	[°C]	F- 2.1
Downward	Inner surface resistance	0,17	[m^2K/W]	T- 6.2.1
* change ground supported floor T- 6.9.1	Outer surface resistance	0,04	[m^2K/W]	T- 6.2.1
Inhomogenious layer				
	Material 1		N/A	
	Thermal conductivity λ		[W/mK]	
	Area		[m^2]	
	Material 2		N/A	
	Thermal conductivity λ		[W/mK]	
	Area		[m^2]	
	Material 3		N/A	
	Thermal conductivity λ		[W/mK]	
	Area		[m^2]	
	Layer thermal conductivity λ'	#DIV/0!	[W/mK]	
Composition				
	No material - λ=1			
Inner leaf	Material		N/A	
	Thickness d		[m]	
	Thermal conductivity λ		[W/mK]	
Insulation leaf	Material		N/A	
	Thickness d		[m]	
	Thermal conductivity λ		[W/mK]	
Middle leaf	Material		N/A	
	Thickness d		[m]	
	Thermal conductivity λ		[W/mK]	
Outer leaf	Material		N/A	
	Thickness d		[m]	
	Thermal conductivity λ		[W/mK]	
	Component transmission coefficient U' for slab	#DIV/0!	[W/m^2K]	
	Corrected transmission coefficient U for slab	#DIV/0!	[W/m^2K]	
	Transmission loss ϕ_t for slab	#DIV/0!	[W]	
Cold bridges	Annex A			
Insulation				
	Level of air cracks in insulation layer	1		S- A.2.3
	Correction for air-cracks in the insulation ΔU''	0,01	[W/m^2K]	T- A.1
	Heat flow resistance of the insulation layer R_i	#DIV/0!	N/A	
	Heat flow resistance of the construction R_T	#DIV/0!	N/A	
	Correction for air-cracks in the insulation ΔU_g	#DIV/0!	[W/m^2K]	

10.2.6 Foundations

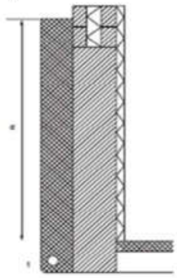
				Section/ Table/ Figure
Element	Foundations			
Identification no				

Colour codes
Revit input
Revit extract
Manual input

Inner temperature θi	20	[°C]	F- 2.1
Outer temperature θe	10	[°C]	F- 2.1

Outer basement wall foundations

Requirements: 1 Materials accoding to tables 6.13.7 a,b



[1] Drain layer
[2] E.g. drain layer or insulation

Measurement	Value	Units	
Material of basement wall	Concrete		
Raise of the floor from bottom of the foundation		[cm]	
Soil coverage to the level of the floor d		[m]	
Thickness of inside wall insulation		[mm]	
Length of linear loss		[m]	
Linear loss Ψf		[W/mK]	T- 6.13.7a,b

For other construction, Annex D

Foundations for partition walls that penetrate the insulation of ground deck in basement floor

Measurement	Value	Units	
Foundation structure			
Length of linear loss		[m]	
Linear loss Ψk		[W/mK]	T- 6.7.3

Total linear loss for foundation ϕt	0	[W/mK]

Foundations at ground supported walls

Requirements:

1 Terrain level is at most 30 cm lower than floor level

2 The width of the foundation is no more than 2 cm less than the thickness of the external walls

3 The external wall covers the whole top part of the foundation. Where the foundation is carried out with insulation in the centre, it is adequate to cover the centre insulation and 20mm on each side of it

4 The floor concrete's thickness is at most 12 cm
The rear wall's thickness is for bricks at most 11 cm, and for light weight concrete and concrete at most 12 cm.

For other construction types or other location of ground or floor the linear transmission coefficient is to be calculated as shown in annex D

External wall foundations at ground supported floors inconnection with frame walls and equivalent lightweight walls

Requirements:

1 Materials according to table 6.13.1

Measurement	Value	Units
Insulation above concrete plate		
U-value for terrain deck		[W/m^2K]
Material of external wall		
Cold bridge interruption		[mm]
Insulation placement in the wall		
Linear loss Ψf		[W/mK]

T- 6.13.1

Foundations in connection with cavity walls or walls with inner leaf of concrete, bricks or lightweight concrete

Requirements:

1 Materials according to table 6.13.2a-c

Measurement	Value	Units
Insulation above concrete plate		
U-value for terrain deck		[W/m^2K]
Material of external wall		
Cold bridge interruption		[mm]
Insulation placement in the wall		
Linear loss Ψf		[W/mK]

T- 6.13.2 a,b,c

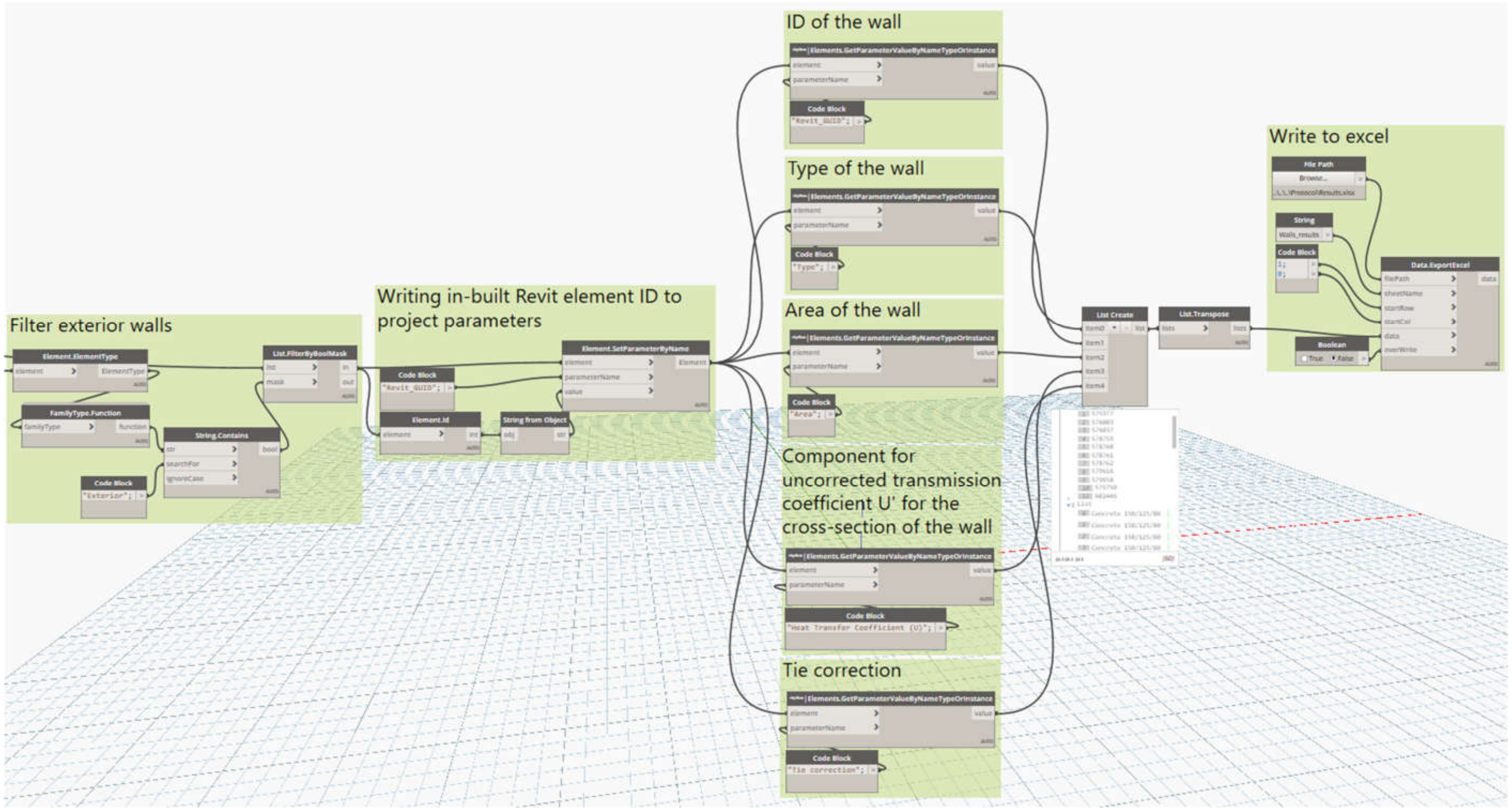
Foundations in connection with concrete sandwich elements

Measurement	Value	Units
Insulation above concrete plate		
U-value for terrain deck		[W/m^2K]
Material of external wall		
Cold bridge interruption		[mm]
Insulation placement in the wall		
Linear loss Ψf		[W/mK]

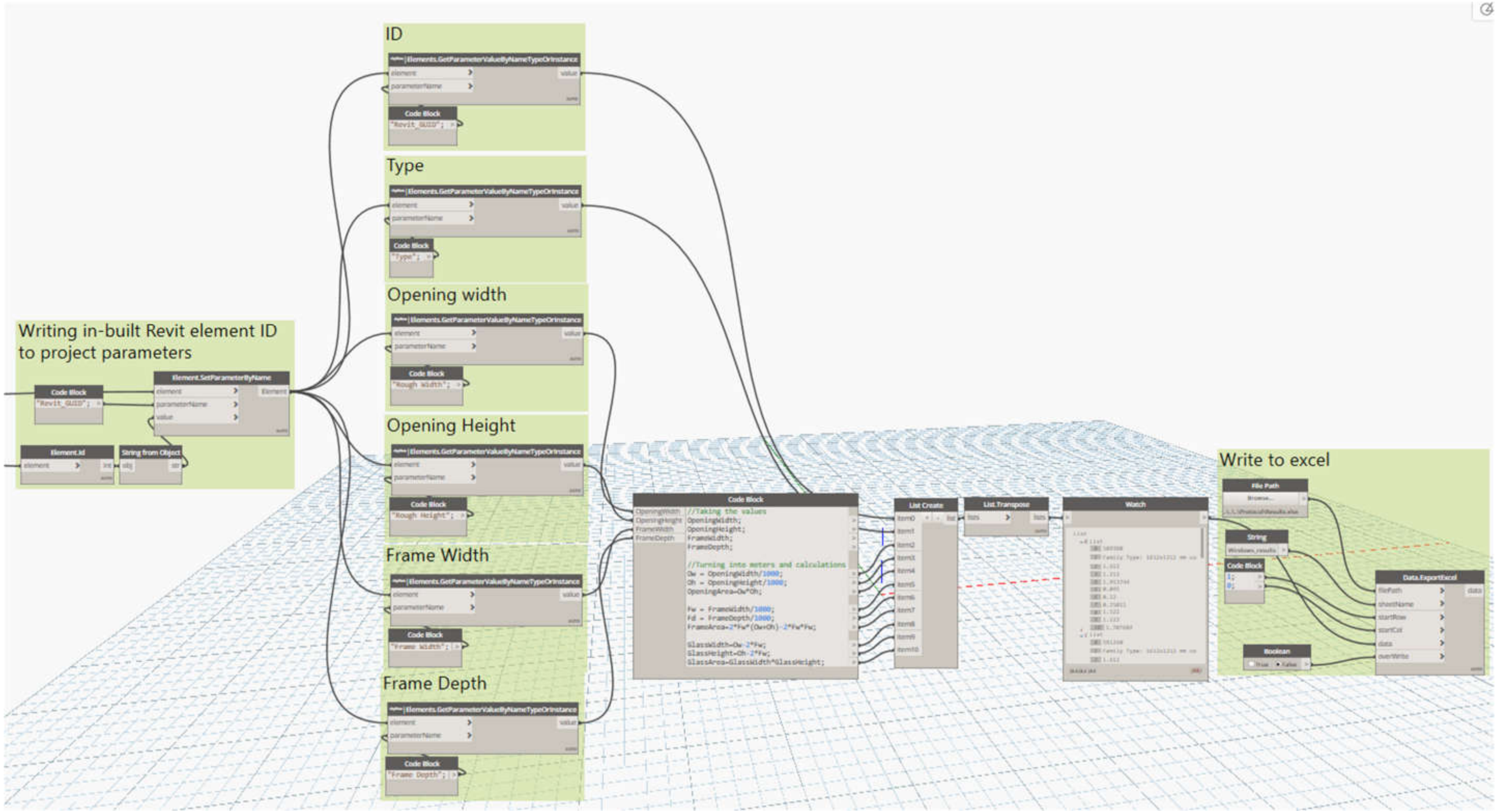
T- 6.13.2 a,b,c

10.3 Dynamo scripts

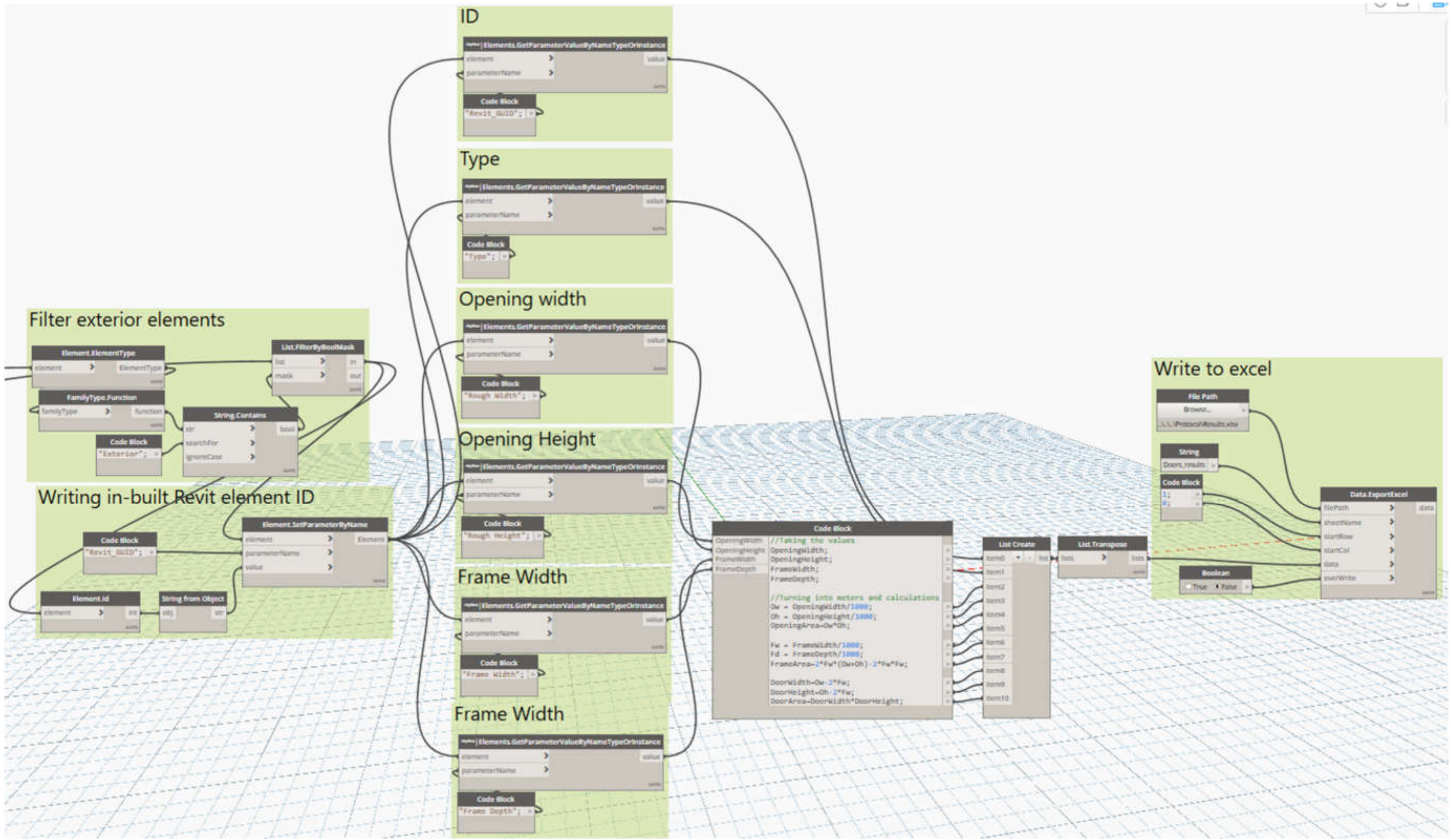
10.3.1 Walls



10.3.2 Windows

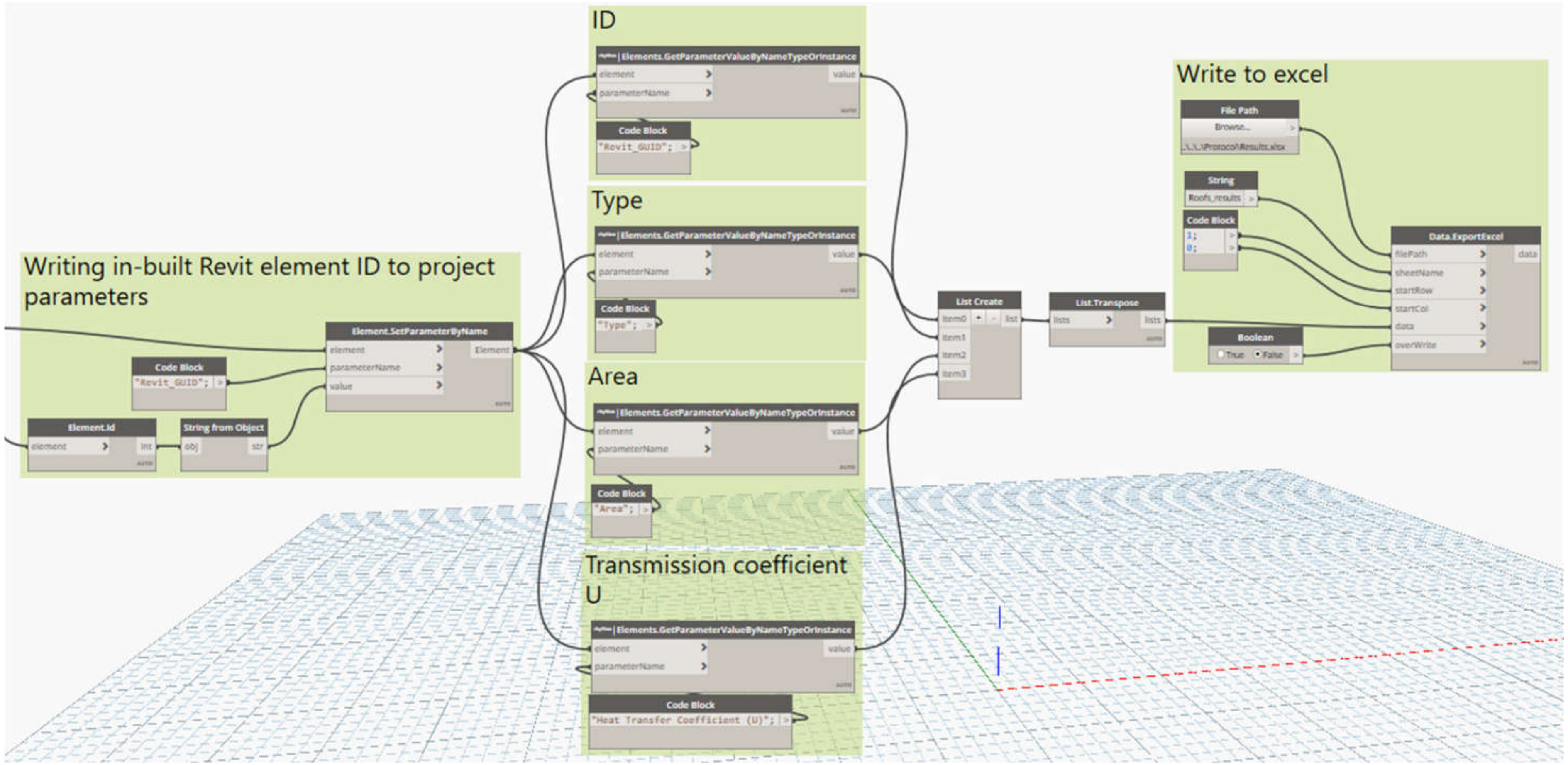


10.3.3 Doors



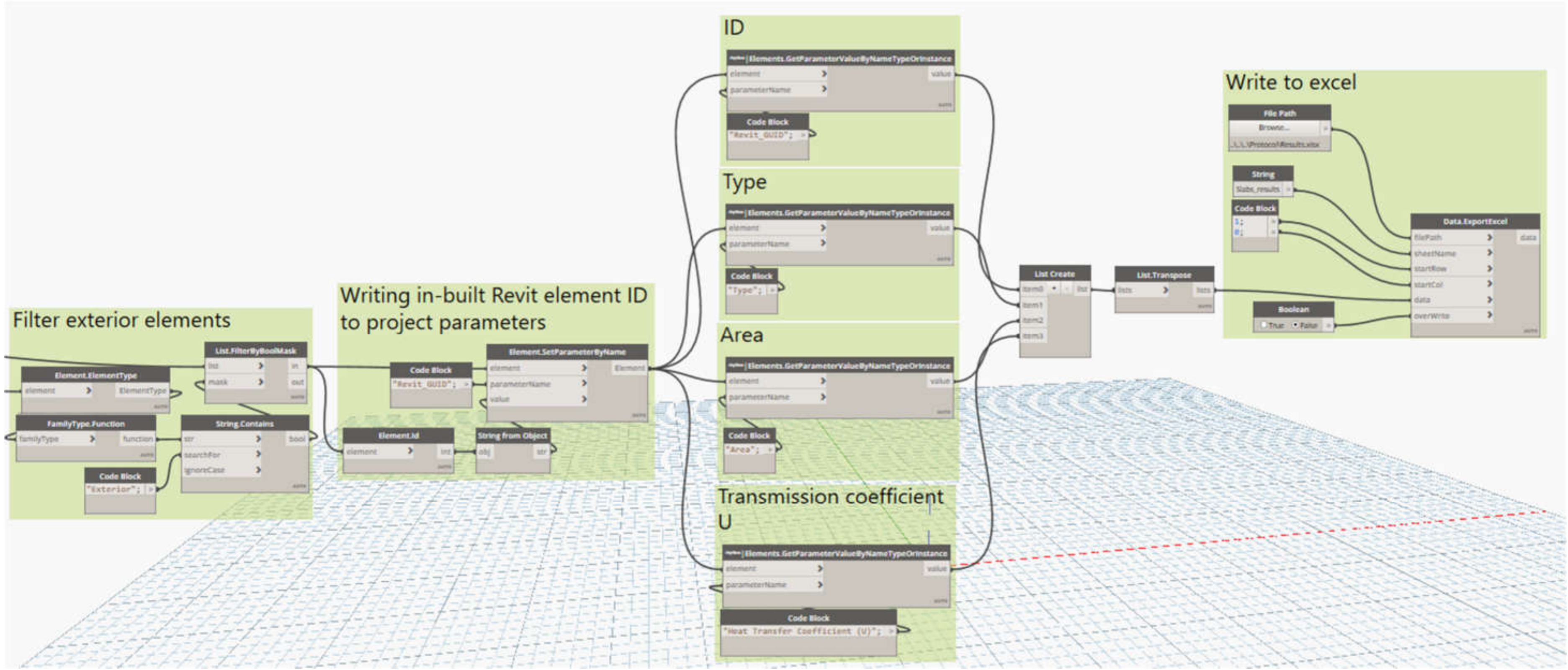
ID
Type
Opening width
Opening Height
Frame Width
Frame Width
Filter exterior elements
Writing in-built Revit element ID
Write to excel
Code Block
List Create
List Transpose
File Path
String
Boolean
Data.ExportExcel

10.3.4 Roofs



ID
Elements.GetParameterValueByNameTypeOrInstance
element
parameterName
value
Code Block
"Revit_GUID";
Type
Elements.GetParameterValueByNameTypeOrInstance
Code Block
"Type";
Area
Elements.GetParameterValueByNameTypeOrInstance
Code Block
"Area";
Transmission coefficient U
Elements.GetParameterValueByNameTypeOrInstance
Code Block
"Heat Transfer Coefficient (U)";
Writing in-built Revit element ID to project parameters
Element.SetParameterByName
Code Block
"Revit_GUID";
Element.Id
String from Object
List Create
List.Transpose
Write to excel
File Path
Browse...
String
Roofs_results
Code Block
1;
0;
Boolean
True
False
Data.ExportExcel
filePath
sheetName
startRow
startCol
data
overWrite

10.3.5 Slabs



ID
Type
Area
Transmission coefficient U
Write to excel
Filter exterior elements
Writing in-built Revit element ID to project parameters

10.3.6 Foundations