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Proposing a Standard Reference Template (using LOD BIM) for the Project Manager to Evaluate the Parameters Needed for the Energy Simulation in the Early Phases of Building Design.

Master thesis

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धन्यवाद | Vielen Dank | Thank You

COPY OF PROPOSED CONCEPTUAL FORMULATION

ABSTRACT

Recently, BIM-based energy simulation has emerged of much importance due to expectancy for sharing of building information, and it is efficient reuse. The global call for sustainability and energy conservation has led to building energy modelling. BIM is beneficial in contributing to significant design development and information availability from the perspective of building energy modelling. Building simulation has been widely used in the late phases of design, whereas it will be highly useful to use simulations in the early stages of design to achieve better building performance. The role of a project manager is to make sure that the building meets all the environmental and zoning standards by overseeing the design and construction phases. In this case, it will be highly effective if **"The project manager has a precise list of parameters required from the architects, essential for the energy simulation of buildings in the early phases of design to achieve better energy performance"**.

Thus, the purpose of this paper is **"to develop a standard reference template with an inventory or list of parameters".** These parameters have to be included in the BIM in the early phases of design following the specifications of LOD's in different stages. To simulate it for energy performance and follow it as a standard reference template by the project managers. As architects often have limited experience in energy simulation, they are unaware of the necessary parameters required for building simulation software.

This **thesis aims to study and analyze**:

- **The inventory of required parameters** (to be researched by literature study, scientific papers, project manager interviews and cross-checked by simulators) needed from BIM to performance energy simulation.
- To **study the different LOD's and phases of design** and which parameters can be extracted in which stage of design.
- **The process of extracting those parameters** and whether it can be translated directly from BIM or any **intermediate programming tool is required to translate the geometric and technological information from BIM**.

Keywords:

Building Information Model (BIM), Building Energy Model (BEM), LOD (level of development), Building Energy Simulation (BES), Component Parameters, Industry foundation classes (IFC), Dynamo (Visual programming tool).

Research Objectives:

The main objective of this thesis is to **propose a standard reference template (using LOD BIM) for the project manager to evaluate the parameters needed for the energy simulation in the early phases of building design**.

To fulfil the main objective, secondary objectives are established:

1. To study and identify different phases of design and construction, referring to GBC & LOD.
2. To summarize and generate the parameter list based on the inputs received from energy simulation experts and also address the practical issue manifest in retrieving the required parameters.
3. To list the parameters and attributes that exist in the model or can be accurately exported to the ones that cannot be. Furthermore, to evaluate the prioritization of these parameters.
4. To explain the practical process of retrieving parameters, that exists in the BIM model but can be extracted only with the help of external software (programming tools).
5. To generate a standard list of parameters required for early-stage energy simulation to be referred by the project manager. Additionally, elaborating the benefit for the project manager and project overall.

Research methodology:

The methodology of this research is designed according to the book "**Research methods for business students**".

Firstly, a literature review of primary and secondary literature related to the fundamental concepts of this study is carried out. Only **the publications issued within the last five years have been studied** and considered as new advancements are made every day in the AEC Industry.

Secondly, a practical experiment in which **a box model is prepared as a reference model for different LOD,** inserting the required parameters and the process to generate and extract parameters is implemented.

Furthermore, **the pilot project results are validated through the case study of the EUREF project, Berlin.**

Research Questions:

With the help of research, the thesis will try to examine and answer the following questions:

1. **What are the major issues and challenges related to retrieving the parameters in different LOD's?**

2. **How can one retrieve the parameters? What tools are used in this process and how efficient are the results?**

3. **Why has BIM not been actively used for building energy simulation? What are the research gaps that exist?**

4. **Is it possible to develop templates with a standard inventory of parameters to be used by the project manager for different types of the project? And how accurate are the results?**

Expected Outcome:

The expected result or outcome is a **reference model with an inventory of parameters which can be used as a standard by the project managers in different projects for the purpose of energy simulations**. This reference model can serve as **a foundation for analyzing energy performance in building design**.

Signature of the Supervisor

ABSTRACT

Recently, BIM-based energy simulation has emerged of much importance due to expectancy for sharing of building information, and it's efficient reuse. The Global call for sustainability and energy conservation has led to building energy modelling. BIM is beneficial in contributing to significant design development and information availability from the perspective of building energy modelling. Building simulation has been widely used in the late phases of design, whereas it will be highly useful to use simulations in the early stages of design to achieve better building performance. The role of a project manager is to make sure that the building meets all the environmental and zoning standards by overseeing the design and construction phases. In this case, it will be highly effective if "**The Project manager has a precise list of parameters required from the architects, essential for the energy simulation of buildings in the early phases of design to achieve better energy performance"**.

Thus, the purpose of this paper is **"to develop a standard reference template with an inventory or list of parameters".** These Parameters have to be included in the BIM in the early phases of design following the specifications of LOD's in different stages. To simulate it for energy performance and follow it as a standard reference template by the project managers. As architects often have limited experience in energy simulation, they are unaware of the necessary parameters required for building simulation software.

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LIST OF ABBREVIATIONS

Fig.	Figure
AEC	Architecture, Engineering, and Constructions.
AIA	The American Institute of Architects.
ASHRAE	The American Society of Heating, Refrigerating and Air-Conditioning Engineers.
BIM	Building Information Modelling.
BEM	Building Energy Modelling.
BES	Building Energy Simulation.
BREEAM	Building Research Establishment Environmental Assessment Method.
BUI	Building Input Description File.
DHV	Display of Higher Value.
DGNB	German Sustainable Building Council. *(German: Deutsche Gesellschaft für Nachhaltiges Bauen eV*)
DPM	Design Performance Modeling.
ESP-r	Energy Simulation Software tool.
EnEV	The German Energy Saving Ordinance. *(German: Energieeinspaarverordnung)*
IDA ICE	Indoor Climate Energy.
IES-VE	Integrated Environmental Solutions - Virtual Environment.
gbXML	Green Building XML.
HOAI	Honorarium Regulations for Architects and Engineers. *(German: Honorarordnung für Architekten und Ingenieure)*
HVAC	Heating, Ventilation, and Air Conditioning.
IFC	Industry Foundation Class.
LEED	Leadership in Energy and Environmental Design.

LOC Level of Coordination.

LOD Level of Development.

LOG Level of Geometry.

LOI Level of Information.

IEA International Energy Agency.

nZEB Net-Zero Energy Building.

P.V. Present Value.

RIBA The Royal Institute of British Architects.

TGA Thermogravimetric Analysis.

VPL Visual Programming Language.

WWR Window to Wall Ration.

S.C. Shading Coefficient.

TRNSYS Transient System Simulation Tool.

1. CHAPTER - INTRODUCTION AND RESEARCH SCOPE

1.1 Background

The construction industry has a reputation for being slow in terms of technological advancements and is responsible for producing 1/3rd of the total waste generated annually. With the global awareness about the impacts of the construction sector in climate change the green building codes and regulations are becoming sterner which has led to a massive demand for energy-efficient buildings and structures. BIM and energy simulation software are the two technologies that heavily impact the energy efficiency of the AEC industry (Lewis Anderson M., 2014).

An energy-efficient building produces less carbon, low greenhouse gas emissions, and less wastage in comparison to an average structure and thus has a minimal negative impact on the environment. The increased demand for energy-efficient or sustainable buildings has led to leverage the information stored in BIM to design better energy-efficient buildings (Lewis Anderson M., 2014).

BIM is a virtual 3D parametric design software that provides the users with the insights and tools to improved design, information, coordination, management, and operations. The purpose of BIM is to provide the required information at the needed time to make the right decisions concerning the whole design process. BIM can also prove to be valuable in terms of identifying the building components which can be reused, recycled, or salvaged. If the project follows the standards of BIM in its processes, then it can be of substantial importance in attaining an energy-efficient building through monitoring different phases of design, construction, and operations. Energy simulation is a fundamental tool for optimizing and calculating the energy performance of a building through software during the design phase (Lewis Anderson M., 2014).

As per the studies, the energy calculations from BIM differs from the energy calculations done by transferring data from BIM into other energy analysis tools. Similarly, the energy analysis is different for the different design phases. One of the objectives of this thesis is to study the influence of energy analysis when carried out in the early stages of design (Hensen and Lamberts, 2012).

Also, the purpose is to generate a parameter list for the project manager which can assist him in delivering a successful sustainable project as the project manager is one of the key stakeholders and holds one of the most critical positions in the project execution.

This study is descriptive-exploratory and is based mainly on three research methods, bibliography review, energy simulation case study analysis, and work meetings with experienced energy simulation experts & industry professionals, i.e. project managers.

This research is organized into five main chapters. Chapter I explains the introduction and research scope of this study along with the objectives and methodology. Chapter II envisages the literature review and describes the building process, different levels of development in design (L.O. D 100, 200, 300 & 400), attributes and parameters existing and required for carrying out energy simulations. Additionally, the chapter also covers workflow of energy simulation, tools associated with modelling & Simulation and how visual programming tools like dynamo can help in achieving the required parameters in the early design phases. The chapter further highlights the importance of adopting an integrated design process, and it is benefits to the client and project managers. Chapter III is about research methodology, where the author executes a pilot project based on the literature review and guidelines given by the simulation expert. In this chapter, the author produces a list of parameters extracted from the pilot project. Chapter IV delivers validation of the result produced by the author in chapter III based on the case study. Chapter V establishes a discussion concerning the limitations of the research by the identification of the issues and suggests future recommendations and investigations. Furthermore, in the end, the study is completed with a conclusion.

1.2 Research Problem

The AEC industry consumes the highest resources in the world. As per the reports,in the European Union (E.U.) the building sector consumes 40% of the total energy. Additionally, the AEC industry is accountable for 40% of the raw material depletion and 70% of the electricity consumption (Delnavaz, 2012).

The early phases of design decisions have a significant impact on defining the ecological and economic feasibility of a project. The building services are hardly discussed or given importance in the early phases, despite these being the key contributors in determining the cost and energy performance of a project (Toth and Arch, 2017).

For sustainable design, it would be of great importance if the various design options are assessed for their energy performance, and the simulations are carried out before deciding the details. Currently, the AEC industry is struggling to resolve the design and energy performance issues simultaneously. Thus, in the early phases emphasis should be given in locating the co-dependencies between the three main areas of the project, i.e., architecture design, building services, and energy use (Toth and Arch, 2017)

However, the early stage uncertainty analysis is another factor for the difficulties in early-stage Simulation as the models in these LOD's often have low or unclear information, and they always deal with a certain degree of fuzziness. Moreover, clients are usually not inclined to pay for such analysis (Scholl, 2019).

In addition to this is the architects often have limited experience in energy simulation and are unaware of the necessary parameters required for building simulation software. Accessibility of the parameters and priority list in the early phases of design will help the project manager to ensure that the building meets all the environmental and zoning standards by overseeing the design and construction phases (Scholl, 2019).

Despite the ongoing research of the software companies and energy companies working on advancements, the interconnectivity of the BIM and energy simulation software have not been explored thoroughly. Keeping the current scenario and technologies in mind this investigation addresses the research problem and tries to find a unifying thread so that the full potential of these software and information can be utilized by the project manager and construction companies in achieving an energy-efficient sustainable project.

1.3 Purpose and Objectives

The main objective of this thesis is to propose a standard reference template (using LOD BIM) for the project manager to evaluate the parameters needed for the energy simulation in the early phases of building design.

To fulfil the objective, secondary objectives are established:

1. To study and identify different phases of design and construction, referring to GBC & LOD.
2. To summarize and generate the parameter list based on the inputs received from energy simulation experts and also address the practical issue manifest in retrieving the required parameters.
3. To list the parameters and attributes that exist in the model or can be accurately exported to the ones that cannot be. Furthermore, to evaluate the prioritization of these parameters.
4. To explain the practical process of retrieving parameters, that exists in the BIM model but can be extracted only with the help of external software (programming tools).
5. To generate a standard list of parameters required for early-stage energy simulation to be referred by the project manager. Additionally, elaborating the benefit for the project manager and project overall.

1.4 Relevance of the Study

The current trend of carrying out BES in the last stage of planning is a stumbling block and expensive. In this stage, only minor changes can be carried out to the building design and layouts. Proving design effectiveness in the early stages helps in identifying the blockages, collisions, and structural weakness, and thus changes or variations can be carried out without much of an effort. This whole process helps the designers to do the simulations on multiple design options and identify the critical parameters for successful assessments (Scholl, 2019).

The entire building design process consists of seven phases and is broadly categorized into three major phases outline phase, schematic phase, and detailed phase. Each one of these phases has a specific objective, scope, data, and information (Li, 2017).

As shown in the figure below the MacLeamy curve, the early design phase has a high impact on the result and costs of the project. As opposed to the traditional approach, the optimization should be conducted in the schematic design phases rather than the construction documentation phase. Several BES tools operating in the virtual environment has taken over the market to evaluate the design options in the early conceptual stage (Li, 2017).

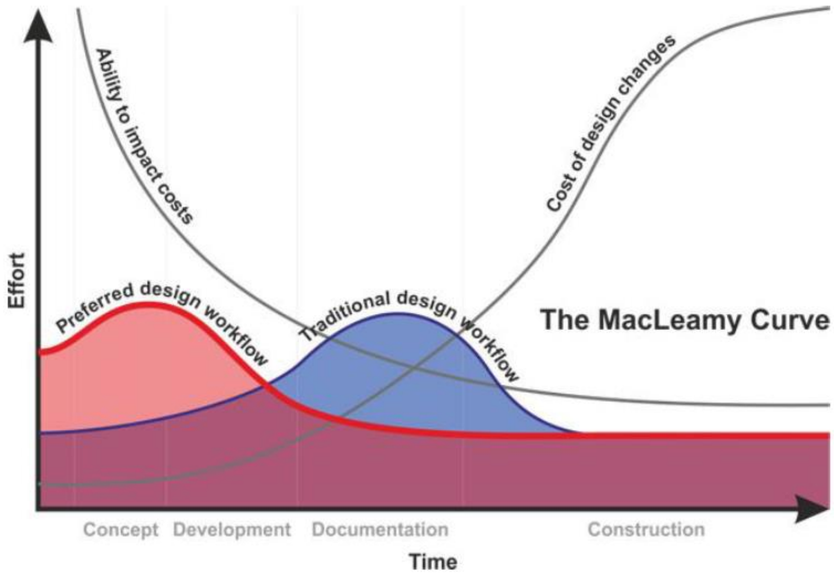


Figure 1: The Macleamy Curve of BIM Design Workflow.
Source: (Li, 2017).

The project manager is responsible for management and coordination between different stakeholders and processes. As shown in the figure below the project manager is the most involved stakeholder and plays a crucial role in sustainability responsibilities (Akotia, Opoku and Hafiz, 2017).

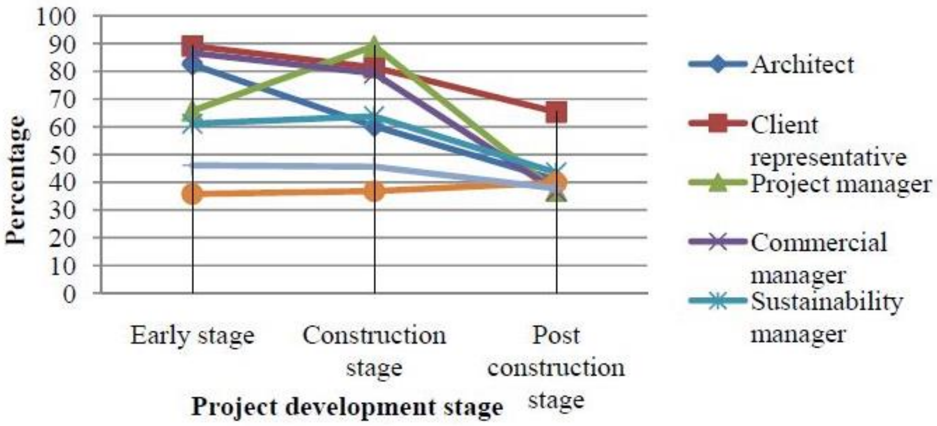


Figure 2: Graphical Representation of Practitioners Involved in Main Project Phases.
Source: (Akotia, Opoku and Hafiz, 2017).

Thus, It would be beneficial if the project manager has a standard BES template to follow in the early phases of design which will help him in convincing and suggesting the client with the most suitable energy-efficient design option to choose from (Akotia, Opoku and Hafiz, 2017).

The financial savings and the social and environmental advantages that this can offer to the AEC industry are evidence that supports the relevance of studying the feasibility to generate a parameter list as a standard template for the project manager.

1.5 Methodology

The methodology of this research is designed according to the book “Research methods for business students”(Mark Saunders, Phillip Lewis, 2009). The whole thesis is defined into six phases, based on primary and secondary objectives see fig. below.

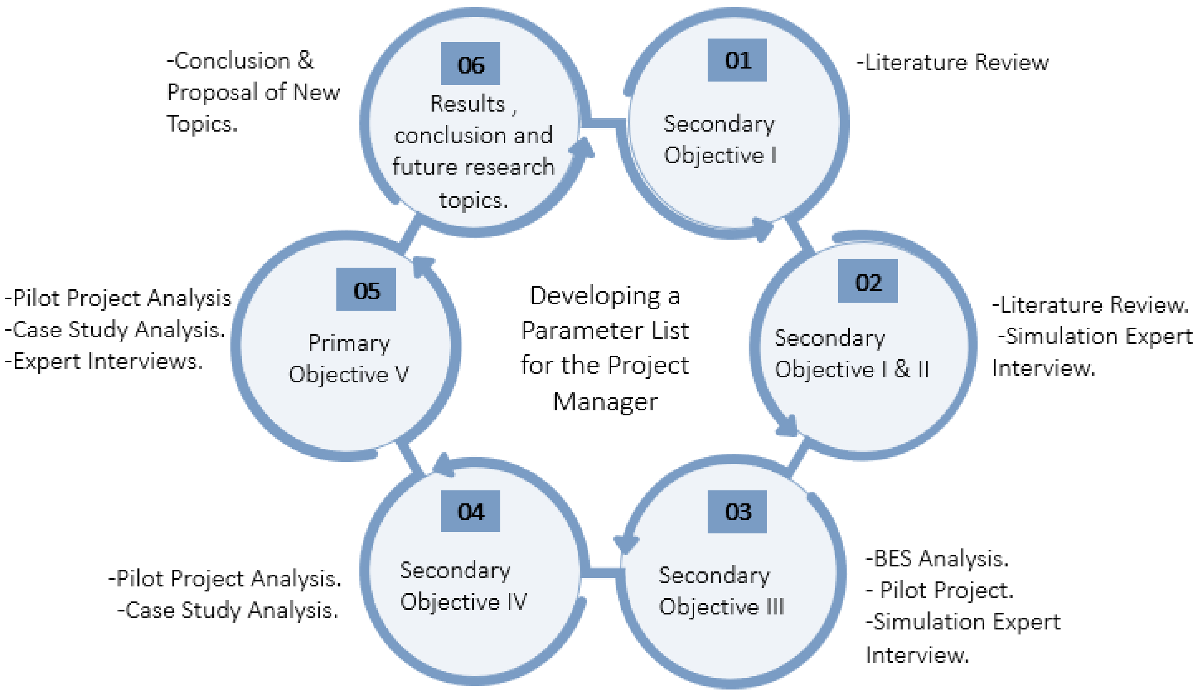


Figure 3: Phases of Thesis Work.
Source: (By Author,2020).

The study is descriptive-exploratory and considers three research techniques. The descriptive section gives a detailed insight into the BIM and BES, the parameters and attributes related to it. Whereas, the exploratory section focuses on the process of extracting the parameters, the phase in which it can be located and on establishing a template for the project manager.

There are three techniques explained to attain the objectives, i.e. Bibliography review, Semi-structured interviews, and EUREF case study analysis.

1. Literature review

Firstly, a literature review of primary and secondary literature related to the fundamental concepts of this study is conducted. The information is gathered online and through books in the library. The online database is narrowed down based on two main factors the quality of data and year of publication as new advancements are made in the AEC Industry every day. The time frame selected is in the span of the latest five years and the latest ten years. To maintain a good quality of research information, the database of the government websites, European standard report, manuals, and online sites (Mendeley, Research Gate, Google Scholar, Springer Link, OAPEN Library, Directory of Open Access and the Electronic Journals Library) are studied and researched.

2. Semi-structured interview

Secondly, an interview is conducted with an experienced energy simulator expert and industry professional, project managers to understand the feasibility of adopting early-stage energy simulation of the projects, existing techniques and loopholes in the full process of data exchange from BIM to BES software and interoperability issues related to it. The accuracy and reliability of the result extracted is also discussed in brief. The interview conducted is of non-standardized type as the questions are based on the flow of conservation and focus on the topics and objectives of the research (Mark Saunders, Phillip Lewis, 2009).

The experts are:

Energy Simulation Expert – Mrs. Sabine Krutzsch, EUREF project.

Industry Professionals – 1. Mrs. Angelika FehnKrestas, Tempelhof Projekt GmbH.

2. Mr Arnd Wittchen, SMV mBH.

The experts are industry professionals currently practising and with more than ten years of diverse work experience to their credibility.

3. EUREF case study analysis

Finally, EUREF HAUS 11 case study analysis is carried out. The project comes under Research campus Mobility2Grid which is an ongoing project (Research campus Mobility2Grid Main phase (EUREF research campus) is a public-private partnership created to research and innovate in the field of energy transition and electromobility in networked urban areas. The Hochschule für Technik und Wirtschaft Berlin (HTW) is a member of this organization under the direction of the Project leaders: Prof. Dr.-Ing. Nicole Riediger and Prof. Dr.-Ing. Friedrich Sick. More information: https://mobility2grid.de). The case study is selected as the author is an active participant in the project and the project goals align with the research objective of the thesis.

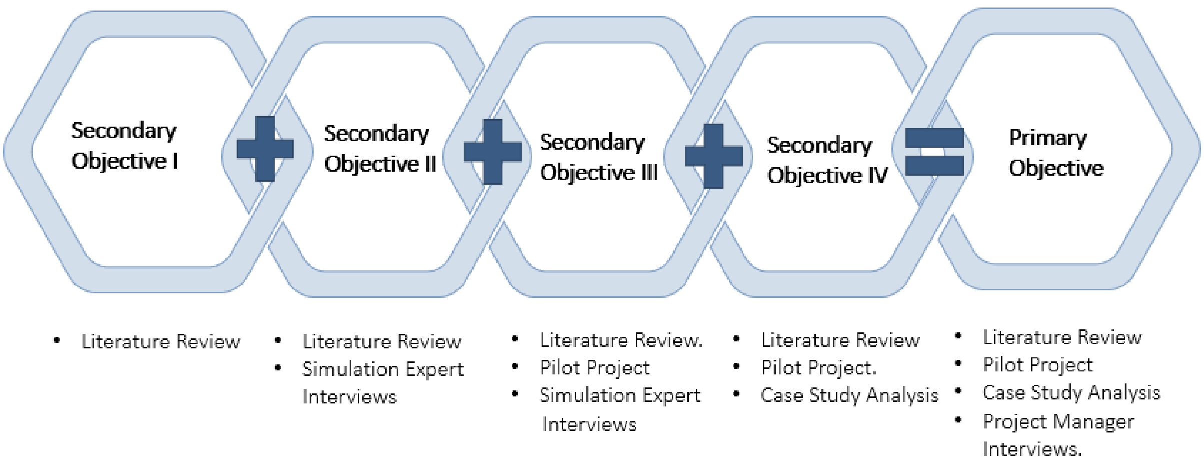


Figure 4: Research Techniques Defined for Each Objective.
Source: (By Author,2020).

Shown in the figure above (see fig.4) is a depiction of the research techniques adopted to gain qualitative and quantitative data. It should be noted that the quantitative data is generated based on the past studies conducted in the research field and the execution of the pilot project. In contrast, the qualitative information is gathered through reliable sources in literature and expert interviews conducted to structure up the process and validate the result.

2. CHAPTER – LITERATURE REVIEW

The building design is a collective and collaborative process by nature with several factors contributing to the technique spread across various disciplines. The whole process involves the exchange of information models multiple times. A BIM model is a 3D model consisting of parameters (roof, floor, wall, window) comprising of information about the elements (u value, cost, slope). These parameters are of utmost importance as the model contains valuable information to carry out structural estimations and energy analysis. These can play a significant role in cost estimation, clash detection, and facility management. The standard programs of BIM are ArchiCAD, Vector works, and the most widely used Revit (Kensek, 2015). Using BIM is of great advantage as the model is enriched with information, and it allows for the exchange of semantically rich 3D data models. BIM allows regular refinement of models at different phases as gradually the design and engineering decisions are made. These gradual refinements in terms of its geometric and graphic information can be termed as Level of Development (LOD) (Abualdenien and Borrmann, 2019).

However, there is a difference between the level of development and level of detail. The level of development refers to the reliability factor. To which point the AEC professionals can rely on the information concerning the development of the project. Whereas the level of detail is the measure of information, the model contains. If the project process follows the standards, then the two concepts coincide. By far, there is no clear explanation or definition of the uncertainty involved in each level or the requirements related to it (Abualdenien and Borrmann, 2019).

This chapter deals with the information on the subject of the different phases LOD's and all information regarding the attributes and parameters related to the process of energy simulation. Without this crucial information, it will be hard for the reader and researcher to understand the process, but the current research cannot be executed. The chapter will give a deep insight into the topics necessary for the flow of the study.

The first sub-chapter (chapter 2.1) gives a deep insight into different building phases adopted concerning different national standards and green building certifications. The second sub-chapter (chapter 2.2) provides a profound comprehension of the various stages in the design development of a project and the data or information available in each phase. In the third sub-chapter (chapter 2.3) focus is given towards understanding the concept of building energy modelling, the Workflow of energy simulation, information required to carry out productive simulation result, and the process of extracting these parameters from the model. After identification of the phases and parameters, the fourth subchapter (chapter 2.4) identifies the early design phases parameters attributes and develops a parameter inventory required in the early stages. The fifth sub-chapter (chapter 2.5) emphasizes the advantages of integrating the integrated design approach. The sixth sub-chapter (chapter 2.6) spotlights the benefits of the whole process to the client and project manager and all of this together forms a base for the third chapter Research Methodology (see chapter 3).

2.1 Building Design Process

The building design process comprises of design phases. Each of these phases has its own set of defined tasks and responsibilities. Sometimes these phases are tailor-made to accommodate specific client needs, but mostly these are standardized to create a strategic structure for a successful project (Svalestuen *et al.*, 2018). The management of these design phases is one of the most critical tasks for a project manager. The project stakeholders must understand the building process. It is to note that to have a productive project each phase should be planned in detail as phase interdependencies vary throughout the building process (Knotten *et al.*, 2015a)

2.1.1 The Building Design Phases as per National Standards (AIA, RIBA, HOAI)

The national standards that are currently majorly used for construction project- life cycle management are AIA, RIBA, and HOAI, respectively.

The American Institute of Architects (AIA), a professional association for architects in the United States (U.S.), which defines the phases of design to breakdown the work of the project and refer it as a standard for the architects and other design stakeholders to follow. The design phases are the framework of the design process (AIA, 2013).

The Royal Institute of British Architects (RIBA), a professional association in the United Kingdom (U.K.), they define and issue documents that standardize the various process in the lifecycle of a building project (Davies and Davies, 2020).

The Honorary regulations for architects and engineers (HOAI) is a federal law by the state of Germany to standardize the fee regulations for the architects and engineers according to the different design phases (Fachmedien, 2013).

Table 1: Comparison of Design Phases Following AIA, RIBA & HOAI.
Source: Adapted from (AIA 2013), (RIBA 2013), (HOAI 2013).

Plan of Work	Corresponding Design Phases of American, British and German Architects Plan of Work							
The American Institute of Architects (AIA)	0 Project Brief	1 Pre-Design	2 Schematic Design	3 Design Developmen t	4 Constructio n Documents	5 Bidding	6 Construction	7 commissioning 8 Occupancy
Royal Institute of British Architects (RIBA)	0 Strategic Definition	1 Preparation	2 Concept Design	3 Development Design	4 Technical Design	5 Construction	6 Handover and Closeout	7 In Use
Honorarordnun g für Architekten und Ingenieure (HOAI)	0 -	1 Fundament al Evaluation	2 Preliminar y Design	3 Final Design	4 Planning Permission Application	5 Execution Planning	6 Preparation of contract Award 7 Involvement in Contract Award	8 Project construction, supervision and documentation. 9 Post Completion Services

The table above compares the three different national standards (U.S.,UK & German) as per their plan of work concerning different design phases. It is to note that despite differences in the design phases adoption and responsibilities, the early stages of all the three standards are almost the same with the consistent understanding of requirements and deliverables.

HOAI is a federal ordinance that regulates the fee for architects and engineers in Germany (HOAI, 2013). It follows the principle of LOD, as the entire fee divides into the share as per the corresponding design phase. It provides a standard for the client and the architects to adhere to the work phase and make informed decisions regarding the process (Prozesse, 2018). HOAI has set out nine stages (Basic determination, preplanning, design panning, approval planning, execution planning, preparation of award, site supervision, and property management) of the whole integrated design process which clearly states the services to be carried out in relation with the phase (Fachmedien, 2013).

A LOD standard outlines the extent, nature, and accuracy of the data in a BIM model as per the work phase following HOAI regulations (AEC Process Engineering, 2013). The BIM-based services are included in HOAI as an additional service or task. However, BIM is an integral part of the project from the concept till construction and handover and cannot be justified to be just put as a service fee. The below-given figure is adapted from HOAI and elaborates the percentage of the payment received as per the different level of phase.

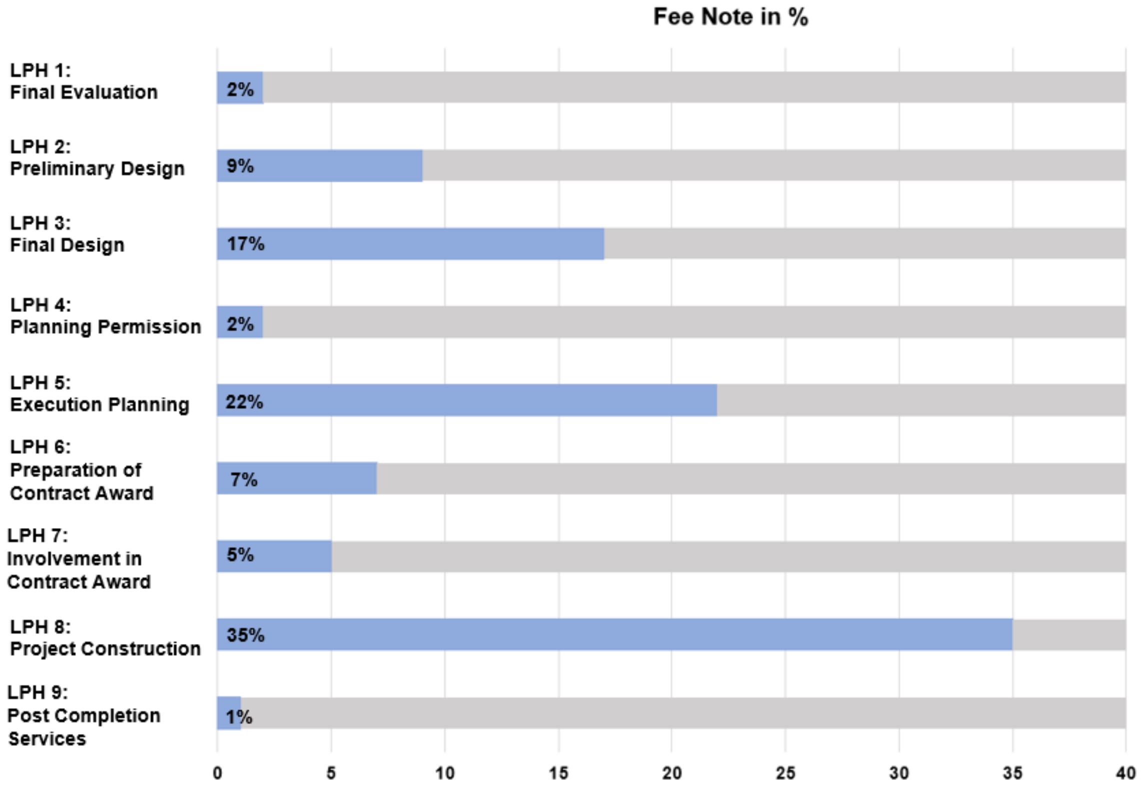


Figure 5: Fee Components According to HOAI.
Source: Adapted from (HOAI, 2013).

2.1.2 The Building Design Phases and Green Building Certifications (LEED, BREEAM & DGNB)

The design phases are the framework of the design process, which is crucial in delivering a sustainable building. It is vital to define the sustainable green objectives in the early phases of design to achieve an energy-efficient building. The approach adopted for the same is not as the traditional approach; hence, the decisions should be taken before the start of design phases.

There are numerous ways to accomplish sustainable development; one of them is the certification of buildings as per the sustainable Green building certifications (GBC) available in the market. The most used of these are Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Methodology (BREEAM), German Sustainable Building Council (DGNB) (Zimmermann *et al.*, 2019). The below-given table compares the different national standards based on schemes, ratings, and the process to be adopted.

Table 2: Comparison of Different GBC, Based on Schemes, Ratings, and Process.
Source: Adapted from (U.S. Greem Building Council., 2009),("BREEAM rating," 2020), (About us | DGNB, 2020).

	LEED	BREEAM	DGNB
Building type (schemes)	New buildings (Residential) New buildings (Commercial) Interiors (Residential) Interiors (Commercial) Renovations (Residential) Renovations (Commercial) Existing (Residential) Existing (Commercial) Urban areas (Residential and commercial)	New buildings (Residential) New buildings (Commercial) Interiors (Residential) Interiors (Commercial) Renovations (Residential) Renovations (Commercial) — Existing (Commercial) Urban areas (Residential and commercial)	New buildings (Residential) New buildings (Commercial) — Interiors (Commercial) Renovations (Residential) Renovations (Commercial) Existing (Residential) Existing (Commercial) Urban areas (Residential and commercial)
Ratings	Platinum (+80 pt) Gold (+60 pt) Silver (+50 pt) Certified (+40 pt)	Outstanding (+85%) Excellent (+70%) Very good (+55%) Good (+45%) Pass (+30%) Acceptable (-30%)	Platinum (80%) Gold (65%) Silver (50%) Bronze (35%)
Process* (Process varies depending on certification scheme used)	1. Submission of design phase documents to certification body for approval. 2. Submission of construction phase documents to certification body for approval.	1. Selection of Typology 2. Addition of an assessor to guide documentation 3. Submission to certification body for approval	1.Project online registration (online navigator assessment) 2. Addition of an assessor to guide documentation 3. Submission to certification body for approval

It is essential to understand which GBC to refer and follow based on the location of the project and requirement within the contract.

The Leadership in Energy and Environmental Design (LEED) has been established by the U.S. green building council, which focuses on the environment and social sustainability (U.S. Greem Building Council., 2009).

The Building Research Establishment Environmental Assessment Methodology (BREEAM) has been established in the United Kingdom (U.K) This was earlier used at a local level but is currently adopted all over Europe ("BREEAM rating," 2020).

The German Sustainable Building Council (DGNB) is developed in Germany and focuses not just on sustainability but also the process and technical quality. However, for the federal projects in Germany evaluation system for sustainable buildings ("Bewertungssystem Nachhaltiges Bauen") BNB is followed by the government (About us | DGNB, 2020).

It is evident from the table 2 that carrying out the early phases of Simulation helps in achieving the green building certifications which are now a pre-requisite requirement in most of the countries and helps the client and project manager in a better understanding of the whole process of sustainability in buildings.

Summary of 2.1

The main goal of the current sub-chapter was to understand the necessary building process and the phases within it. The Sub-chapter 2.1 compared the building phases of three prominent institutions AIA, RIBA & HOAI of countries the U.S., the U.K. & Germany respectively (see table1). Also, the renowned GBC certifications of these respective leading countries were discussed briefly. The association of GBC certifications (see table 2.1.2) with the tasks involved in the phases (see heading 2.1.1) were established.

The main findings of this current sub-chapter are that there is no standardized approach towards building process within different countries. However, the initial tasks and requirements in the early on phases are almost the same. Additionally, It is essential to understand and adapt energy goals early in the design phase to attain GBC certifications and should be mentioned in the contract. All of the points mentioned above forms a good base for the continuing chapters under the section of literature study.

2.2 The Level of Development in Design

The LOD specification illustrates the different phases of design through the gradual nature of the design process, enabling the practitioners to take quality decisions at the right time (Hooper, 2015). The LOD specification is developed by AIA and revised by the BIMForum yearly. The main objective of the specification is to classify and explain the model elements of the system according to their respective phases, which helps in the standardization of the model and makes the LOD's more reliable. The concept takes the design from the basic level of detailing and adds model elements and attributes to refine it to the advanced level at the higher end of LOD's (BIM Forum, 2019). The explanation of LOD's is through the textual classifications and semantic illustrations of the various model elements updated through the building life cycle. The LOD is reliable only when it depicts the accurate LOG and LOI, respectively, of the model elements (Abualdenien and Borrmann, 2019). As per AIA, guideline 2013 Level of development is the summation of four different factors which are 'Level of detail' (LOD), 'Level of Logic (LOL), 'Level of information' (LOI), and 'Level of coordination' (LOC) (AIA, 2013).

According to BIMForum level of development specification 2019, the AIA categorizes LOD into six levels, starting from LOD 100 to LOD 500, with LOD 350 in between to add as a combining interface for the building elements (BIM Forum, 2019). As shown in the figure 5, the LOD lies between the information deliverables and the contractual responsibility for information.

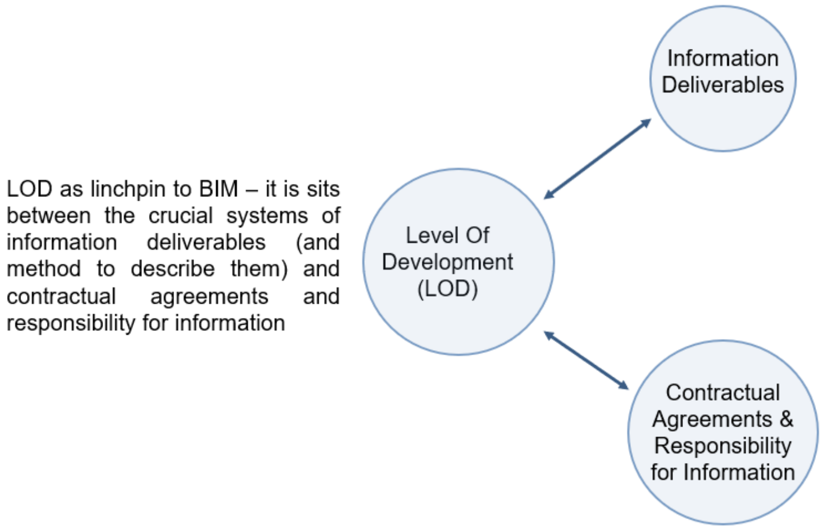


Figure 6: LOD as Linchpin to BIM.
Source: Adapted from (Hooper, 2015).

2.2.1 The Level of Development, LOD (100-400)

The building 3D model is composed of several elements, which are labelled objects. Each of these objects has a visual representation and characteristics associated with it. These objects are exported or analyzed based on different criteria such as cost, number, energy and others. For a successful interpretation, these objects should contain information. The model without any object information is not a digital model but an architectural model. The digital models have no scale, concerning this issue, the AIA established LOD, as a unifying common thread internationally to understand the geometric resolution and degree of detail in the BIM models (Borrmann *et al.*, 2018).

It is to note that for this research, only four LOD's (L.O. D 100-400) are considered. As LOD 500 is the as-built model and does not fit the criteria of this result. The focus of this research is on the early phases of LOD, which is LOD 100 & 200. Different LOD's have been discussed briefly in the following paragraphs.

LOD100

LOD 100 is termed as the conceptual model and represents a generic model with no geometry and shape information (BIM Forum, 2019). German BIM guidelines focus on LOD 100 as the preliminary design (Modeling, 2020).

LOD200

LOD 200 is termed as approximate geometry and represents placeholders with approximate geometry and shape information (BIM Forum, 2019). German BIM guidelines focus on LOD 200 as the draft design (Modeling, 2020).

LOD300

LOD 300 is termed as precise geometry and represents the elements according to size, shape, quantity, location, and orientation information (BIM Forum, 2019). German BIM guidelines focus on LOD 300 as the approval design (Modeling, 2020).

LOD400

LOD 400 is termed as suitable for construction documentation and represents the assembly, fabrication, detailing, and installation information (BIM Forum, 2019). German BIM guidelines focus on LOD 400 as the execution design (Modeling, 2020).

LOD500

LOD 500 is termed as-built documentation and represents actual site representation of elements (BIM Forum, 2019). German BIM guidelines focus on LOD 500 as the object documentation (Modeling, 2020).

The figure below illustrates the information visually according to the LOD's phases as per the exterior and interior of the building (Agugiaro, Hauer and Nadler, 2015).

LOD is a critical project management tool. However, the concept of LOD is to provide transparency and certainty about the model elements, not the building model as a whole identity (NATSPEC, 2013).

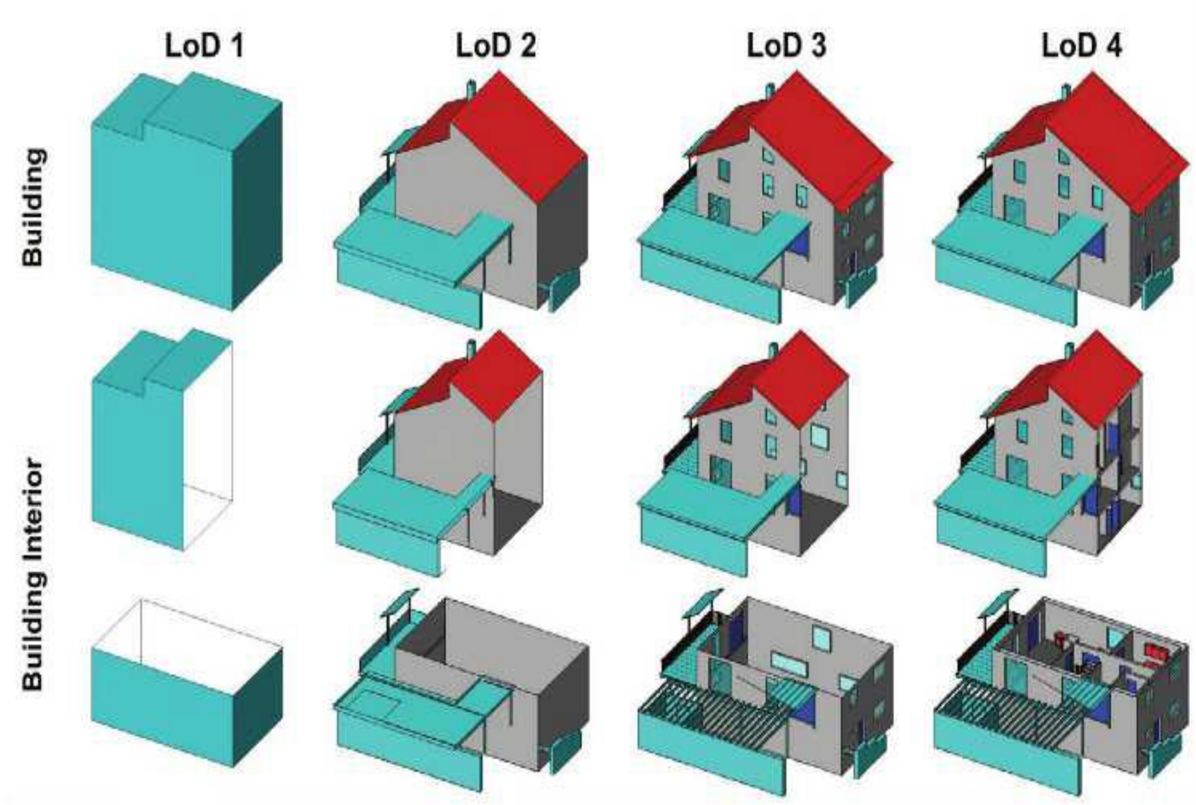


Figure 7: Visual Representation of Different Levels of Detail (LOD).
Source: (Agugiaro, Hauer and Nadler, 2015).

In all, LOD is an excellent way to check the model's reliability (Abualdenien and Borrmann, 2019). On the other hand, there has been certain arguments and discussion regarding the number of levels (five phases) are not adequate to encapsulate the overall development of a project and the risk of uncertainty is relatively high in this case (Biljecki, Ledoux and Stoter, 2016). There has been quite researching done about providing a refined series of more detailed phases based on currently available models and literature data.

One such example is the given figure below where there are 16 LODs version (four refined versions for the LOD 0-3). As per the studies, these are more standardized and provides low ambiguity.

The conclusion drawn after running operations through these 16 variants was that each of them has a different geometric version and thus outcomes are different results in the spatial analysis (Biljecki, Ledoux and Stoter, 2016).

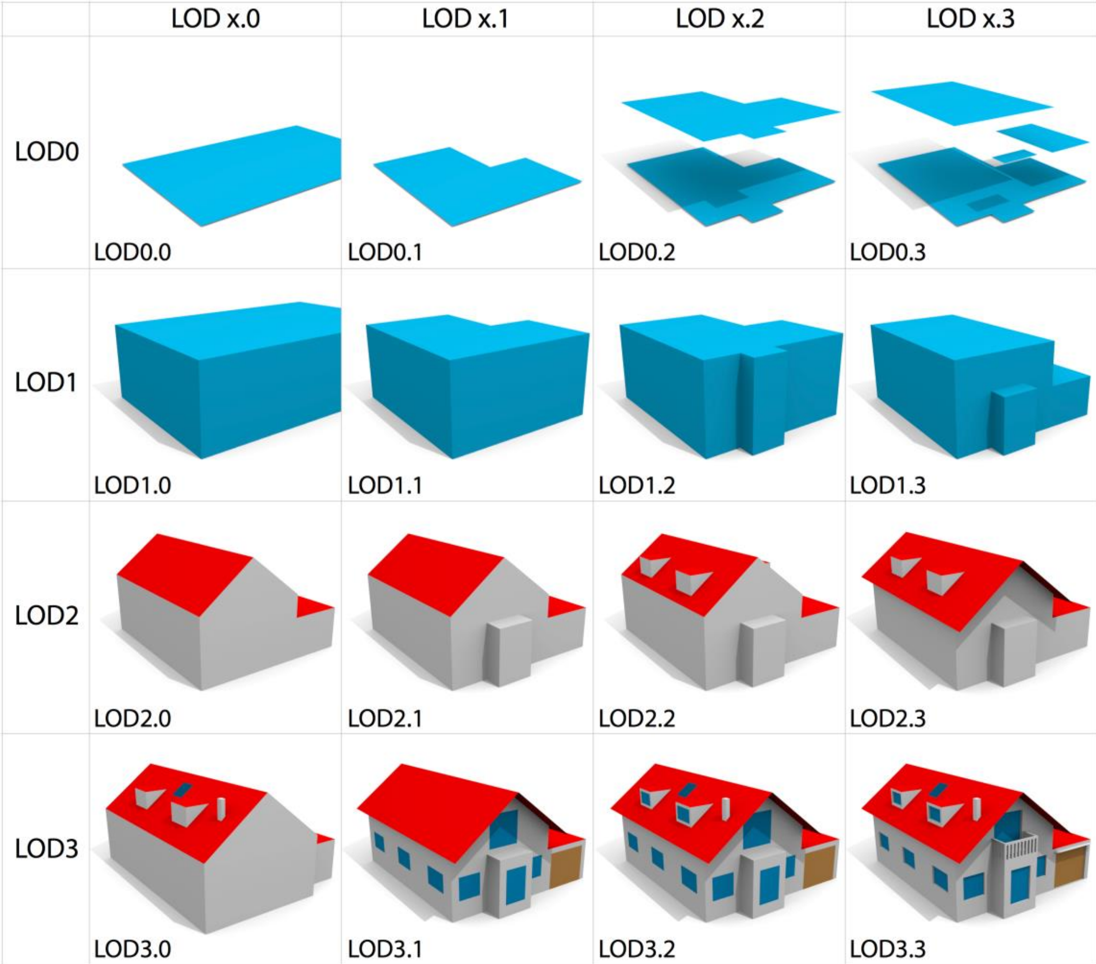


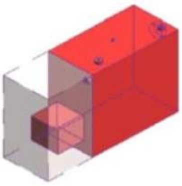
Figure 8: Visual Representation of the Refined LOD.
Source: (Biljecki, Ledoux and Stoter, 2016).

2.2.2 Parameters List in Different Phases

Based on the literature review and researches carried out following LOD, the below table comprises a list of parameters or attributes that can be extracted out in different phases of LODs. Parameters are associated with the model element as they contain and transmit information about the model elements. They are used in Revit and are used to identify and revise elements. Thus, they play a vital part in the LOD concept as the level of information, detail and geometry of these model elements stored up in parameters progresses with the model. (About Parameters in Models | Inventor 2020 |

Autodesk Knowledge Network, 2020). Below is the table of different LOD's concerning the parameters the model element contains in a specific LOD.

Table 3: List of Parameter in respect to the LOD.
Source: Adapted from (NATSPEC, 2013).

LOD	VISUAL INTERPRETATION	PARAMETER LIST
Lod 100 Conceptual		• Volume • Area • Orientation
Lod 200 Approx. geometry		• Approx. quantities • Approx. size • Approx. position • Orientation • Non-graphical information
Lod 300 Precise geometry		• Specific quantities • Specific size • Specific position • Orientation • Non-graphical information
Lod 400 Fabrication		All the parameters of LOD 300 • Detailing. • Fabrication. • Assembly. • Installation • Non-graphical information
Lod 500 As-built		Confirmed presentation • Size • Appearance • Position • Quantities • Orientation • Non-graphical Information

Summary of chapter 2.2

All in all, to perform energy simulations successfully, the concept of LOD and parameters needs to be understood clearly. The level of development is a combination of the level of geometry and level of information (non-geometric detail). In a project, LOD100-200 comes under the planning phase, LOD 200-300 comes under the approval and draft design further LOD 300-400 for the planning phase and LOD 500 as built for construction documentation. LOD defines the design information in each phase and considerations for carrying out simulation analysis. The given table below explains what type of analysis can be carried out in which phase.

Table 4: Analysis concerning LOD.
Source: Adapted from (NATSPEC, 2013).

	LOD 100 Conceptual	LOD 200 Approx. Geometry	LOD 300 Precise Geometry	LOD 400 Fabrication	LOD 500 As-built
Analysis	Analysis based on Area, Volume, orientation by application of generalized performance criteria assigned to other Model elements.	Performance Analysis of selected systems by application of generalized performance criteria assigned to the representative model elements.	Performance analysis of selected systems by application of specific performance criteria performance criteria assigned to the representative model element.	Performance analysis of systems by application of actual performance criteria assigned to the model element.	Performance measured from installed systems.

2.3 Building Energy Modeling & Building Energy Simulation

The energy model in the most exact word is the use of computer-based programs as a calculation engine to deliver outputs such as building performance, efficiency and others from the inputs of building data such as geometry, form, shape, orientation, and operations. As with any software, all energy modelling software differ in terms of their workflow, inputs they accept, and the integrity of their interfaces (AIA, 2012).

Building energy simulation is a computer-based analytical process, which helps in identifying and calculating the energy demand and performance of a building in the design phase before the construction. The most critical aspect of an energy simulation is the input, for the software to accurately predict the energy loads and demands the input has to be accurate and in detail. This input requires experience, expertise and good software skills as the reliability and accuracy of the result depends on the quality of data inserted in the energy model (Toth and Arch, 2017) The below-given figure illustrates most simply what is an energy model.

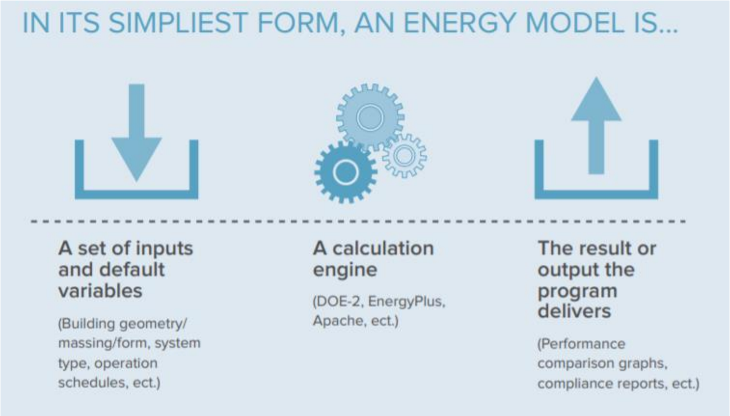


Figure 9: Energy Model Workflow.
Source: (AIA, 2012).

When carrying out the building energy simulation, several factors are needed to explain the characteristics of the building to be simulated. The input information is stored within a model element. Below given table highlights some of the critical model elements and their essential information (AIA, 2012).

Table 5: Model Element in Relation to Input Information.
Source: Adapted from (AIA, 2012).

MODEL ELEMENT	INPUT INFORMATION
Architectural massing and form	• Building shape & orientation, • Principal building function, • Total floor area, • Number of floors & thermal zoning of floors, • Floor to floor height & floor to ceiling height.
Envelope	• Window dimensions (for different locations), • Windowsill and head height (above floor), • Window to wall ratio. • Window & skylight characteristics (SHGC, U-value , VLT, frame –type), • External shading geometry. • Wall, roof & foundation construction makeup. • Interior partitions , internal mass and infiltration assumptions.
Internal loads	• Anticipated building occupancy, lighting power density, plug-load density & exterior lighting peak power. • Daylighting and occupancy sensors to be used • Elevators.
Internal loads schedules	• Anticipated occupancy, lighting , plug load & exterior lighting schedules (summer/winter, weekday, weekend, holiday hours of use)
HVAC equipment & schedules	• Type of system. • Size(efficiency , capacity etc.) • Schedule of operation and controls.

Building Energy Modeling is an umbrella term used for building energy simulation software programs such as (EnergyPro, eQuest, TRNSYS, Green Building Studio, etc.)

selected as per the need of the project as each project is unique. The purpose of this software is to calculate heating and cooling loads, HVAC size, and the thermal comfort of the inhabitants (Kensek, 2015). The objective of using an energy simulation tool is to analyze the energy performance of a building so that it utilizes a reduced amount of energy. Currently, with the awareness regarding sustainability and advancement of technologies, numerous energy analysis tools have taken over the market and can be used during the different life cycles of the project. However, things to consider is the reliability of the software as they come with their complexity and limitations. The whole process of energy simulation has a lot of ambiguity and assumptions. The issues with data exchange and interoperability is a significant concern, and a lot of the information must be inserted manually (Li, 2017).

2.3.1 Workflow of Energy Simulation

With an array of energy simulation tools available, it is now feasible to carry out the complex energy simulation process with additional variables and meticulous methodology. The given figure illustrates the simulation workflow straightforwardly

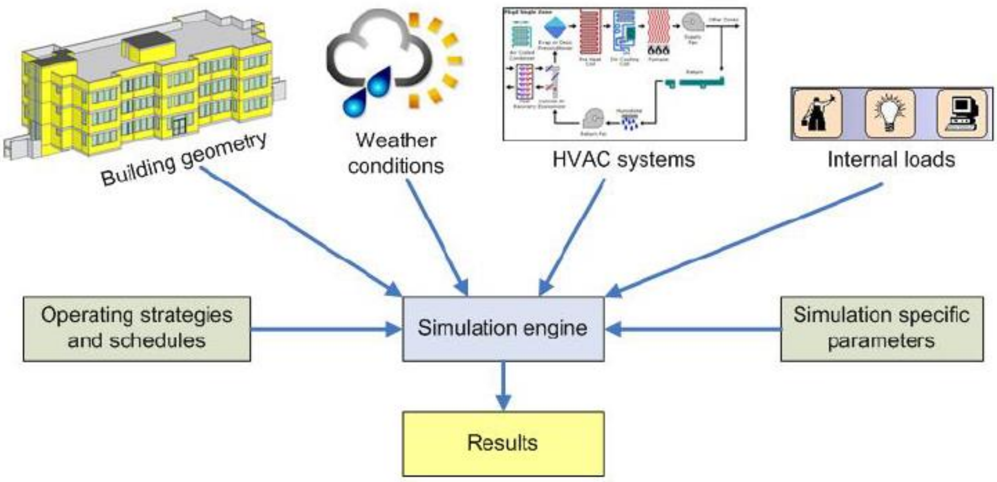


Figure 10: Simulation Workflow.
Source: (AIA, 2013).

All the Workflow goes through a necessary three-step process, as discussed below (Sousa, 2012).

1. **Building Modelling**
2. **Building Simulation**
3. **Result Analysis**

Building Model

The first step is the modelling of the building which can be carried out in three ways. First option is to create two separate 3D models for design and energy simulation, the second option would be transferring the model in formats of gbXML or IFC into the simulation programs. The third would be using a plug-in where the modelling software connects to the simulation software (Kensek, 2015). It is crucial to give inputs such as geometry, size, and materials of the building components (Sousa, 2012). It should be noted that the whole process is not as simple as stated above, despite the efforts of software companies in trying to make the whole process seamless and reliable. One such option that is being evaluated currently is the process of connecting the model to the simulation software in a visual programming setting that can allow the direct transfer of information through common work setting even if it is created by distinct developers (Kensek, 2015).

Building Simulation

The second step is to identify the variables that need to be held for Simulation. As the thermal efficiency of a building depends on its type, usage, and services, these attributes ought to be defined in detail to calculate the ventilation and Internal load (Sousa, 2012).

Result Analysis

The third and final step is to check the results. The simulation software issues warnings regarding the error or incompatibility of the variables. The most important factors to be considered are the physical environment, building systems, HVAC systems, human aspects, location, and weather characteristics (Sousa, 2012).

The main aspects of the Workflow of the Simulation are

- Location and weather conditions
- Physical factor
- Building structure
- Usage

The below-given figure illustrates the ideal workflow of the simulation process incorporating BIM as a digital model software.

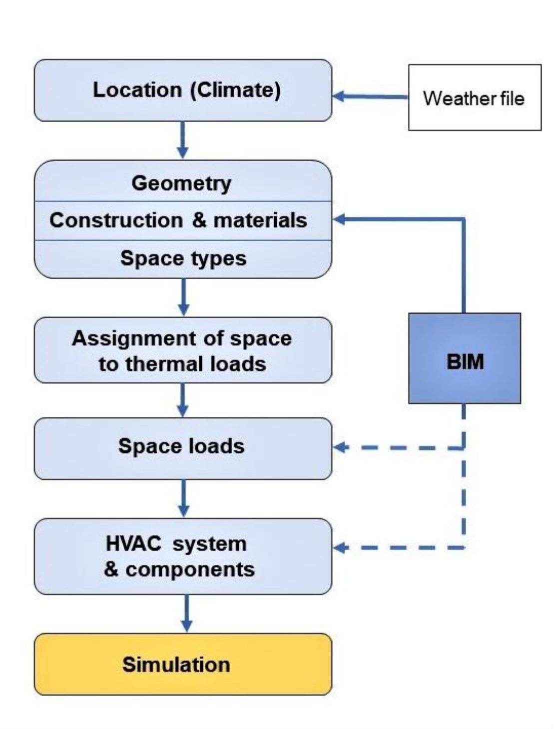


Figure 11: Ideal Workflow of BES Tools.
Source: Adapted from (Maile, Fischer and Bazjanac, 2007).

2.3.2 Selection Criteria for a Simulation Tool

At present, an overwhelming breadth of choices of the simulation software is available in the market. It is essential to evaluate which tool should be used according to the user need and project specifications. As software companies rarely explain the incompetence and limitations of a tool. Hence the research carried out (Attia, Hensen, *et al.*, 2012) has laid out a detailed study on how to select the simulation tools which is at first according to the user's requirement and second according to the BPS ranking of tools. Which maybe is shortly a metric to justify the cost and benefits of each BPS tools to fit the idea and perspective of the users. The main objective is to select a tool that is user friendly, adaptive, accurate and can be used in the entire lifecycle of the project (Attia, Hensen, *et al.*, 2012).

The purpose of providing selection criteria is to simplify the process by listing the critical factors to focus on while selecting the tool. The main benchmarks for selection are usability and information management ability of the software, the accuracy of these tools in simulating complex projects, minimum interoperability issues and seamless data transfer between different software, design decision support and optimization capabilities, the adaptive nature of the tool to fit in for various stages of the building process, the software should permit diverse user type to carry out simulations in the design phase. The BPS is also common ground between different practitioners such as architects and engineers with different data needs from the tool. (Attia, Hensen, *et al.*, 2012). The below figure states the five main factors on which the selection of BPS tools should be based.

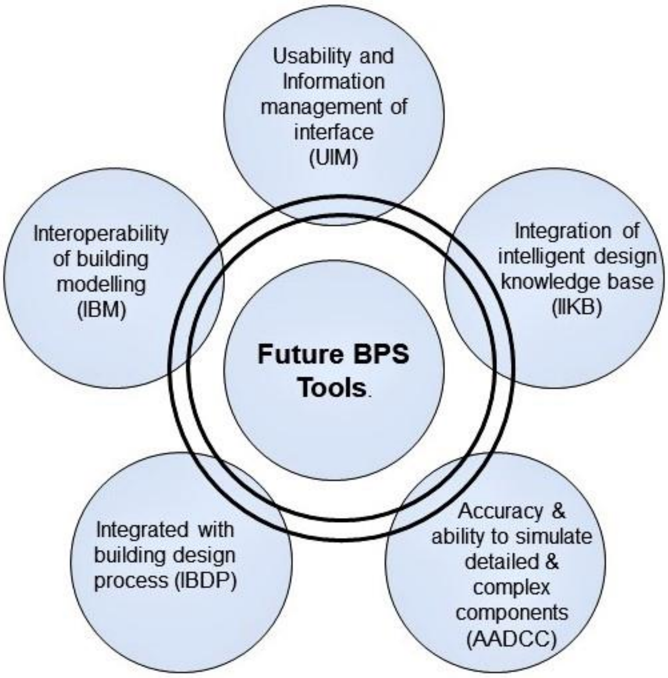


Figure 12: The Selection criteria for BPS Tools.
Source: Adapted from (Attia *et al.2012).*

The five criteria to be considered for the selection of tools are explained briefly in the paragraph below (Attia, Hensen, *et al.*, 2012).

1. **UIM**

   The UIM of the interface means usability and information management of the tool. The usability integrates the functional procedure of a tool such as output and input data, and the information management is accountable for the quality of input, assumptions, and information entry.

2. **IIKB**

   The IIKB of the interface means the Integration of an intelligent design knowledge base. The intelligent design means optimizing the design process, and the knowledge base is responsible for qualitative and quantitative results of the design decisions.

3. **AADCC**

   The AADCC of the interface means the accuracy of the tools and the ability to simulate detailed and complex building components. As the name suggest, this is one of the critical responsibilities of the simulation tool and should be given utmost importance.

4. **IBM**

   The IBM of the interface means interoperability of building modelling; this is related to the competency of the tool in storing and sharing of the information with one virtual representation.

5. **IBDP**

   The IBDP of the interface means integration with the building design process. This highlights the tools competencies in terms of the whole building design delivery stages incorporating multidisciplinary interfaces.

2.3.3 Identification of Parameters in Different Design Phases

Several research and studies have been conducted to understand the relevance of the parameters following their energy features. The energy attribute contributes to its current phase in BES software but can be utilized for future optimization. The significant decisions tend to be made in the early design phases such as decisions about the HVAC and ventilation systems, building systems and façade, etc. The process of sensitivity analysis and optimization are the methods used to identify the relevance of the energy elements. Research and previous studies show that factors like building airflow, volume, shell, thermal properties, and heat efficiency determine their consumption (Li, 2017).

Numerous researchers have studied the sensitivity analysis and its impact on the final energy requirements. (Pacheco, Ordóñez and Martínez, 2012) the paper analyzed sustainable energy buildings and concluded that the most responsive inputs are the shape and volume of the building, its orientation, and the ratio of the external shell. Similarly, (Ourghi, Al-Anzi and Krarti, 2007) recommended a straightforward calculation encompassing building type, glazing, and relative density of a commercial structure. Similarly, (Flager *et al.*, 2009) and (Wang, Gwilliam and Jones, 2009) concluded that the most classified aspects are a type of wall, window to wall ratio, building systems, roof system, shading, air infiltration, thermostat, length of the building, service equipment and u- values of the materials used. Below is the list of Parameters according to its design phase (Li, 2017).

Table 6: Parameter List following the Design phase.
Source: Adapted from (Li, 2017).

OUTLINE STAGE	SCHEMATIC STAGE	DETAILED STAGE
• Orientation (appraisal) • U-values (opaque/ transparent) • Heat recovery systems • Light/Heavy construction • Air change rate (appraisal) • Space usage • Glazing area (appraisal) • Floor plan depth • Fuel type	• Glazing area (detailed) • Glazing type. • Shading/blinds. • Blind control. • Orientation (adjusted) • Air change rate (detailed) • Material adjustment in overheating areas. • Lighting strategy.	• Heating systems. • Heating control strategies. • Cooling systems (mechanical/free) • Cooling control strategies • Ventilation strategies

The Monte Carlo method suggests testing the combinations of variables randomly to carry out the optimization. The optimization can be carried out via the method of genetic algorithm or parametric run (Li, 2017). The concept of the parametric run is highly feasible if the building type is known beforehand and undergoes certain limitations when exposed to a variety of building types with a different pattern of designs (Harding *et al.*, 2013). To explore several design options, real-time feedback can be carried out via available parametric software such as Grasshopper, DesignScript, Rhino, etc. Highly predominant parameters are outer building shell, length, width, height, orientation, etc. (Civil, 1993). Despite the separate agenda and aim or process of the research, the common factors in the process of energy simulation are stated below (Li, 2017).

In terms of buildings

1. U-values (roof, floor, wall, windows).
2. Airtightness.
3. Aspect ratio.
4. Thermal bridge.
5. Heat recovery.
6. Airflow.

Based on location

1. Weather conditions.
2. Geography.
3. Orientation.
4. District heating.

2.3.4 Tools Associated with Building Energy Simulation

The **integrated cad tools** are considered excellent in the process of energy simulation as they generate the 3D energy models internally which is more time-efficient than the models generated by the energy software which are even susceptible to more mistakes. The most commonly used cad tools are Autodesk Revit, Graphisoft, ArchiCAD, and SketchUp (Li, 2017). BIM is considered to be the best as it provides simplified integration with the performance simulation tools by representing the building as coordinates and integrated database and aids in selecting the best building orientation and shape (Azhar, Brown and Farooqui, 2009).

The **energy simulation engines** are the software used to perform the energy predictions where they usually provide design alternatives by comparing the simulation results of different design variations. There are various simulation tools currently in the market with slightly different file formats. Some of the most used tools are DOE-2, Energy plus, ESP-r, IDA ICE, TRNSYS, IES-VE, etc. As per research, TRNSYS is the most advanced energy simulation tool but with the drawback of connectivity issues for the import and export of cad files. In this case, the other software work better (Sousa, 2012).

The below-given table is a comparison of different energy modelling tools available in the market. It is noted that the tools are compared based on five main contributing factors i.e. the calculation engine, whether it is free to use or not, the graphic interface, whether it is suited for early-stage Simulation and code compliance. The comparative table is the result of literature research studied.

Table 7: List of Building Energy Modeling Simulation Tools.
Source: Adapted from (AIA, 2012),(Li, 2017),(Oh *et al.*, 2018),(Johari *et al.*, 2019).

ENERGY MODELLING TOOL	CALCULATION ENGINE	FREEWARE	GRAPHIC INTERFACE FROM FRONT END INPUT	GRAPHIC RESULTS PROVIDED	FOR EARLY PHASE DESIGN SIMULATIONS	FOR CODE COMPLIANCE MODELLING
COMFEN (RESFEN-residential)	EnergyPlus	Yes	Yes	Yes	Yes	No
DesignBuilder	EnergyPlus	No	Yes	Limited	Yes	Yes
Ecotect	CIBSE Admittance Method	No	Yes	Yes	Yes	No
EMIT1.2	None (spreadsheet)	Yes	No	Not specifically	Yes	No
EnergyPro	DOE-2.1 E	No	No	No	No	Yes (easiest to use)
eQUEST	DOE-2.2	Yes	Yes	No	Must be far enough along to input HVAC	Yes (most popular)
Green Building Studio/Vasari	DOE-2.2	No	Yes	Yes	Yes	No
Hourly Analysis Program (HAP)	Transfer Function Method	No	Limited	No	No	Yes
IES Virtual Environment	Apache	No	Yes	Yes	Gaia+Toolkit yes Pro requires input of HVAC	Yes
OpenStudio	EnergyPlus	Yes	Yes (similar to sketchup)	Yes	Must be far enough along to input HVAC	Yes
Sefaira concept	Sefaira	No	Yes	Yes	Yes	No
Simergy	EnergyPlus	Yes	Yes	Limited	Not yet	Yes
TAS	TAS	No	Yes	Yes	Yes	Yes
TRACE 700	TRACE	No	No	Limited	Must be far enough along to input HVAC	Yes
TRNSYS	TRNSYS	No	Yes	No	No	No

Visual programming tools are the languages that provide a bridge for a smooth workflow between BIM and BES. They help in providing a neutral file format exchange between the software and the capability to modify the attributes of the 3D models. Some of the standard visual programming tools used in energy simulation are Grasshopper and Dynamo etc. Dynamo is a plug-in for Revit that allows to parameter variation in Revit. Python is the programming language on which both Grasshopper and Rhino is based and creates many aspects for architects to use Revit and Rhino (Skolan, Arkitektur and Samhällsbyggnad, 2016).

2.3.5 Research Gaps in Simulations

Interoperability issues

Interoperability is the capability to transfer data from one software to another. As building construction is a collaborative process between different stakeholders using different tools and demanding different data from the model, interoperability has become one of the substantial issues. The AEC industry currently is dealing with the lack of interoperability between different software as this software is usually owned by different companies (Abualdenien and Borrmann, 2019). For import and export of 3D geometry file formats such as DWG, DXF, etc. are majorly used. The file formats commonly used are IFC and gbXML. Despite all the advancements neither of the processes is free of uncertainty or ambiguity. The companies use the file formats as per their convenience and sometimes generate some program that follows their Workflow. To avoid substantial mistakes, companies generally prefer modelling two separate models for design and Simulation. Which limits the potential of the software and the process as a whole (Kensek, 2015).

Uncertainty

As the early stages are associated with high uncertainty due to the decisions made in this phase, impact of energy simulations can be analyzed in this phase. Thus to run the simulations in this phase, it is usually integrated with information uncertainty (Hopfe and Hensen, 2011). It can be used as a broad term to define the missing information or vagueness in the data. This anonymous information can be variable which can have a significant impact on deciding the energy efficiency of a given project such as building shape or spatial structure (Hawer, Schönmann and Reinhart, 2018). The uncertainty can be majorly of four types:

- Specification
- Modelling
- Numerical
- Scenario

Physical and design uncertainties have an impact on the early phase of simulation. The goal of being informed about the uncertainty is to provide the concerned stakeholders with the opportunity to make early design decisions by using “quantitative calculation of the performance pointers” (Sanguinetti, Eastman and Augenbroe, 2009).

Fuzziness

Fuzziness is a term generally used in the early design phase to state an attribute that has a lack of information or knowledge due to its design phase. Thus, one can say the first energy simulations always have a degree of fuzziness in its results. This range of fuzziness is based on empirical research, and the missing information is usually completed with assumptions. Thus, the results of early-stage energy simulation are always affected by the quality of assumptions and a range of fuzziness (Schneider-Marin *et al.*, 2020).

However, factors such as uncertainty and fuzziness in the early stage of LOD cannot be termed as bad as these can be the motivating force behind the early-stage analysis. For these parameters, the maximum and minimum range of fuzziness is anticipated, creating the opportunity of uncertainty analysis. Thus, lack of information provides the prospect of uncertainty and sensitivity analysis which further helps to know about the building and improve its concept (Scholl, 2019).

Summary of Chapter 2.3

To sum up the current subchapter, the main benefit was to understand in detail the Workflow of the building energy simulation. As buildings are complex structures and every project is unique, interdependent on various stakeholders and can be enormously affected by external factors. Where building energy simulation can be of much aid in the design and optimization of the building process throughout its life cycle. However, a large amount of ambiguity is found in the results of the measured and actual building energy, which makes it essential to analyze the whole building energy simulation and modelling workflow.Thus, for the current use, the workflow, parameters, and limitations should be considered while incorporating BES to gain the best possible optimized results.

2.4 Early Design Phase

The preliminary and conceptual phase is generally termed as the early design phase. (Kraft and Nagl, 2007). Uncertainties in the early design phase provide an excellent opportunity to incorporate the simulations, as the decisions are not yet made (Knotten *et al.*, 2015b). Several studies have claimed there is a huge potential in integrating information uncertainty and utilizing the capabilities of early phase energy simulations (Struck, Kotek and Hensen, 2007). However, a large amount of disparity occurs when simulations are carried out in the early phases (Menezes *et al.*, 2012). It can be stated that the lack of decisions, information, and inserting approximate attributes based on past studies and research contribute to the ambiguity (van Dronkelaar *et al.*, 2016). Hence, it is recommended that the uncertainty should be communicated and clarified in each phase to be incorporated in the decision making process by the project stakeholders (Sanguinetti, Eastman and Augenbroe, 2009). Below given image highlights the benefit of using BEM early in a design process which results in high performance integrated project delivery.

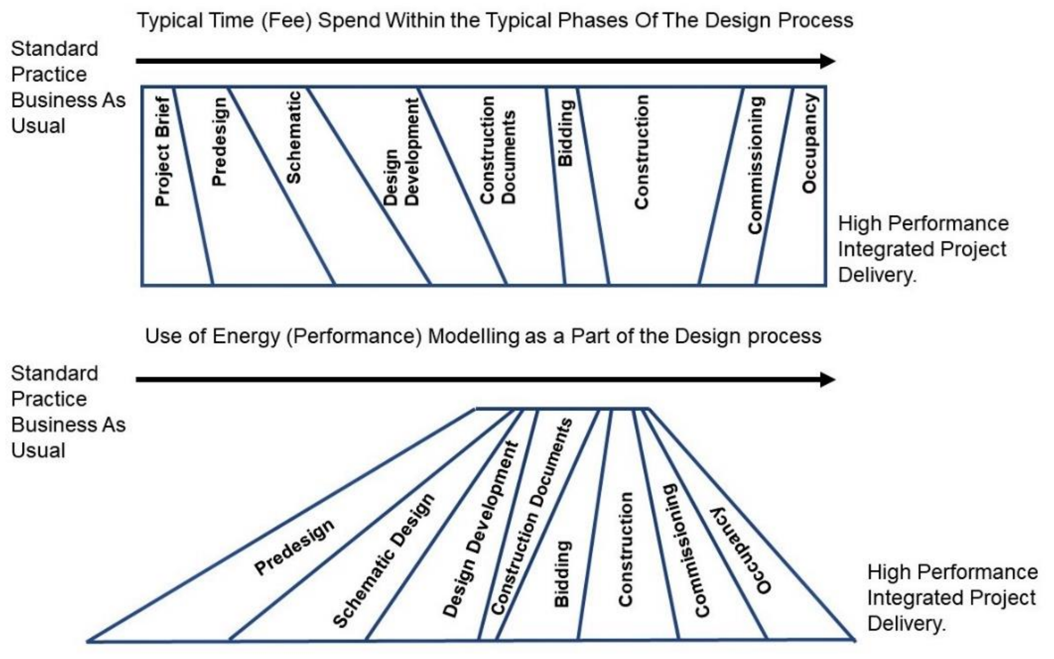


Figure 13: Incorporating BEM in Early Phases of Design Process.
Source: Adapted from (AIA, 2012).

In the early stages, the emphasis is on building structure, shell, and interior organization (Struck, Kotek and Hensen, 2007). Currently, many tools exist in the market which generates detailed design and makes the model look precise and complete, but this leads to false assumptions and analysis as the data inserted in most of the cases is not accurate (Cavieres, Gentry and Al-Haddad, 2009). In addition to this, the LOD also contains a lot of disparity and uncertainties within them.

To solve this issue, there have been in-depth studies about introducing a multi-LOD meta-model that represents the uncertainties and introduces flexibility in information management. Based on the approach of defining the uncertainty of parameters in the early phase and allocating a suitable value to these attributes to enhance their performance and allow informed decision making (Singh and Geyer, 2020). The below given figure demonstrates the parameter uncertainty in the multi LOD model.

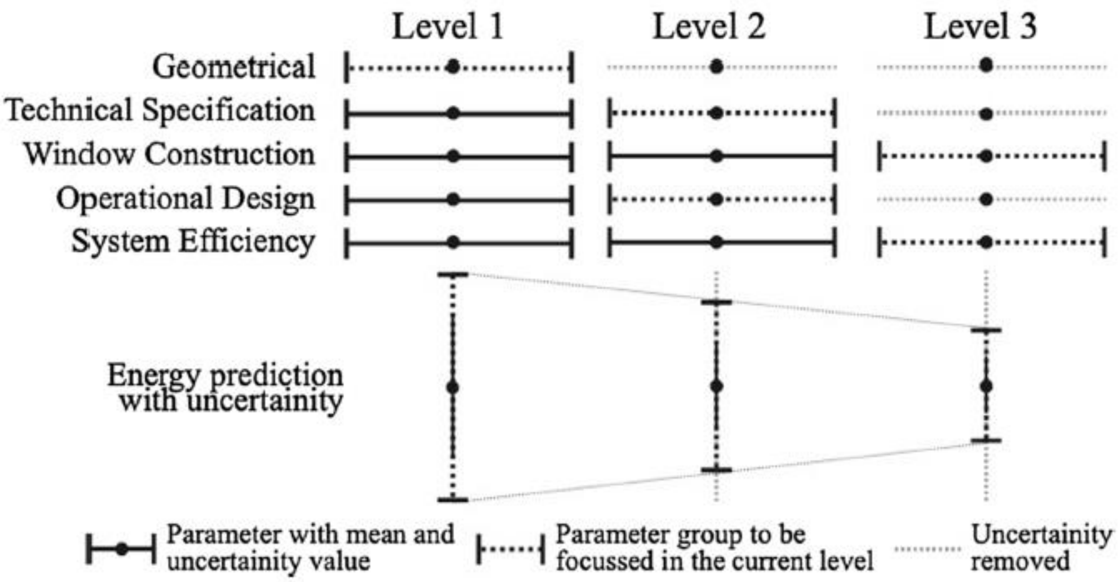


Figure 14: Uncertainty in Parameters in Multi-LOD.
Source: (Singh and Geyer, 2020).

2.4.1 Early Design Phases Energy Simulation

The table 5 (see heading 2.3.4) showcases several BEM tools, and few of them can be used to calculate energy performance for decision making in the early phases of design. The same simulation can be followed throughout the building phases by increasing the subsequent level of detail with appropriate design details. To get an approximate accurate result, most of the simulation tools require information about building systems that are not available in the early design phase, and hence numerous design performance modelling DPM tools exist to assist in decision making in the early phases of design. The limitations with these tools are that they can only provide early-stage Simulation, not for the life cycle. These are usually developed as an individual program that does not assimilate easily with other programs and packages. The table below developed by the author studying various sources mentions some of the tools that can be used for early-stage energy simulation (AIA, 2012).

Table 8: Early Design Simulation Software Tools.
Source: Adapted from (AIA, 2012), (Li, 2017) (Oh *et al.*, 2018), (Johari *et al.*, 2019).

EARLY DESIGN PERFORMANCE MODELLING TOOL	ADVANTAGES	LIMITATIONS
ECOTECT	• Somewhat REVIT/ AUTOCAD compatible . • Graphic Intuitive understandable results. • Easy user interface to adapt and learn	• For purchase software • Not well supported • Models not back compatible
OPENSTUDIO	• SketchUp –style input models. • Freeware. • EnergyPlus analysis engine. • Easy to use if familiar with SketchUp	• Only provides numeric output (currently no graphic results) • SketchUp not yet compatible with AUTOCAD/REVIT/ArchiCAD, etc. • Some training on defining components that E+ understands required.
COMFEN (Commercial Projects) RESFEN (Residential Projects)	• Very easy to use • Freeware • Well supported (LBNL – helpdesk) • EnergyPlus analysis engine. • Graphic intuitively understandable results. • Provides the broadest range of performance implications (including energy)	• Provides only envelope alternatives analysis (doesn't address mechanical or electrical system alternatives specifically) • Only assesses performance of a single zone (does not address a whole building) • Not yet compatible with AUTOCAD/REVIT/ArchiCAD, etc.
Spreadsheets (RMI-EMIT 1.2)	• Easy to use if familiar with spreadsheets freeware.	• Only assesses specific components (does not address a whole building) • Provides numeric output with only basic graphic results.
Sefaira	• User friendly with SketchUp type input environment. • Is a whole building model (can specify conceptual mechanical systems) • Graphic institutively understandable results. • Allows comparisons of multiple options side by side • Uses its own engine(faster, multiple models)	• For purchase software • Not yet compatible with AUTOCAD/REVIT/ArchiCAD, etc. • Uses its own engine (black box/ unvalidated by ASHRAE.
Whole Building EM-Tools (eQUEST, Simergy , etc.)	• Some are somewhat REVIT/AUTOCAD/ArchiCAD/SketchUP compatible. • Early component assessment can easily transition into a whole building energy analysis.	• Some are for purchase software some are freeware • Not easy to learn/ use without training. • Typically only provides numeric output.

Most of the BEM tools developed are usually for the later stage energy simulations, and now with the understanding of the benefits of early-stage simulations, architects are trying to incorporate energy modelling tools in the early phases of design. However, the whole process is burdensome; it is challenging to adapt in the early phases due to the fluid nature of the design process. The software and I.T. companies are working continuously in developing a workflow that is seamless and produces efficient results (AIA, 2012).

2.4.2 Parameter Inventory in the Early Phase of Design

Based on the findings of the early phase building energy simulation, one can conclude that the objective of the BES tool should be to calculate the energy utilization of a building given with specified geometry, energy inputs, project location, and u values (Li, 2017).

The below-mentioned inputs should be allowed to be modified by the tool (Li, 2017).

1. Thermal properties of the building exterior.
2. Interior temperature
3. Airflow
4. Window solar transmittance factors.
5. Heat recovery
6. Weather conditions
7. Air leakage.

Furthermore, the tool should be able to deliver the following results (Li, 2017).

1. Energy demand per user.
2. Potential of solar energy production.
3. Results following the standard codes.

2.4.3 Parameter Priority list

The prioritization of the attributes can be helpful in the prediction of energy. Based on the research, it has been proved that there is only a slight adjustment insensitivity of the parameters and no change in the ranking of the parameters. Hence it can be said that in the early phases of design, there is no modification in the ranking of the parameters in the energy model. In a multi-LOD approach, an architect starts the phase with a basic idea of the design parameters. Then the emphasis should be given to the geometrical parameters, technical and operational design parameters, and window construction and system efficiency parameters.

It should be noted that the preference should follow the order stated above. The building shape also has a considerable significance in the energy efficiency of a building, and hence, the designer should focus on designing and ideal shape. The objective of using sensitivity analysis is to distinguish the key parameters (Saltelli *et al.*, 2010). The design parameters are usually ranked and grouped based on uncertainty which allocates for a more accurate prediction of energy requirements (Singh and Geyer, 2020).

When the screening algorithm was carried out following the Morris method, the results state that the significant parameters with a considerable value of u and σ mean a high relationship with other parameters. Nevertheless, the order or prioritization of parameters cannot be generalized as each building is unique, and hence it is equally important to carry out the building simulations for separate buildings separately. The below table showcases the result of the Morris Method on two buildings. It should be noted that the ones in bold have a high impact on both buildings (Olivero *et al.*, 2015).

Table 9: Morris Method Results of List of Parameters in the Order of Importance.
Source: Adapted from (Olivero *et al.*, 2015).

Order of importance	Output of Morris study, Torino	Output of Morris study, Vaucanson
1	**AHU Rated air flow rate**	Outdoor temperature
2	**Outdoor Temperature**	**AHU Rated air flow rate**
3	AHU_Tsetpoint_Torino	**Light power density**
4	**Light power density**	Thermal Bridges
5	**Equipment power density**	Zone heating temperature setpoint
6	Zone heating temperature setpoint	**Boiler efficiency**
7	Zone cooling temperature setpoint	Fan efficiency
8	AHU humidification setpoint	**Equipment power density**
9	**Boiler efficiency**	Roof U-value

Summary of chapter 2.4

In the end to conclude the most critical parameters after conducting the sensitivity analysis are **WWR (wall to window ratio), glass type, orientation, building type and form, and wall insulation** following the preference order. If the simulations are carried out in the later phase, then the project loses its opportunity to make informed decisions about these prioritized parameters in the early phase of design. Thus, the early-stage design simulation is to strengthen not to replace later stage energy simulations (Samuelson *et al.*, 2016).

2.5 Integrated Design Process

The European directive 2018/31/UE aims that by 2030 it will be mandatory for all the new buildings to be nearly zero energy buildings (nZEB) (E.U., 2018). Nearly zero-energy buildings are energy-efficient buildings where the energy is produced on the site from the sources of renewable energy. Leading to the demand for an integrated approach as the traditional design and instinct would not be enough to provide with nZEB buildings (AIA, 2012).

The integration of the energy model in the design process helps in making significant decisions in detail and in a collaborative way. Decisions such as what should be the internal temperature for the comfort level of the inhabitants, what can be the sources of renewable energy, and how can the current problems have an innovative solution (Ferrero *et al.*, 2015).

However, it is not that easy to collaborate both the process as model preparation and simulation time usually do not follow up. Other factors include cost of getting the license of the software, skilled professionals to work on the software, and the level of information needed to carry out the simulations and get an accurate result. All these factors limit the use of Simulation (Timothy L hemsath, 2013).

The traditional design process usually comprises of each phase as a single activity involving the architect and client. In this phase, the energy simulation is not considered until the later phases, which makes it challenging to implement the change without increasing the cost of the project. Building energy efficiency is not of that much significance in this approach (Brunsgaard *et al.*, 2014). To tackle this issue now, many projects are aiming for an integrated design approach, which is more collaborative with a different set of experts working in the project simultaneously. The project is divided into phases, and milestones are set, which are crucial to optimize the whole design process (Ferrero *et al.*, 2015).

In the integrated design process where the whole design phases are divided into three main design phases and subdivided into six steps.The design and energy modeling is done collaboratively. For each of the design processes, the energy simulation process is also explained. Thus, the energy simulation process enhances the design process and helps in the decision making of optimized solutions (Ferrero *et al.*, 2015).

The below given figure explains the mentioned paragraph visually. The process is broadly categorized in the pre-design phase, design phase and post-design phase.

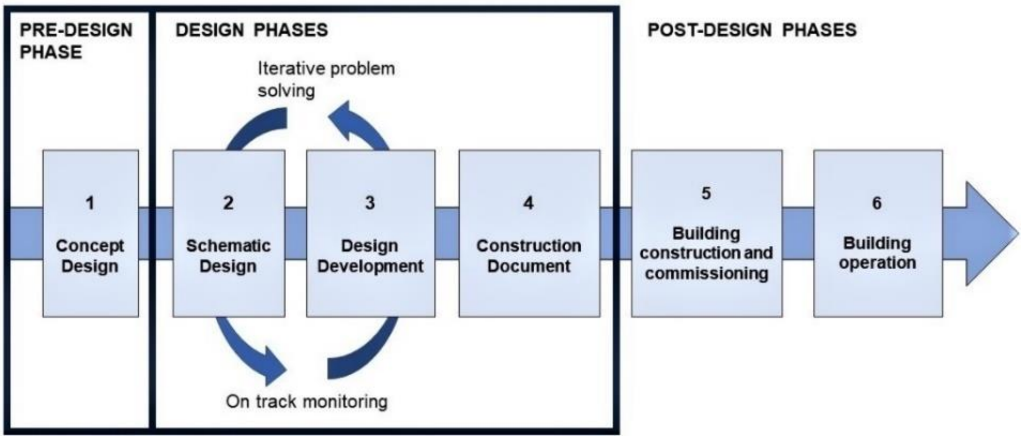


Figure 15: Integrated Design Process.
Source: Adapted from (Ferrero *et al.*, 2015).

Additionally, the table given below explains the specific goals of the simulation model and the design solution concerning different design phases.

Table 10: Goals of the Integrated Design Approach According to Design Phases.
Source: Adapted from (Ferrero *et al.*, 2015).

INTEGRATED DESIGN							
	CONCEPT DESIGN			SCHEMATIC DESIGN		DEVELOPMENT DESIGN	CONSTRUCTION DOCUMENT
DESIGN SOLUTION	• Identification of energy goals , strategies • Site analysis • Climate analysis • Available energy source analysis • Building functional requirement analysis	• Compare with reference building model to evaluate energy goals and strategies.	• Building volume and form design • Building energy system studies (thermal generating unit) definition according to energy sources • Concept of DHW production and PV	• Envelope design (walls and windows) • Solar shading design • Natural Ventilation system definition	• HVAC system design according to envelope needs and thermal generating unit. • DHV production system design. • PV system design	• Design solutions and control schedule optimization • Prove concept design energy goal compliance.	• Prove regional energy code compliance. • Prove rating system compliance.
SIMULATION MODEL	• Consult weather data (climate consultant , weather tool)	• Input data collection from reference buildings	• Building orientation simulation. • Building volume and form simulation. • Simulation to define heated and unheated zones.	• Simulation to define window to wall ratio. • Simulation to define opaque envelope stratigraphy. • Simulation to define glazing surface. • Simulation to evaluate solar shading solution • Natural Ventilation simulation	• HVAC system sizing simulation • Simulation to contrasting different kind of HVAC system • DHW production and PV system modelling or according input data from another model.	• HVAC system optimization simulation. • Simulation to optimize use and control schedule of air conditioning, lighting (input data from lighting simulation) Ventilation, solar shading. • Simulation to optimize DHW production system and PV system.	• Baseline building creation and compare with design solution.

2.6 Benefits of Early Phase Simulation for the Client & Project Manager

Project managers are mostly the client's representative on the project and have the responsibility to successfully deliver the project of the decision quality in the given time and money. Their task is to strategize for the long-term vision of the project while they plan, control, and monitor the whole building process from conception to completion. In small projects, the planning manager and project manager are usually the same people whereas in the larger project these roles are assigned to separate individuals, and the project manager is not involved in the design phase (Lahdou and Zetterman, 2011).

The most crucial decisions regarding building sustainability are taken in the early phases of design. The early phase is significant for the project manager as it is their responsibility to inform the client and make decisions about setting clear goals, design process, end-user requirements, evaluation methods, tools to be used, a timeline of the project, finances, etc. With the incorporation of the early phases of energy simulation, the project manager is more informed about the reality of the project and has a better grasp of the situation which helps them in further convincing the client to opt for energy-efficient design options (Delnavaz, 2012).

Below is the table stating the objectives and goals of the energy modelling in the early design phases with the key requirements from the team and advantages to the client and project manager (AIA, 2012).

Table 11: Energy Modelling Objectives and Benefits to the Client and the Project Manager.
Source: Adapted from (AIA, 2012),(Delnavaz, 2012).

	Concept Design	Schematic Design	Design Development	Construction Documentation	Construction Post Occupancy
Energy Modelling goals	-The early-stage design simulation experiments with building location and orientation. -Determine effective outer envelope ideas and construction. -Evaluate the effect of daylighting and other passive strategies.	-Formation of a rough basic energy model. -Assess different energy-efficient measures to determine the one with the minimum possible energy use.	-Generate suggested models with system alternatives to select from and refine, modify the models, add details as per the requirements.	-Do quality checks on the completed model. -Generate results and other documentation required for code compliance.	-Finish the modelling with installed element cut-sheet performance data of an as-built model. -Gather metered operating information for generating a calibrated model to

	-Discover ways to reduce loads.	-Define thermal zones and HVAC choices.	-Provide yearly energy use charts and other indicators as base versus the one proposed. -Assess and test various product alternatives for the project. -Quality check of the models and test the control approaches.		disclose with an outcome-based database.
Team Goals	-The early-stage design simulation can assist in defining the goals of the project. -As per the modelling data, the project requirements can be defined.	-Analyze financial and energy performance-based data from the model to assist in design decisions.	-Evaluate design options based on the set goals and as per the modelling outcome. -Generate baseline and options to select from.	-Generate documentation required to go with energy models outcome for code compliance. -Generate documentation required to go with energy models outcome for metering/monitoring and commissioning certification.	-Utilize the outcome of the as-built model for commissioning. -Evaluate outcomes of the as-built model to the metered information to locate the operating issues.
Benefits to PM	-The entire design team works together with the objectives of the project. -Architects and engineers can decide similar goals to achieve energy efficiency in the building. -Design decisions based on modelling results informed by integrated system performance.	-The opportunity to test different variations before finalizing one. -The whole process makes it feasible to choose the most cost-effective and energy-efficient option. -Various delays, setbacks, and risks can be evaluated earlier on minimizing the risk of re-designing in the later phase.	-Decide the best solutions which are efficient and cost-effective. -Choose the right size and type of Mechanical equipment.	-Utilize the energy models to assist in obtaining the GBC certifications. -Correct prediction of the energy need and use in the building.	-Provide the information to enhance operations to satisfy the optimized energy use goals in the built project.

Benefits to Client	-When the simulation is carried out in this phase, it is estimated that the project can achieve up to 49% energy savings on average (Franconi *et al.*, 2013). -Finance can be a significant motivator for the client.	-The process makes it easier to obtain GBC certifications by implementing and setting GBC goals early in the design phase.	-The measure of Heating and cooling demands and lighting requirements assist in taking the right decisions and satisfying the GBC goals.	-Easier for the client to estimate the future energy use of the building.	-The project is within the GBC guidelines with a sustainable and cost-effective option.

2.7 Main Outcome of the Literature Study

The main objective of this chapter was to deeply establish the understanding of the various factors related to early-stage energy simulation. The past years have seen a considerable increase in the number of projects incorporating building energy modelling. Partially due to the awareness in the market and majorly due to more rigorous building energy efficiency guidelines and strict green building certification programs such as LEED, BREEAM, etc.

The initial point to note is that there is no standardized approach to the design phases globally. The design phases vary depending on the country and the national standard followed in that respective region. So, is the case with the GBC., there is no global standard but specific prominent certifications that are renowned and accepted on a global scale which should be mentioned in the contract to adhere to (see chapter 2.1).

In the early phases of the building process, significant decisions are made regarding building general form, layout, orientation, and construction method, which has an enormous impact on deciding the energy efficiency of the building. The early decisions affect the usefulness, productivity, and flexibility of the design alternative. It is crucial to integrate the active and passive design strategies as passive design decisions can hugely place excessive demands on active design strategies. (passive design strategies deal with the architectural decisions to increase the energy efficiency of the building without the use of electromechanical energy, for example, building shading, building envelope to name few. At the same time, active design strategies encompass the use of building systems to do so, such as HVAC, mechanical systems).

The critical factor to note is that the lack of information (fuzziness) in the early phases of building design should not be termed as a negative term as it is the driving force behind integrating early-stage simulations. Incorporation of uncertainty and sensitivity analysis in the initial phases helps in understanding the building behaviour and improvising the concept accordingly. Though LOD 100 is very basic and cannot be simulated alone for simulations, in combination with LOD 200, it can be evaluated successfully. The whole process allows the architects to insert a maximum and minimum range of fuzziness in the parameters and produce design variations.

However, despite the proliferation of energy simulation tools, factors the lack of standardization of software, the abundance of unfamiliar data, limiting knowledge of how to decipher the result and different needs and requirements of different stakeholders can present an overwhelming scenario. Thus, adoption of integrated design approach (see table 9) is of vital importance to minimize the unpleasant situations

Also, from the above literature study, it can be analyzed that the most contributing parameters are already present in the early phases (see table 9). The need is to adopt a useful energy simulation tool which works with these parameters and produces an accurate result. As the benefits of carrying out early-stage simulation (see table 11) is abundant for the client, project manager and project overall.The above-collected information and studies will be put into application in the methodology section through the execution of a pilot project (see chapter 3) based on the knowledge gained above.

3. Research Methodology

The current chapter aims to do a preliminary study to examine the feasibility of the literature review mentioned above. For this purpose, a pilot project study is executed and evaluated. As the full workflow of carrying out the energy simulation can be confusing this pilot project will help in illustrating the sequence of steps.

The first sub-chapter (see chapter 3.1) involves modelling a simple box model according to the different level of development (100-400) and then extracting the parameters through the Box model in that specific LOD. It is to note that the project is modelled separately for the TGA and architecture, which will help in comparing the difference in the level of information in these two models for the same level of development.

After setting up the base, the second sub-chapter (see chapter 3.2) lists out the attributes needed for the energy simulation as provided by the simulation expert. The chapter further investigates the parameters existing in the BIM 3D model and can be extracted simply via the model to those parameters which cannot be and needs a plug-in or another programming tool. This chapter also explains the workflow of extracting the parameters in detail, integrating different software.

Based on the above sub-chapters, the limitations or research gap is located and mentioned as what are the issues when the model exists in practical not just in theory. Further in the last sub-chapter (see chapter 3.3) the early design simulation is discussed in-depth, and a parameter list is established based on the evaluation of the whole BES process and pilot project. Furthermore, the main outcome of the research methodology will be discussed in subchapter (see chapter 3.4), which layout the base for validation in chapter 4.

3.1 Developing BOX Revit Model & Generating Parameter List

For executing the pilot project, Revit is used as a modelling tool. The LOD models with variants such as the number of floors, different sizes of the room to name a few are modelled. To better understand the concept and parameters, the model is developed as an architecture model and as a TGA model for the corresponding LOD. The TGA model is modelled keeping in mind the TGA requirements for EnEv/ heating and cooling loads /Airducts / simulation etc.

1. **LOD100**

As shown in the modelled render below, In LOD 100, the spaces correspond as generic and conceptual objects with estimated shape, size, and location. This level refers to the blocking and stacking phase. This level can be represented graphically in a generic manner or with the use of the symbol. In this model, the model element shows the presence of a component, but no other data related to its shape, size, or location (BIM Forum, 2019).

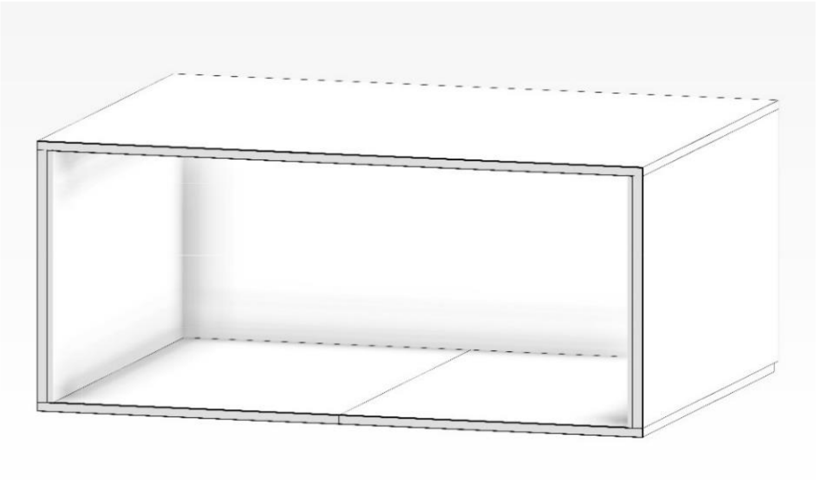


Figure 16:: A Box Model Representation of Arch 100 Model.
Source: (By Author,2020).

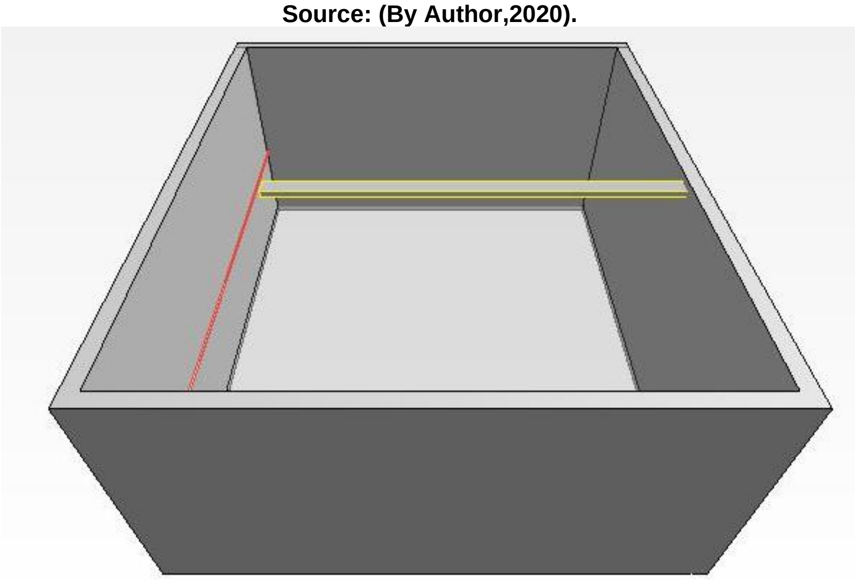


Figure 17: A Box Model Representation of the TGA 100 Model.
Source: (By Author,2020).

This model can be used to prepare estimate as information related to model elements like cost per square foot and tonnage of HVAC etc. can be obtained or to perform analysis on the subject of building orientation or cost per square meter etc. (Boton, Kubicki and Halin, 2015)

2. **LOD200**

As shown in the modelled render below, In LOD 200, usually all the model elements are placeholders they may depict the components or reserve the space for the components. Despite being more precise than LOD 100, this LOD graphically symbolized model elements with approximate shape, size, quantities, location, and orientation. Approximate non-graphical information which may be attached to the model element (BIM Forum, 2019).

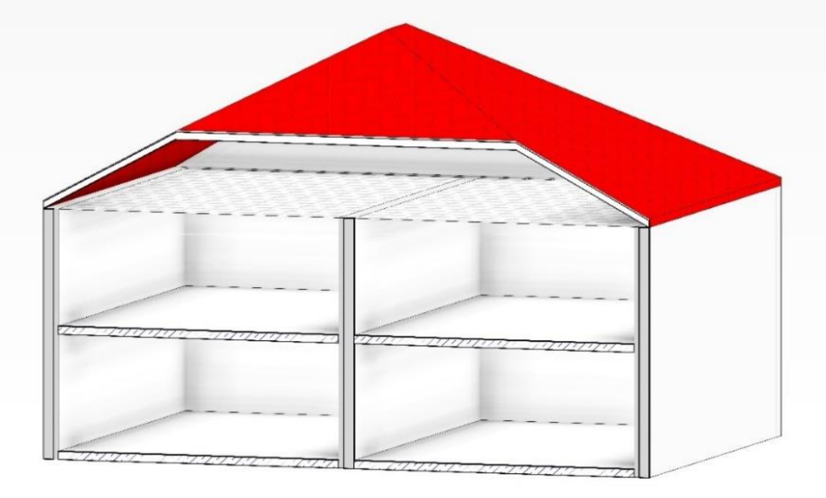


Figure 18: A Box Model Representation of Arch 200 Model.
Source: (By Author,2020).

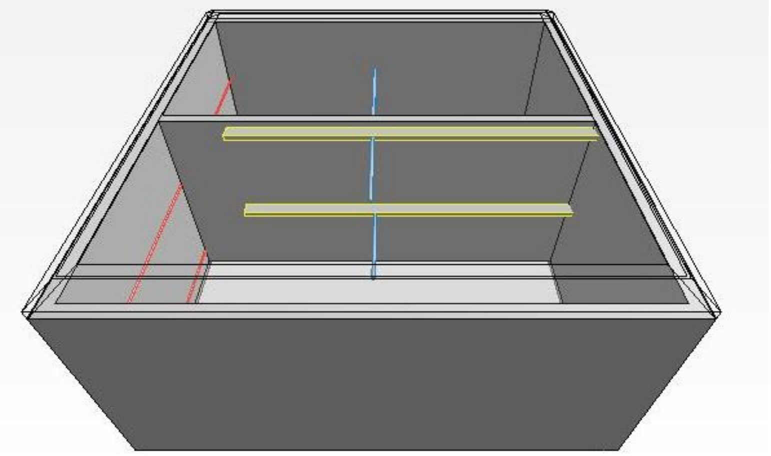


Figure 19: A Box Model Representation of the TGA 200 Model.
Source: (By Author,2020).

Similar to LOD 100 information such as cost per square foot and tonnage of HVAC etc. may exist but cannot be termed as final information (Boton, Kubicki and Halin, 2015).

3. **LOD300**

As shown in the modelled render below, In LOD 300, all the model element is of a specific shape, size, quantities, location, and orientation. This LOD is also termed as a detailed design level as in addition to graphical information, and the model also contains non-graphical information that comprises finishes, cost, materials, etc. (BIM Forum, 2019).

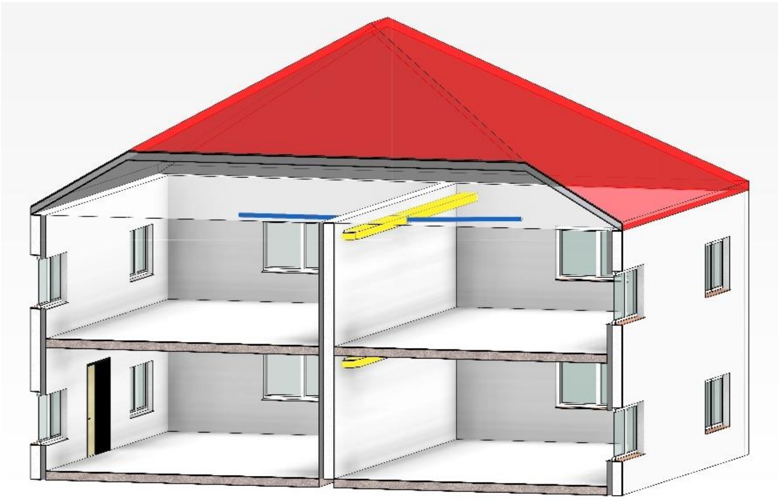


Figure 20: A Box Model Representation of Arch 300 Model.
Source: (By Author,2020).

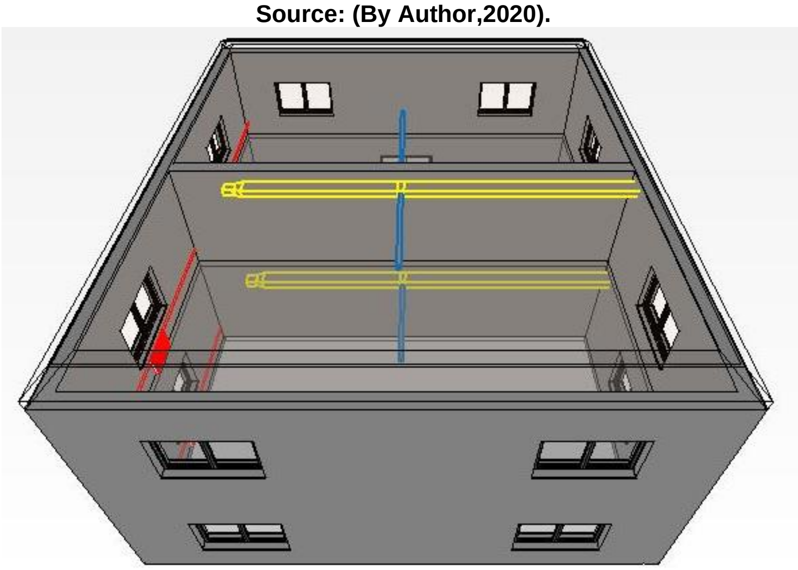


Figure 21: A Box Model Representation of the TGA 300 Model.
Source: (By Author,2020).

Since all the information that the model contains at this stage is specific, this stage is used to produce the construction documents (Boton, Kubicki and Halin, 2015).

It should be noted that an additional phase of LOD 350 is usually generated to bridge the supporting gap between LOD 300 to LOD 400 (Boton, Kubicki and Halin, 2015).

4. LOD400

As shown in the modelled render below, In LOD 400 in addition to the phase with specific graphic and non-graphic information, this phase also contains information regarding detailing, fabrication, assembly, and installation of the model element (BIM Forum, 2019).

Figure 22: A Box Model Representation of Arch 400 Model. Source: (By Author,2020).

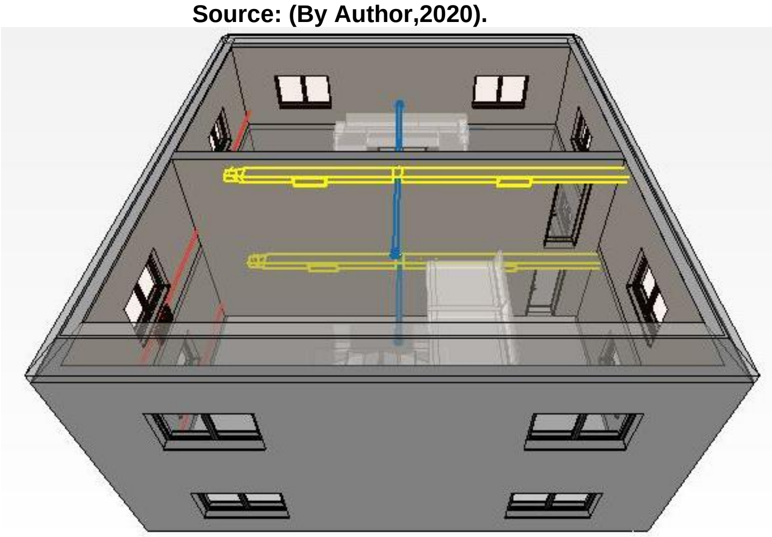


Figure 23:A Box Model Representation of the TGA 400 Model. Source: (By Author,2020).

This LOD is more useful to the manufacturers due to the detailed specification of the materials, manufacture, and assembly, etc.(Boton, Kubicki and Halin, 2015).

The final LOD 500 is the as-built model which is useful for the scope of operation and facility management (Boton, Kubicki and Halin, 2015) and is not in the scope of this research.

Generating Parameter list in different phases.

A detailed and hidden database lies beneath every Revit model. This information can be accessed through schedules in Revit through the create panel tab existing in the top ribbon of the software. The below given table is a snip of a room schedule with the data existing in the model. These schedules exist in the model and can be generated at any design phase. The schedules get automatically updated with the update in the model. These schedules can be exported directly into the excel files.

Table 12: Snippet of Inbuilt Revit Room Schedule.
Source: (By Author,2020).

Room Schedule						
				Finishes		
Number	Area	Volume	Occupancy	Floor Finish	Wall Finish	Ceiling Finish
5	115.37 SF	1673 CF	Shared	Ceramic Tile	White Painted	Acoustic Tile 2'x2'
27	1988.39 SF	28833 CF	Shared	Ceramic Tile	White Painted	Acoustic Tile 2'x2'
Circulation: 2	2103.76 SF					
10	436.32 SF	6327 CF	Office	Ceramic Tile	Light Blue Painted	Acoustic Tile 2'x2'
13	313.14 SF	4541 CF	Office	Ceramic Tile	Light Blue Painted	Acoustic Tile 2'x2'
14	358.36 SF	5196 CF	Office	Ceramic Tile	Light Blue Painted	Acoustic Tile 2'x2'
15	350.66 SF	5085 CF	Office	Ceramic Tile	Light Blue Painted	Acoustic Tile 2'x2'
17	235.44 SF	3414 CF	Office	Ceramic Tile	Light Blue Painted	Acoustic Tile 2'x2'
18	235.44 SF	3414 CF	Office	Ceramic Tile	Light Blue Painted	Acoustic Tile 2'x2'
21	265.59 SF	3851 CF	Office	Ceramic Tile	Light Green Painted	Acoustic Tile 2'x2'
22	235.44 SF	3414 CF	Office	Ceramic Tile	Light Green Painted	Acoustic Tile 2'x2'
25	268.48 SF	3893 CF	Office	Ceramic Tile	Light Green Painted	Acoustic Tile 2'x2'
26	262.69 SF	3809 CF	Office	Ceramic Tile	Light Green Painted	Acoustic Tile 2'x2'
Office: 10	2961.54 SF					

There are following inbuilt types of schedules existing in a Revit model (About Schedules | Revit Products 2020 | Autodesk Knowledge Network, 2020)

1. Schedules (or Quantities)
2. Key Schedules
3. Material Takeoffs
4. Annotation Schedules (or Note Blocks)
5. Revision Schedules
6. View Lists
7. Drawing Lists
8. Panel Schedules
9. Graphical Column Schedules

As per the schedules and the information generated from the modelled Box model, the given below table has been generated stating the parameters available during different LOD phases.

Table 13: LOD List and Parameter Availability.
Source: (By Author,2020).

L.O.D	PARAMETERS
L.O.D 100	• Sketch mass • Building orientation • Floor levels, areas, and volumes • Overall areas and U-value
L.O.D 200	• External walls (properties) • Floor slabs • Geometric values of walls and floor slabs (Areas, volumes) • Construction material • Analytical properties: U-values, Heat mass, Density, G-value
L.O.D 300	• External walls • Internal walls • Floor slabs • Windows and other openings • Geometric values of walls, floor slabs, and windows (Areas, volumes) • Construction material • Ceiling properties • Analytical properties: U-values, Heat Capacity, G-values, R-values, Density • Orientation/location on the building body
L.O.D 400	• External wall • Internal walls • Floor slabs • Windows and other openings • Geometric values of walls, floor slabs, and windows (Areas, volumes) • Construction material • Ceiling properties • Wall insulation properties • Analytical properties: U-values, Heat Capacity, G-values, R-values, Density • Orientation/location on the building body

Summary of Chapter 3.1

The current sub-chapter gives a detailed insight into the LOD phases with the help of a box model and also depicts the difference in the level of detail between Arch and TGA model for the same level of development. The process of detailing the phases makes it locate and list out the parameters existing in these subsequent phases. Thus, forming a base for the next sub-chapter to evaluate whether these parameters match with the ones provided by the simulation expert, can these parameters be extracted from the Revit model for simulation and is the information received reliable for carrying out energy simulation or not.

3.2 Attributes and Parameters Required for Energy Simulation as Given by Simulation Expert

This sub-chapter is based on the discussion and interview with the Simulation Expert currently working on the mobility2grid research project for the EUREF project

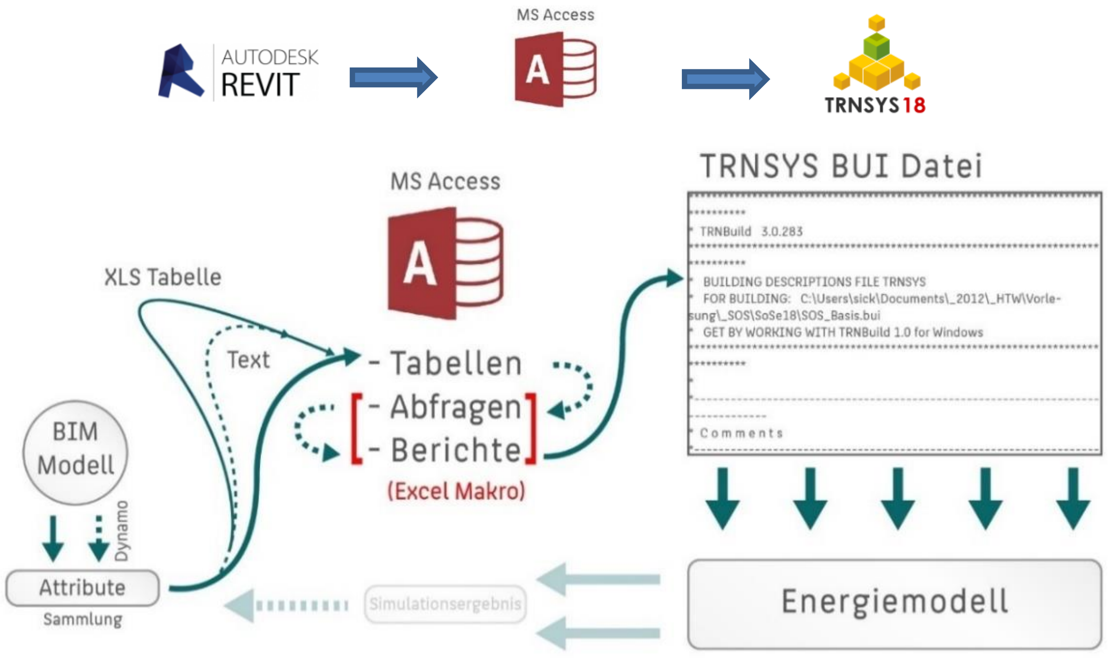


Figure 24: Workflow Adopted By the Simulation Expert.
Source: (By Author,2020).

The workflow followed by the expert for conducting the BES is based on three main software program Autodesk Revit for modelling, TRNSYS for simulation, and the data from the model are reformulated into the syntax of the BUI file by the Access process and exported in text format for simulating in TRNSYS.

The expert based-on experience, knowledge and the inputs required by the software TRNSYS for energy simulation provide the parameter list mentioned in the given below table.

Table 14: Variable List Needed for Simulation.
Source: (Adapted By Author as per the instructions from the Expert).

VARIABLE LIST
[absolute filepath]
[LayerName]
Conductivity
Capacity
Density
[INPUT]
INPUT
[Schedules]
Name
Hours
Values
[MultiLayerElementName]
[LayerList]
[ThicknessList]
[Absorptance]
[Emissivity]
[WindowName]
ZONES
[RoomNameList]
[Direction_AngleH_AngleV]
[RoomName]
[ElementName]
[Area]
[MaterialDescription „Int-Ext“]
[OrientationSyntax]
[WindowName]
[WindowID]
[WindowArea]
[MaterialDescription „Int-Ext“]
[OrientationSyntax]
[INPUT]
[ElementName]
[ElementIDSurf1]
[Area]
[NextRoom]
[ElementIDSurf2]
[DirectionIf „Front_Back“]
[RoomVolume]
[RoomArea]
[RoomName]

All BUI file data categories are as follows: Properties, Layers, Inputs, Schedules, Construction, Windows (Gains / Losses, etc. that is a group of parameters for ventilation and heating systems), Zones including orientations, Outputs, Link types, Node types, and _Extension_Winpool_Start.

Layers (4 parameters): describe the material properties of the materials used in the model.

Schedules (3 parameters): user profiles for the various rooms. The usage profiles, according to DIN 18599, are used as a reference.

Construction (5 parameters): explain the description of the construction elements found in the project, such as walls, ceilings, floors etc.

Windows (1 parameter): List of the window types used in the model.

Zones including orientations (15 parameters): explains the composition of the rooms and their relationship to the building elements (in terms of positioning and individual area, as well as room volume and area).

3.2.1 Revit and Parameter Inventory Generated from Revit

Below is the parameter list provided by the simulation expert and the researched data by the author on the pilot project whether the variables needed for the input in TRNSYS exist in the Revit model or not. It should be noted that the parameters were extracted from the LOD 400 model as the aim here is to investigate the existence of parameters regardless of the phase.

The 3D modeller explains the building into simple blocks known as Types, The information stored within Types is a distinct description which is used to define other Types, or in the explanation of the construction process. For example, Layer is a type, which may be used to define the wall type and further in the description of the building. Within the model, the data is stored within different categories of Types. The description of these types is according to its name and information stored within it. (TRNSYS 16-Multizone Building modeling with Type56 and TRNBuild, 2007). The list given below contains 40 variables categorized broadly into layers, schedules, construction category and zones. These categories are made as per the format required in the TRNSYS, BUI (Building input description file) format.

It should be noted that just because the parameters exist does not mean it can be extracted from the Revit file and exported to TRNSYS. The cross here denotes that these variables exist in the model.

Table 15: Availability of Parameter in the Revit Model.
Source: (Adapted By Author as per the instructions from the Expert).

VARIABLE LIST	FOUND
[absolute filepath]	-
[LayerName]	X
Conductivity	-
Capacity	-
Density	-
[INPUT]	-
INPUT	-
[Schedules]	-
Name	-
Hours	-
Values	-
[MultiLayerElementName]	X
[LayerList]	X
[ThicknessList]	-
[Absorptance]	X
[Emissivity]	-
[WindowName]	X
ZONES	
[RoomNameList]	X
[Direction_AngleH_AngleV]	X
[RoomName]	X
[ElementName]	X
[Area]	X
[MaterialDescription „Int-Ext“]	X
[OrientationSyntax]	X
[WindowName]	X
[WindowID]	X
[WindowArea]	X
[MaterialDescription „Int-Ext“]	X
[OrientationSyntax]	X
[INPUT]	-
[ElementName]	X
[ElementIDSurf1]	X
[Area]	X
[NextRoom]	X
[ElementIDSurf2]	X
[DirectionIf „Front_Back“]	X
[RoomVolume]	X
[RoomArea]	X
[RoomName]	X

3.2.2 Programming and Running Dynamo for Different Parameters

The standard industrial formats for energy simulation are IFC, gbXML, and IDF file formats. They summarize many aspects of the project data, such as geometric and alphanumeric BIM data, but at crucial points, the data completeness and integrity are missing. The figure given below explains the workflow applied to the BESTEST, building energy simulation test is the method adopted by the IEA, Paris.

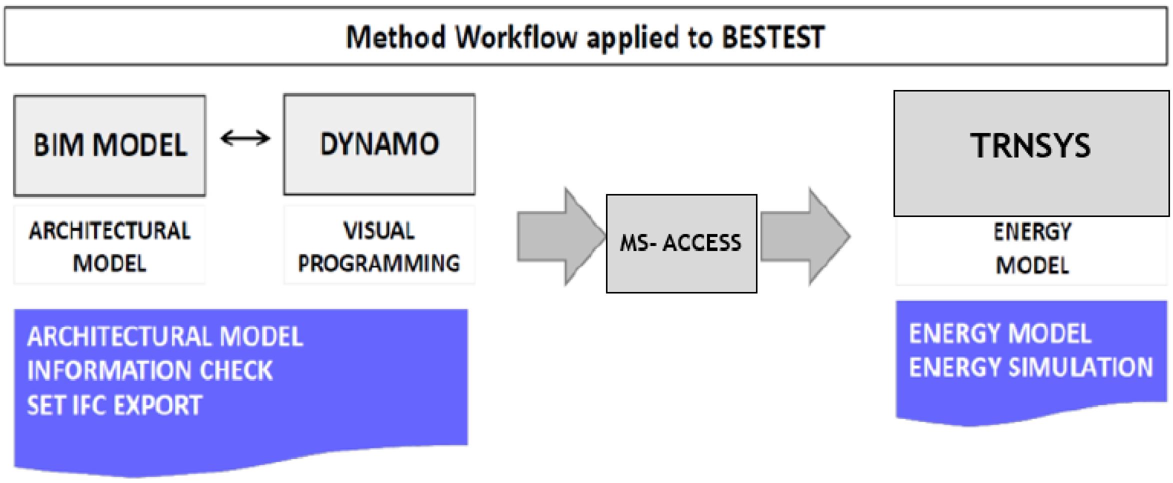


Figure 25: Workflow Adopted in Energy Model Simulation.
Source: Adapted from (Spiridigliozzi *et al.*, 2019).

Dynamo is a visual programming language which is a plug-in for Revit; it has a direct interface with Revit. This VPL consists of nodes and connections to produce BIM objects in Revit (Olowu *et al.*, 2014). It should be noted that Dynamo is not an energy modelling software. It is more like a mediator between modelling and simulation software to transfer data to nodes or programs (Visual scripting environment for designers | Dynamo, 2020).

Dynamo is an open-source add on module which can work as a single software or in combination with BIM for parametric modelling. There are new versions of updates and plugins coming for Dynamo frequently (Spiridigliozzi *et al.*, 2019). Though Dynamo has a lot to offer here in the research, it is used to extract the parameters existing in Revit through programming which cannot be directly extracted into excel or text format to connect it to MS-Access for simulating in TRNSYS. For parameter extraction (see figure 28), the programming differs according to the variable required.

3.2.3 Dynamo Workflow

Dynamo workflow is illustrated in the figure below. In any given Revit model, the properties tab expands into a detailed knowledge about the model element selected, and further on pressing the edit type tab, the information related to the parameters of the model element is shown. Refer to the figures below (Visual scripting environment for designers | Dynamo, 2020)

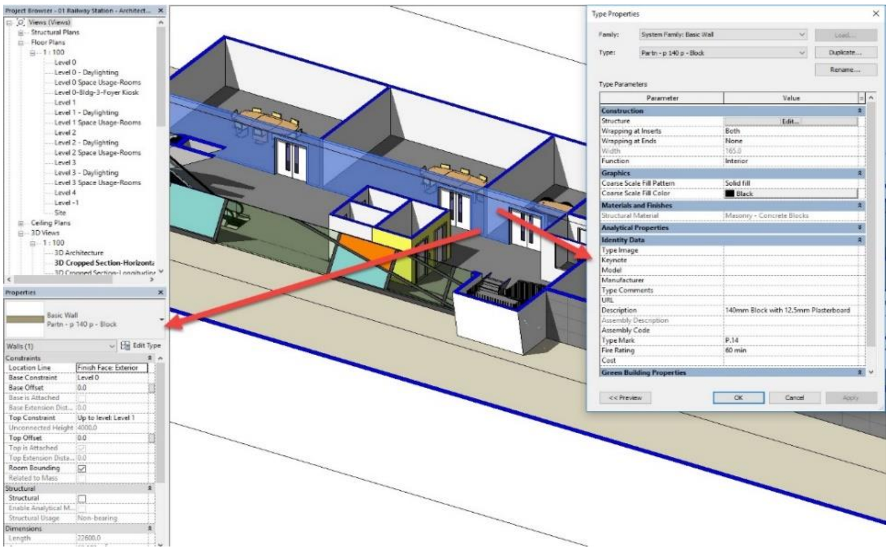


Figure 26: Snippet of Wall Properties in Revit.
Source: (By Author,2020).

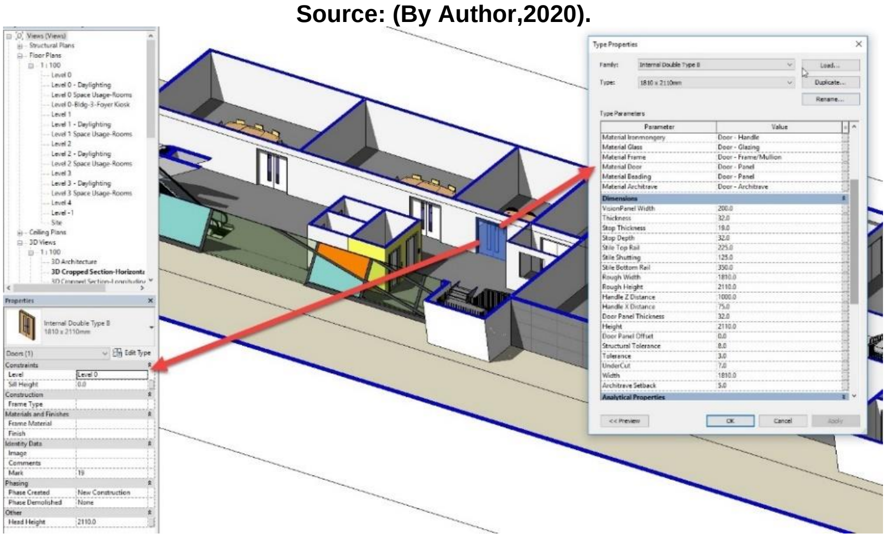


Figure 27: Snippet of Door Properties in Revit.
Source: (By Author,2020).

If the parameters are not within the inbuilt schedules in Revit, then these can be extracted through Dynamo (Computational design tool). Post selecting the parameters go to Dynamo as a plugin in Revit and extract these parameters as shown in the figure below (Visual scripting environment for designers | Dynamo, 2020).

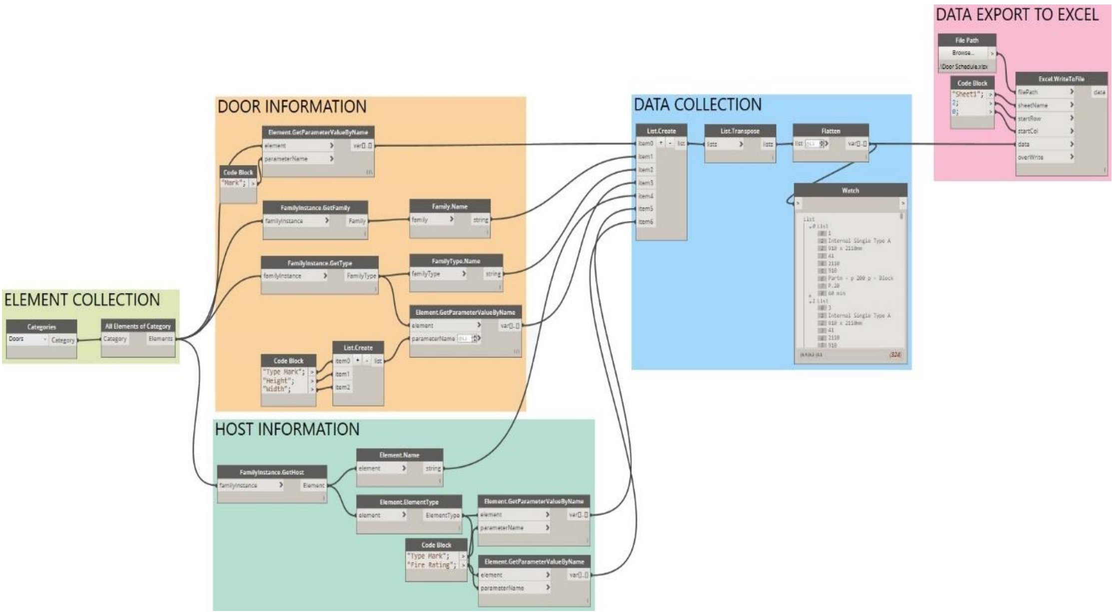


Figure 28: Snippet of Dynamo Workflow for Extracting Parameters from Revit to Excel. Source: (Dynamo, 2020).

After running the script, the data is exported to the excel (pink box). Thus, allowing to customize the relationship between specific elements and following excel files. Below given table shows a snip of the result in the excel file (Data extraction from a BIM model | Search | Autodesk Knowledge Network, 2020)

Table 16:Snippet of Excel File Exported from Dynamo.
Source: (Data extraction from a BIM model | Search | Autodesk Knowledge Network, 2020).

DOOR DATA						WALL DATA (HOST)		
Mark	Family Name	Family Type	Type Mark	Height (mm)	Width (mm)	Family Type	Type Mark	Fire Rating
1	Internal Single Type A	910 x 2110mm	41	2110	910	Partn - p 200 p - Block	P.20	60 min
3	Internal Single Type A	910 x 2110mm	41	2110	910	Partn - p 200 p - Block	P.20	60 min
6	Internal Single Type A	910 x 2110mm	41	2110	910	Partn - p 200 p - Block	P.20	60 min
7	Internal Single Type A	910 x 2110mm	41	2110	910	Partn - p 100 p - Block	P.10	30 min
8	Internal Single Type A	910 x 2110mm	41	2110	910	Partn - p 100 p - Block	P.10	30 min
9	Internal Double Type B	1810 x 2110mm	54	2110	1810	Partn - p 140 p - Block	P.14	60 min
10	ExtDbl Flush	1810 x 2110mm	44	2110	1810	Rainscreen Cladding 275mm - Grey Aluminium		
11	Internal Single Type A	910 x 2110mm	41	2110	910	Partn - p 140 p - Block	P.14	60 min
13	Internal Double Type A	1810 x 2110mm	55	2110	1810	Partn - p 140 p - Block	P.14	60 min
14	Internal Double Type A	1810 x 2110mm	55	2110	1810	Partn - p 140 p - Block	P.14	60 min
15	Internal Double Type A	1810 x 2110mm	55	2110	1810	Partn - p 140 p - Block	P.14	60 min
16	Internal Double Type A	1810 x 2110mm	55	2110	1810	Partn - p 140 p - Block	P.14	60 min
17	Internal Double Type B	1810 x 2110mm	54	2110	1810	Partn - p 140 p - Block	P.14	60 min
18	Internal Double Type B	1810 x 2110mm	54	2110	1810	Partn - p 140 p - Block	P.14	60 min

Dynamo allows parameters export from Revit to excel which can be compiled together and concerning each other as element ID for walls, windows, ceilings, floor, and orientation of these elements as shown in the table below generated from the box model.

Table 17:Table Generated from the Box Model of the Exported Parameters and its Relation with other Parameters.
Source: (By Author,2020).

	A	B	C	D	E
1	Nr	Table Name 1	Param1	Param2	Param3
2	1	Room surounding Wall list	Wall.Element.ID	Room ID	Room ID
3	2	Room surounding Ceiling list	Room ID	Ceiling.Element.ID	Ceiling.Element.ID
4	3	Room surounding Floor list	Room ID	Floor.Element.ID	Floor.Element.ID
5	4	Room surounding Window list	Room ID	Window.Element.ID	Window.Element.ID
6	5	Orientation List	Wall ID	Orientation String	
7	6	Wandelist	Family name	Type	Area
8	7	Material list	Family and Type	Material Name	Material Desciption
9	8	Wall ID and Type list	Wall ID	Wall Type	
10	9	Ceiling ID and Type list	Ceiling Type	Ceiling ID	
11	10	Floor ID and Type list	Floor Type	Floor ID	
12	11	Window ID and Type list	Window Type	Window ID	
13	12	Room Schedule	Number	Room Name	Area
14	13	Wall ID and Window ID	Wall ID	Window ID	
15	14	Room ID and Room Name	Room Name	Room ID	
16	15	Wall ID and Area list	Wall ID	Wall Area	
17	16	Window Type and Area List	Window Type	Window Area	

Nodes and connections of the Dynamo script create constellations in Revit to extract parameters. For example, the room with different wall positioning can be put by element ID in a table, the used nodes, the IDs, parallel the wall materials are linked to the wall in another table. Thus, creating a real element ID of a room with its different wall parameters.

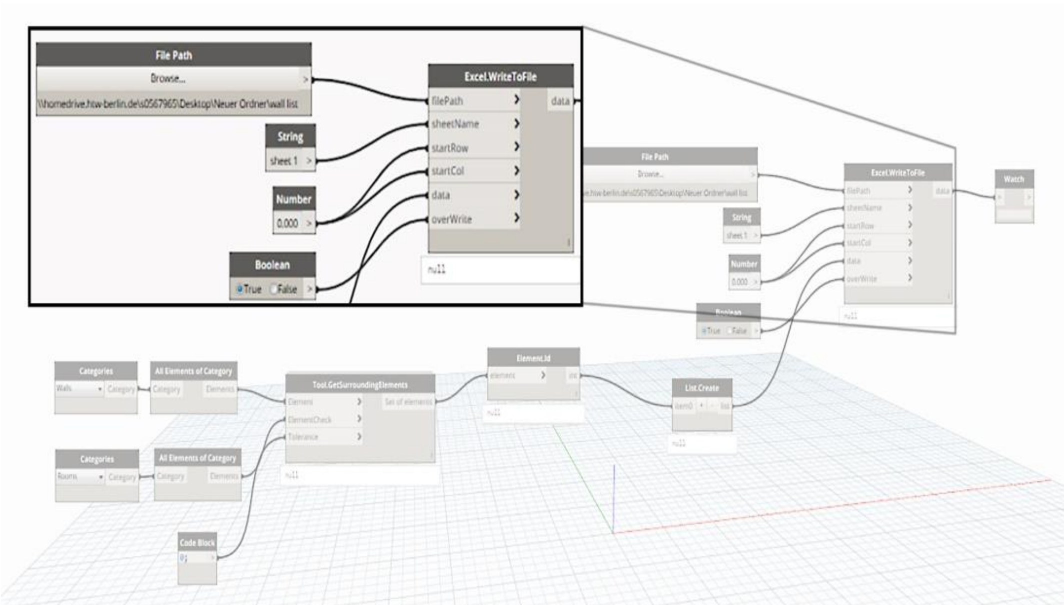


Figure 29: Snippet of Dynamo Script for Establishing the Relationship Between Wall and Room Elements.
Source: (By Author,2020).

However, the composition of data from the model is different from the structure of the BUI file. The conversion should be carried out systematically, and the additional parameters should be added and exported so that all the data can be linked together. The conversion of data by MS-Access is carried out by connecting the properties in tables.

The queries in Access help create logical relationships between data tables, write and enter data in the formula, and bring together the previously non-convertible parameters, explicitly using the element ID.

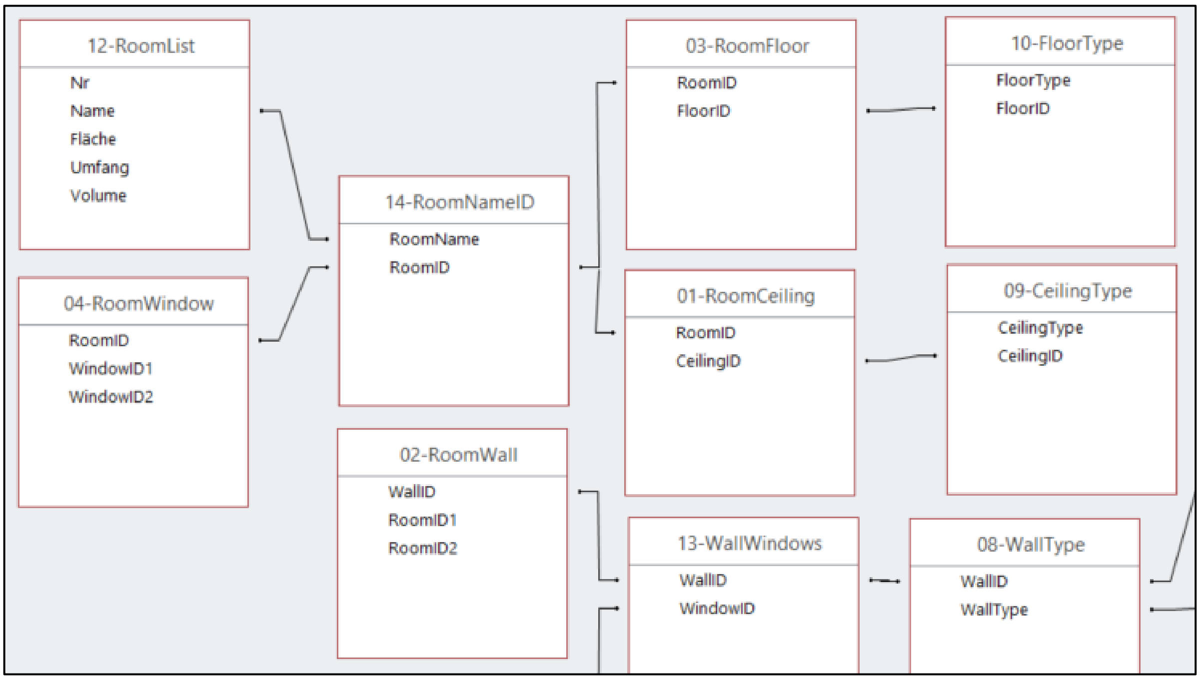


Figure 30: Snippet of Example Relationship Between RoomID in Different Tables.
Source: (By Author,2020).

In the BUI files, there are different categories, such as layer, schedules, construction, and zones. The layers categories in the BUI file is the collection of subcategories of thermal properties

[LayerName]
Conductivity
Capacity
Density

Figure 31: Snippet of Layer Category in BUI File.
Source:(By Author,2020).

As shown in the snip above the variables such as conductivity, capacity, and density come under the layer name categories.

Similarly, the schedules category is a collection of similar listing of time and listing of user's profiles.

[Schedules]
Name
Hours
Values

Figure 32: Snippet of Schedule Category in BUI File.
Source: (By Author,2020).

The construction category is a list of material descriptions used in the model, such as layer list, Thickness list, absorptance, and emissivity.

[MultiLayerElementName]
[LayerList]
[ThicknessList]
[Absorptance]
[Emissivity]

Figure 33: Construction Category in BUI File.
Source: (By Author,2020).

The zones category is the most complex of all as it connects space, elements via surf ID. The connection must be found between elements having different parameters and the subcategories have to be filled in.

[Zones]
[RoomNameList]
[Direction_AngleH_AngleV]
[RoomName]
[ElementName]
[Area]
[MaterialDescription „Int-Ext“]
[OrientationSyntax]
[WindowName]
[WindowID]
[WindowArea]
[MaterialDescription „Int-Ext“]
[OrientationSyntax]

[INPUT]
[ElementName]
[ElementIDSurf1]
[Area]
[NextRoom]
[ElementIDSurf2]
[DirectionIf „Front_Back“]
[RoomVolume]
[RoomArea]
[RoomName]

Figure 34: Snippet of Zones Category in BUI File.
Source: (By Author,2020).

3.2.4 Standard List Created from Revit and Dynamo

For simplification lets divide the table 19, into three parts the first will be the list of the variables provided by the simulation experts, second is the source as to where the variable is found in Revit, and third is whether these variables can be exported from Revit to excel. Kindly note that theses variables are needed for energy simulation in TRNSYS, and all the variable list is extracted from LOD 400.

The below given table is based on the execution of the pilot project.

Table 18: Variable List Generated from the Pilot Project.
Source: (By Author,2020).

VARIABLE LIST	SOURCE IN REVIT	EXPORT / CONVERTED
[absolute filepath]		-
[LayerName]	Material Browser	E / U
Conductivity	thermal properties - Material Browser	-
Capacity	''	-
Density	''	-
[INPUT]		-
INPUT		-
[Schedules]	shared parameters	-
Name	''	-
Hours	''	-
Values	''	-
[MultiLayerElementName]	Material Browser	E / U
[LayerList]	Material Browser	E / U
[ThicknessList]	Material Browser	-
[Absorptance]	Wall List	E
[Emissivity]		-
[WindowName]	Window list	E
ZONES		
[RoomNameList]	Room Schedule	E
[Direction_AngleH_AngleV]	from dynamo definition list	E / U
[RoomName]	Room schedule	E
[ElementName]	Element ID for membership	E / U
[Area]	Wall list	E
[MaterialDescription „Int-Ext“]	Material Browser	E / U
[OrientationSyntax]	Dynamo	E / U
[WindowName]	Room Window ID	E
[WindowID]	Dynamo	E
[WindowArea]	Window Area List	E
[MaterialDescription „Int-Ext“]	Material Browser	E / U
[OrientationSyntax]	Wall-Orientation List Dynamo	E / U
[INPUT]		-
[ElementName]	Wall List	E
[ElementIDSurf1]	Element ID +1,2 , Dynamo	U
[Area]	Wall list	E
[NextRoom]	Room - Wall ID	E / U
[ElementIDSurf2]	Element ID +1,2 , Dynamo	E / U
[DirectionIf „Front_Back“]	''	U
[RoomVolume]	Room Schedule	E
[RoomArea]	Room Schedule	E
[RoomName]	Room Schedule	E

Summary of Chapter 3.2

The BUI file has been reduced in syntax to the essential script lines. These represent the minimum number of parameters that occur for working simulation in the earlier design phases (LPh1 through 3).

- **Found**

From the start list of the **examined 28** parameters, **21** are found. The parameters not found are the thermal material properties, room occupancy, and material thickness. Five additional parameters should be added in Revit (using Dynamo), mainly element ID for connecting to other elements.

- **Layers:** [CONDUCTIVITY], [CAPACITY], [DENSITY]

These can be seen and changed under Material Browser (Fig 39). Since they are material-related, it is impossible to retract the relationship to individual elements.

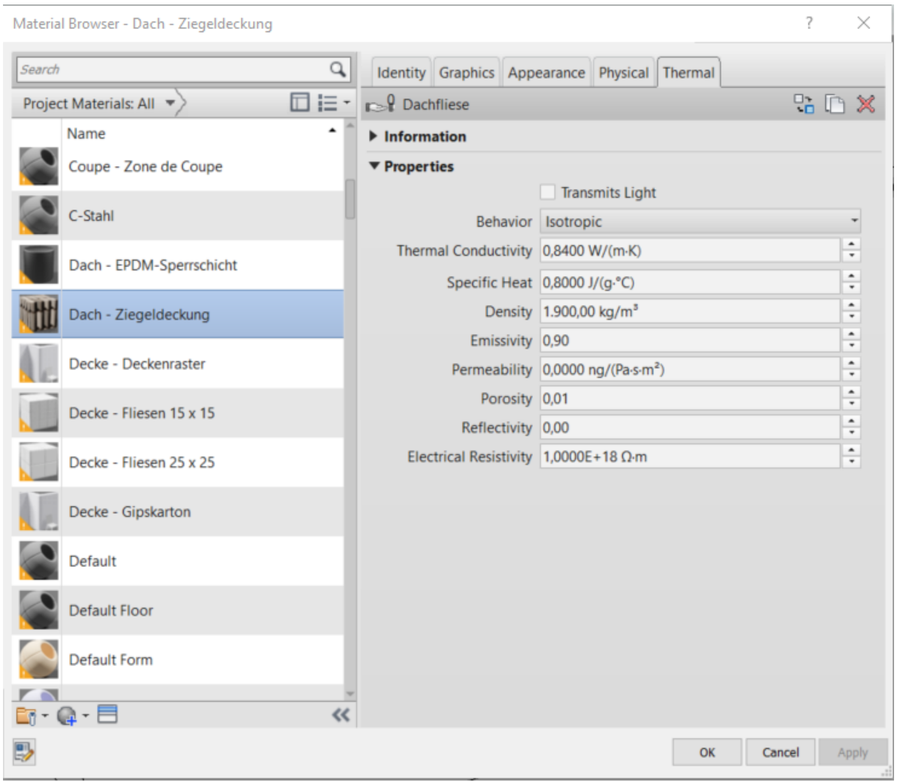


Figure 35: Thermal Properties in the Material Browser (snippet from Revit). Source: (By Author,2020).

- **Exported**

The **21** parameters found, plus five were successfully exported from Revit to Excel tables.

- **Converted**

Out of the **21 parameters, six** require separate formula of conversion since their original shape does not match the BUI syntax. These are Layers, LayersList, SurfID, Orientation, NextRoom, and Input.

- **Problematic jobs**

The conversion is not successful due to the lack of core information about the thermal properties of the project materials. The issue is often discussed in the literature and at Autodesk, and the effort for a full exchange continues.

Below given Figure visually interprets the result of the whole parameter extraction process.

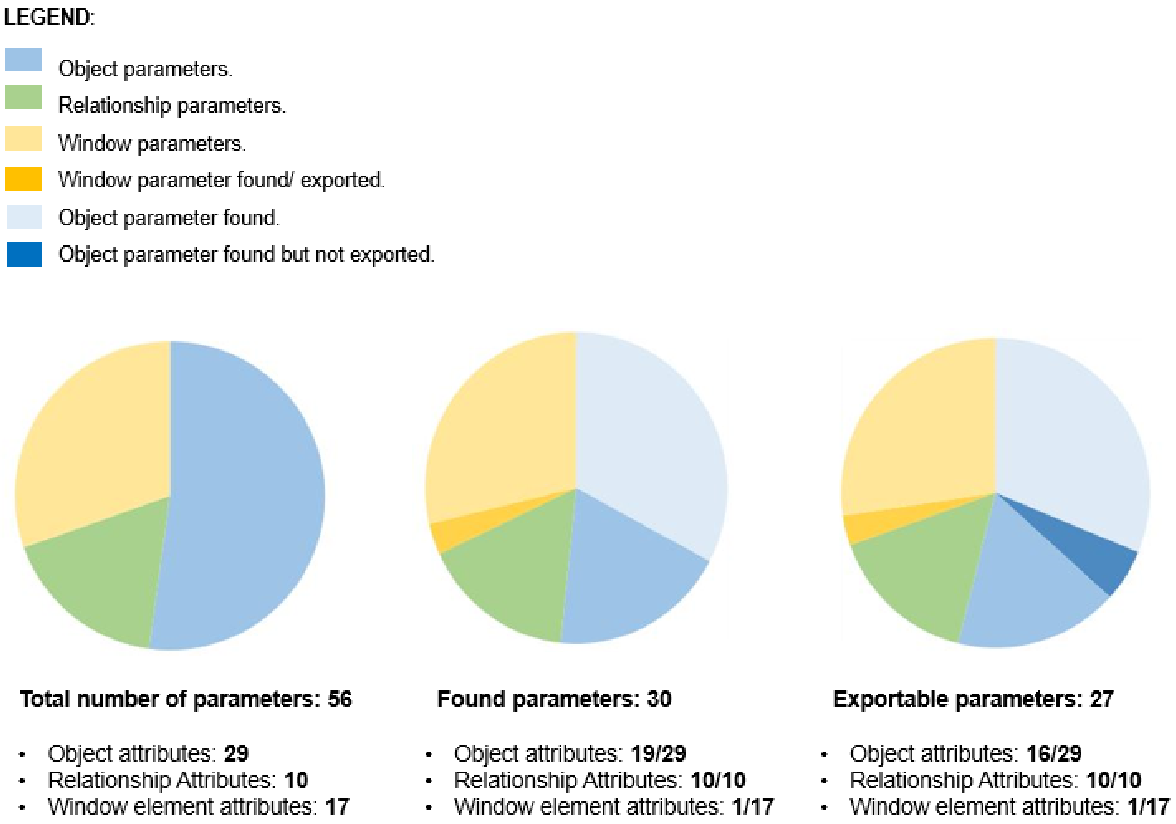


Figure 36: Result of the Parameter Extraction Process.
Source: (By Author,2020).

A parameter list defines the minimum requirements for a simulation, which is provided out of the BIM model. In the case of TRNSYS, the parameters are analyzed according to the native file structure *.bui (building definition). The corresponding attributes are organized in the BIM software (Autodesk Revit) in schedules then exported into Excel sheets. The suggested MS-Access database is a variation of handling the data exchange, which ensures the translation of the model data using a simple house model into the target syntax of the *.bui file, as well as providing the link between different project elements, and the generation of convenient BUI text paragraphs to work out a successful import into the simulation software.

Several parameters for export purposes are already found in the standard schedules of BIM software. However, these are paraphrased via the Access database subsequently in the *.bui syntax. The second type of parameter is developed to maintain the relationships between the elements and other parameters. The non-exportable parameters, such as density and thermal capacity among others, are described and listed in the results

3.3 Early Design Simulation Results

The above-given sub-chapters explain the whole building design simulation, which is to be carried out once the schematic design phase has been achieved in the project. This sub-chapter deals with the issues that come forward in the initial phases.

As discussed with the simulation expert, the parameters required for successful prediction in the early phases in detail are mentioned below. It is to note that the description here is in detail, and the highlighted ones are the significant parameters required. However, the variables mentioned within the highlighted points facilitates in predicting the energy accurately.

The basic guideline for building energy simulation is that the more detailed and accurate the input information, the more reliable is the results achieved.

Parameters (input data) for building energy simulation (Provided by Expert)

1. Building **geometry** and **orientation,** surrounding buildings or other shading areas.

2. **Sizes** and **thermal properties** of construction components (opaque construction types like walls, floors, and ceilings, but also glazing),
    - Thermal properties should be as a minimum: construction type with U-value (for opaque constructions), and U-values as well as g-values for windows, and type of shading devices with a shading coefficient.

- Better would be additional information about the thermal capacity of the components.
- Best solution: detailed information of the different material layers of the construction (thickness, thermal conductivity, density, thermal capacity), and the order of the layers (from inside to outside)

3. **Usage** of different zones (e.g. office, meeting, kitchen, fitness) as a minimum
   - Better would be detailed information about internal thermal loads (how much **people** with what kind of activity in the room, how much and what kind of electrical **devices** with heat emissions like computers, printers, **lighting**), heat emission of all internal loads in W/m² floor area, **hourly load profiles** (usage profiles)**,**
   - **Room temperature set points with profiles** for heating and cooling
   - **Ventilation flow rates and temperature set points with profiles**

4. **The volume** of the different zones, surrounding construction types/areas of the zones (see above)

5. **Weather data/ location** (to consider external loads like outside air temperature and solar irradiation)

Taking this as a base and further on the literature study and the early phases design simulation software as per table (early simulation table number) (kindly note that the requirements of the early-stage simulation software have been studied in detail)

Table 20, has been drawn out regarding the basic parameters that are needed for the early-stage simulation and can exist in the early stage, which will be pre-schematic design phase LOD100 and LOD 200. After generating the table, the box models (see figure 20-27) are evaluated to extract the below-mentioned parameters, and the results are as follows.

In the table shown below, the green box indicates the parameters that exist can be extracted, and the blue one indicates that the parameters can be made available if the decisions are taken in the early design phases. The red one indicates the simulator should assume the parameters based on previous projects and knowledge as these are challenging to decide in the early phases.

Table 19: Parameter Availability in Early Design Stage.
Source: (By Author,2020).

No.	Parameters	Availability Early stage
1	Building Geometry	Yes
2	Building orientation	Yes
3	Building Type (Usage)	Yes
4	Site location (Shading/ wind)	Yes
5	Window to Wall Ratio/ WWR	Maybe
5	Building Envelope /shell	Maybe
6	Type of glazing (High performance, shading coefficient, etc.)	No
7	Opaque wall Performance	Maybe
8	U and R-value of materials	No
9	Building systems (HVAC, lights, etc.)	No
10	Shading	Yes
11	Program flow (energy programming)	Maybe
12	Solar Radiation (Exterior)	Yes
13	Daylighting	Yes
14	Natural Ventilation potential	Yes

It should be noted that the early-stage simulation should be carried out partially as one representation for the repeated modules rather than the entire building so that its less time consuming and more design variations can be extracted.

Another critical point to note is that for carrying out the early stage of simulation DPM energy performance, modelling should be carried out not the BEM. The figure shown below illustrates different energy models based on the design stages.

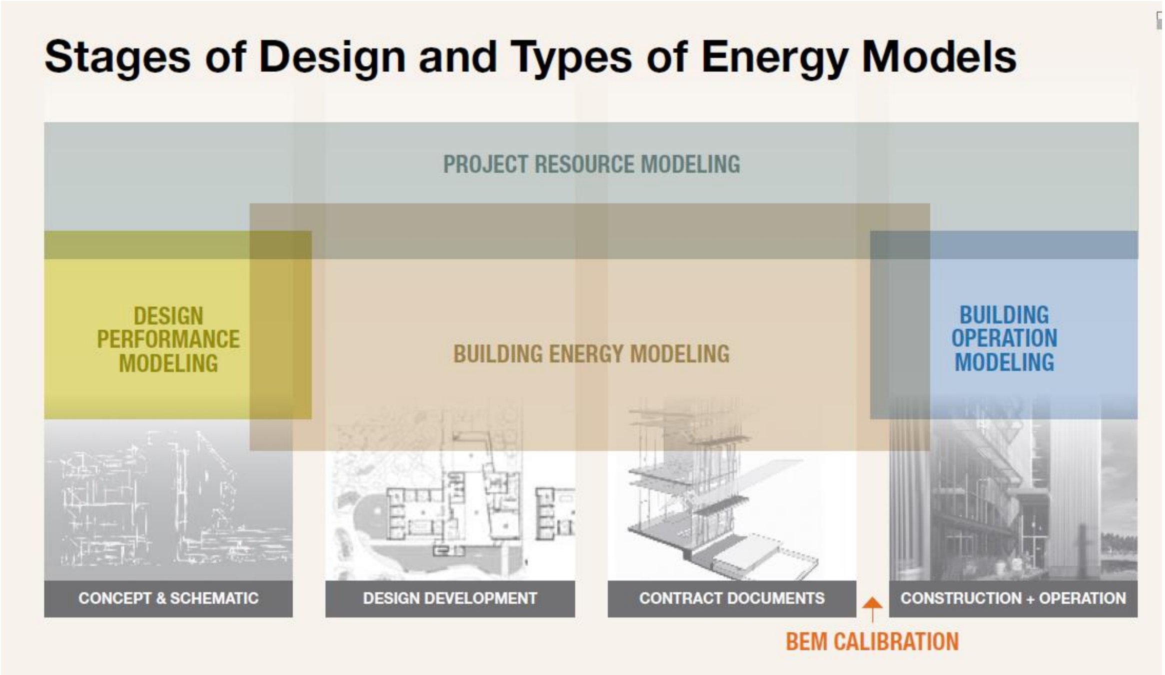


Figure 37: Energy Models Types as per the Design Stage.
Source: (AIA, 2012).

Design performance modelling predicts the design decisions based on the factors that are available in the early stage of designs such as daylight penetration, thermal comfort, ventilation, etc. As building systems are not decided in the prior stage, this model allows us to explore design variants and energy performance based on architecture parameters such as WWR, shading, R-value, etc. Design performance modelling encourages quick exploration of various design variations while giving importance to factors such as cost, aesthetics, and performance. However, one of the disadvantages of adopting DPM is that the software assists the early phase analysis is component-based and captures only a part rather than the whole building. Thus, the modeller needs to be familiar with both DPM and BEM as for code compliance; the whole building evaluation must be carried out (AIA, 2012).

Design performance modelling help in shaping the early-stage design decisions and at this stage, partial models satisfy the scope better to make decisions than the time consuming full-scale models (AIA, 2012).

3.4 Main Outcome from Chapter 3

To sum up, the main objective of this chapter was to develop a pilot project and carry out the practical procedure of locating and extracting parameters. From the beginning of the chapter (see chapter 3.1) LOD, it can be noticed that there is a certain gap between the level of detail in the TGA and Arch Box model.

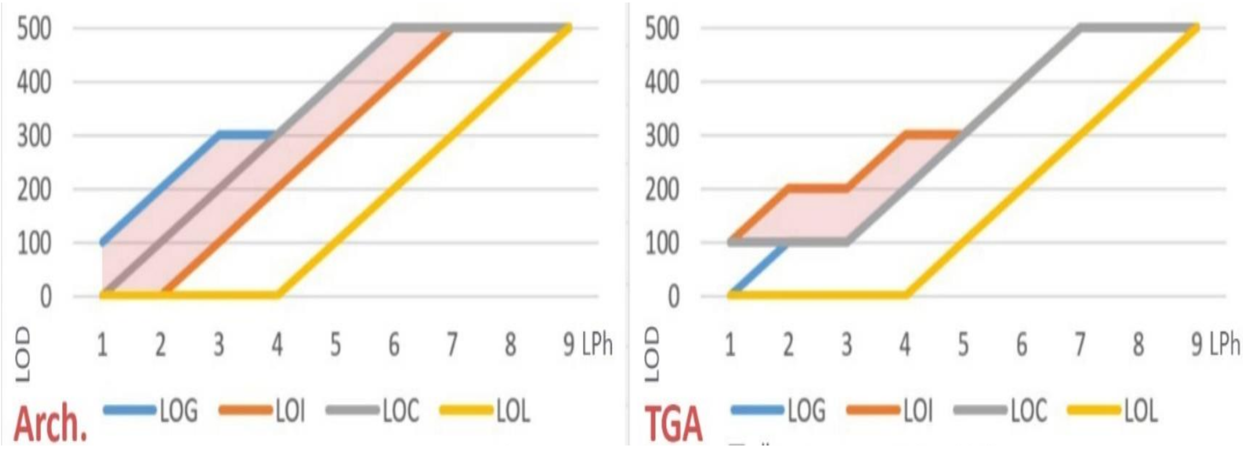


Figure 38: Gap Between Level of Detail of Arch and TGA Model.
Source: (By Author,2019).

In the second chapter (see chapter 3.2) it can be seen in terms of extracting parameters needed for carrying out energy simulation. LOD 100 is of no use as it is just a mass without much-needed information and also there is a considerable jump of information from LOD 200 to LOD 300 due to significant decisions being finalized and the details of the design getting consolidated at the later phase. Also, when it comes to the process of extracting parameters, the whole process is not seamless, and despite the best efforts of researchers and software developers still, not all parameters can be obtained. Due to this, the simulation experts make assumptions of the unextracted data and manually insert it based on key-spaces. The whole process makes the simulation vague and uncertain.

According to the data gathered from simulation expert and researches, the table formed contains attributes which are needed for simulation (see chapter 3.3). The results were that only 50% of the attributes could be extracted in the early phases of design from the models. To present the validity of the above carried out method further case study of an existing EUREF campus will be discussed in detail (see chapter 4).

4 Results/ Validation of the Process

To check the validity of the literature review and the hypothesis of the pilot project, the following case study has been selected. The case study selected projects EUREF HAUS 11. The reason for selecting this project is as follows:

- The researcher has worked on this project as a student assistant and is familiar with the process and workflow involved. (*Research campus Mobility2Grid Main phase (EUREF research campus) is a public-private partnership created to research and innovate in the field of energy transition and electromobility in networked urban areas. The Hochschule für Technik und Wirtschaft Berlin (HTW) is a member of this organization under the direction of the Project leaders: Prof. Dr.-Ing. Nicole Riediger and Prof. Dr.-Ing. Friedrich Sick. More information: https://mobility2grid.de*).

- The amount of information accessible, since the research project Mobility2Grid has ongoing research in the similar lines and a complete reference model and the workflow adopted before is available, which forms a validated base for this study.

- The third is the opportunity to have a meeting with the simulation expert working on the similar lines of the master thesis topic and get an insight into which workflow is reliable and which one is not. About the previous experience with the simulation workflow and how different software responds and which one should be adopted to get an accurate result.

This chapter four is further divided into five sub-chapters, the first subchapter (see chapter 4.1) explains the case study timeline and its agenda as what is the objective of the case study is, how the workflow of the case study follows, Which are the critical key steps in the workflow such as the teams involved and their input and role in achieving the target of the case study?

The second and third subchapter (see chapter 4.2, 4.3) talks about the parameter list generated for the case study project and highlights the issues and complications in extracting them, which will form a base for the comparison of the parameters list derived from the pilot project.

The fourth sub-chapter (see chapter 4.4) discusses the potential of taking a standard model as a reference for the process of simulation and whether it is feasible or not to make a standard template for the same.

The fifth and the last chapter (see chapter 4.5) discusses in detail the research objectives set to achieve through this master thesis and what is the result of the same.

4.1 Case study of the Model EUREF

The EUREF stands for European Energy Research Forum. The case study is taken from the *Research campus Mobility2Grid Main phase.* **Timeline of the project** – The project started in 2014 and is an ongoing research project to make the whole simulation workflow simplified and make the campus sustainable and energy-efficient. The campus consists of 19 buildings, and the case study experiment is being carried out in the building EUREF 11. Below is the rendered image of the case study site concerning building number (Euref-campus, Strategy and Mayor, 2018). The project site location is denoted with .

Figure 39: EUREF Campus Site Plan
Source: (Euref-campus, Strategy, and Mayor, 2018).

The following day-time and night time renders are of the case study building 11, done by the author.

Figure 40: Day-Time Render of EUREF Building 11.
Source: (By Author, 2019).

Figure 41: Night-Time Render of EUREF Building 11.
Source: (By Author, 2019).

4.1.1 Scope of the Case Study

The scope of the case study is to fulfil the following requirements of the project.

1. **Heating and cooling load calculation** for dimensioning of the HVAC systems (e.g. size of radiators)
2. **Energy calculation** of the building, comparison against the legal requirements (standards), and comparison of different energy supply systems
3. **Room temperature profiles** (thermal comfort assessment)
4. **Energy optimization.**

4.1.2 Software Used in the Case Study

The software used in the case study project is Revit BIM for modelling and TRNSYS for simulation. The central concept behind using this software as per the experts is due to the given below advantages.

Advantage of TRNSYS software

1. Modular, very flexible, and adjustable/extendable.
2. Based on physical models.
3. Dynamic time step simulation.
4. Each level of detail possible.

Advantage of BIM for energy simulation

1. Provision of all relevant input data within one model.
2. Less prone to modelling errors.
3. Timesaving.

4.1.3 Workflow Adopted by the Simulation Expert for the Case Study.

The workflow adopted by the team to carry out the case study is as follows:

1. Collection of all input data from architects and engineers
2. Assumption of all other data that cannot be provided from designers
3. Selection of zones of the building that should be investigated
4. Modelling of the zones:

- Material layers
- Construction components based on predefined material layers
- Area and orientation of the construction components
- Window types
- Window area/Window-to-wall ratio
- Shading devices
- Internal thermal loads: people, devices, lighting with hourly load profiles
- Definition of set points and profiles
- Integration of hourly weather profile.

4.1.4 Workflow of the Case Study EUREF-Project

The project is carried out in two teams out of which one is the modelling team to model the BIM model. It should be noted that the shell of the Model of the building is already made in Revit BIM. The services were modelled to calculate the energy load and suggest the best possible energy-efficient layout for the interiors. Thus, comprehensive research is being conducted to achieve the best possible result in terms of energy efficiency.The EUREF building 11 has a typical layout running across ten floors. The modeling team has modelled the services as per the consultant drawings for HVAC, ventilation, and ceiling and then tried to extract the parameters from this model. Below given images are the renders of the services modelled in LOD 400 as per the 2D drawings provided by the service consultants.

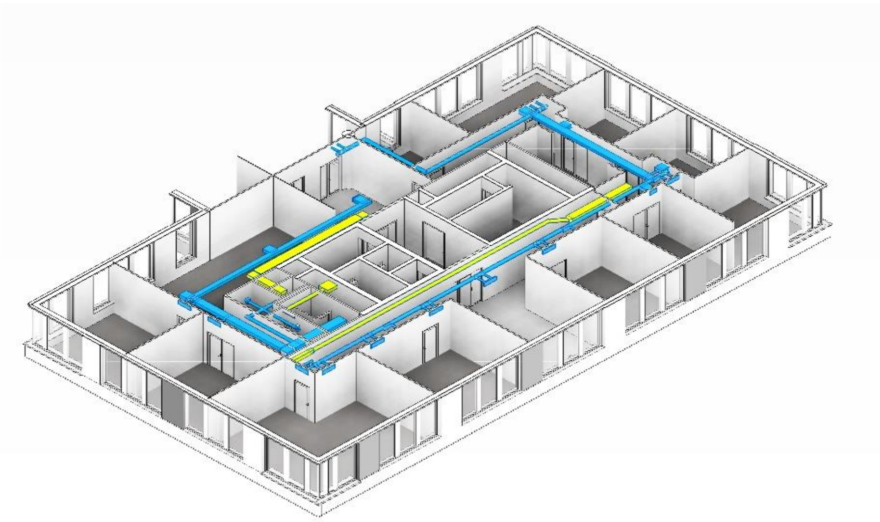


Figure 42:HVAC System on a Typical Floor.
Source: (By Author,2019).

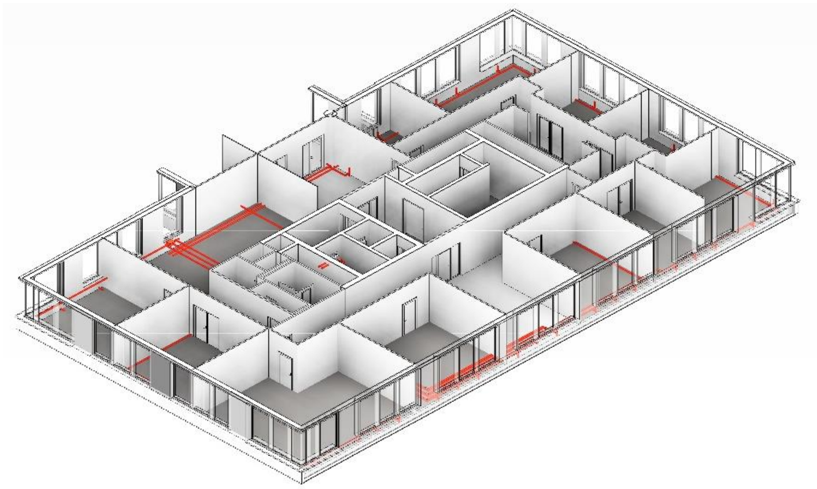


Figure 43:Heating System on a Typical Floor.
Source: (By Author,2019).

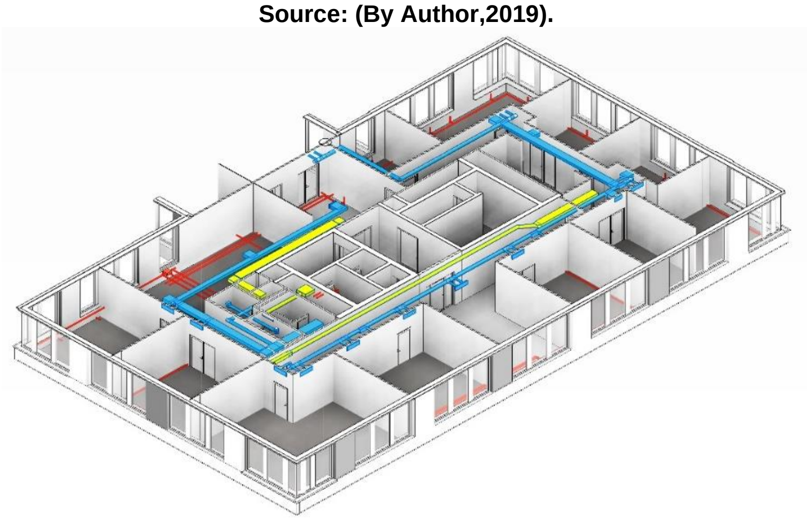


Figure 44: Building System on a Typical Floor.
Source: (By Author,2019).

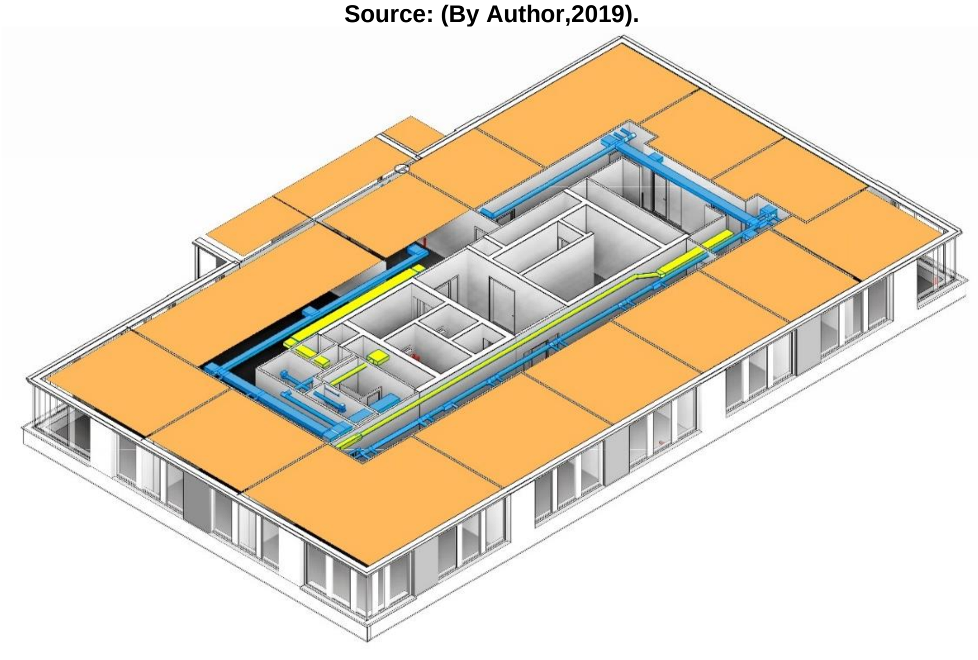


Figure 45: Ceiling panel & Building System on a Typical Floor.
Source: (By Author,2019).

The workflow carried out for the whole process adopted by the case study project is that parameters are extracted from the BIM model. A parameter list defines the minimum requirements for a simulation. In the case of TRNSYS, the parameters are analyzed according to the native file structure *.bui (building definition). The corresponding attributes are organized in the BIM software (Autodesk Revit) in schedules then exported into Excel sheets. The suggested MS-Access database is a variation of handling the data exchange, which ensures the translation of the model data using a simple house model into the target syntax of the *.bui file, as well as providing the link between different project elements, and the generation of convenient BUI text paragraphs to work out a successful import into the simulation software.

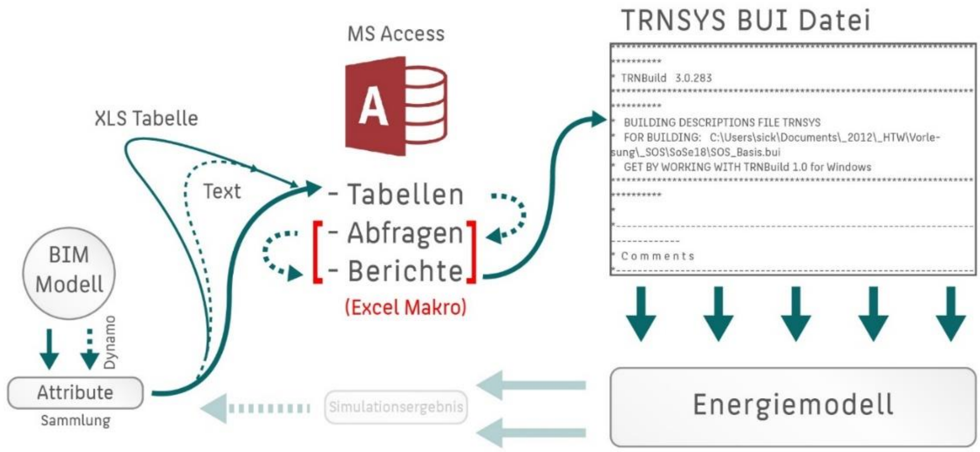


Figure 46: Simulation Workflow.
Source: Adapted from Case Study.

Several parameters for export purposes are already found in the standard schedules of BIM software. However, these are paraphrased via Access database subsequently in the *.BUI syntax. The second type of parameter is developed to maintain the relationships between the elements and other parameters. The non-exportable parameters, such as density and thermal capacity, among others, are described and listed in the results.

4.2 Validation of the Parameter List and its Accuracy

The detailed results of the case study, EUREF 11, can be found in Appendix A and Appendix B. It should be noted that out of 56 parameters required for the energy simulation, 30 can be found and out of which only 27 can be exported into excel. Thus, requiring a lot of manual work and assumptions on the part of the simulation expert to model the zones and assume the missing data.

Also, as mentioned in Table 19, the basic parameters required to carry out the initial simulation are fifteen in number out of which eight can be extracted and exported easily. However, the other seven parameters can be made available in the early phases by incorporating Integrated design (see chapter 2.5 & Table 10) and Design performance modelling (see sub-chapter 2.4.1). The following result and their interconnectivity have been explained visually below.

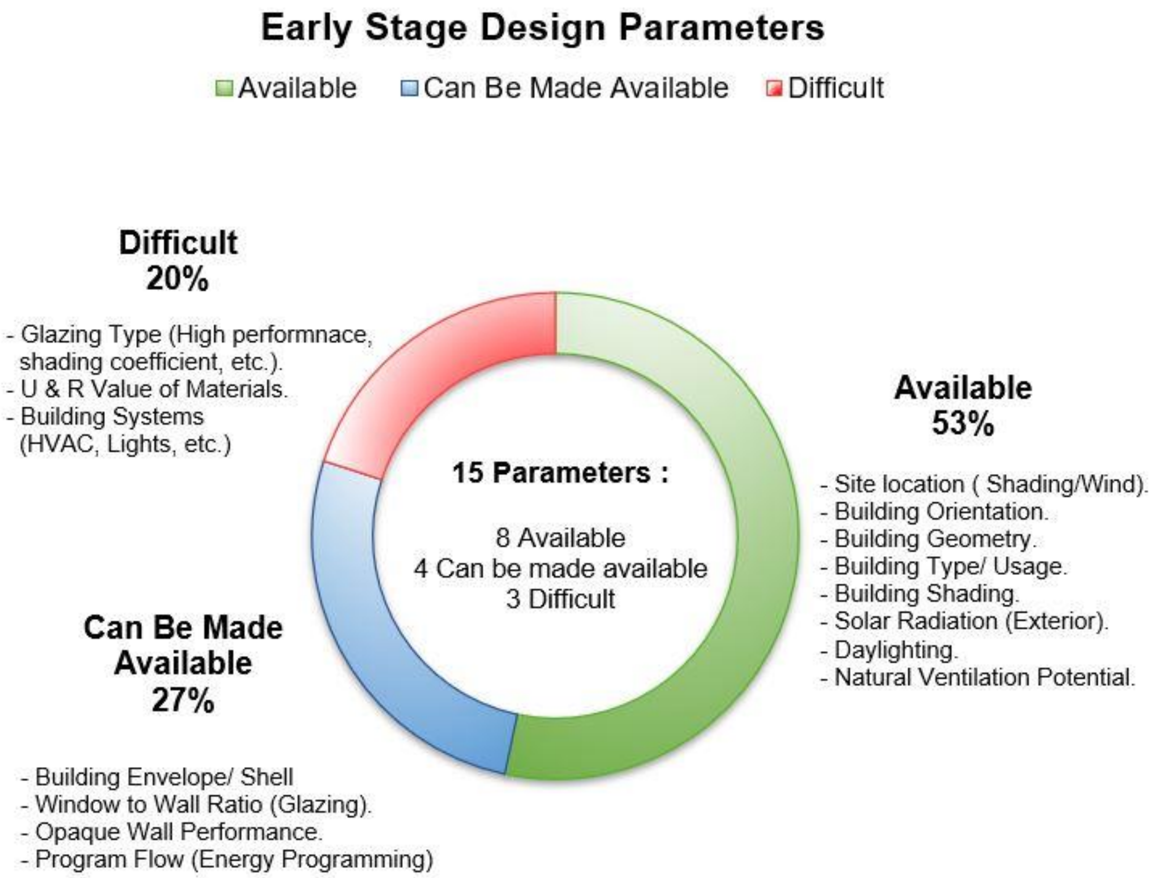


Figure 47: Visual Representation of the Early Stage Simulation Result.
Source: (By Author, 2020)

Thus, it is evident from the following results that if the Integrated design approach is followed for the early stage of design simulation. Then the other four parameters focusing on building outer envelope or shell can be achieved, which plays a significant role in determining the accuracy and reliability of the early-stage simulation results.

As shown in the figure below, building envelope parameters contribute to about 60% in the weightage of the early-stage parameter list.

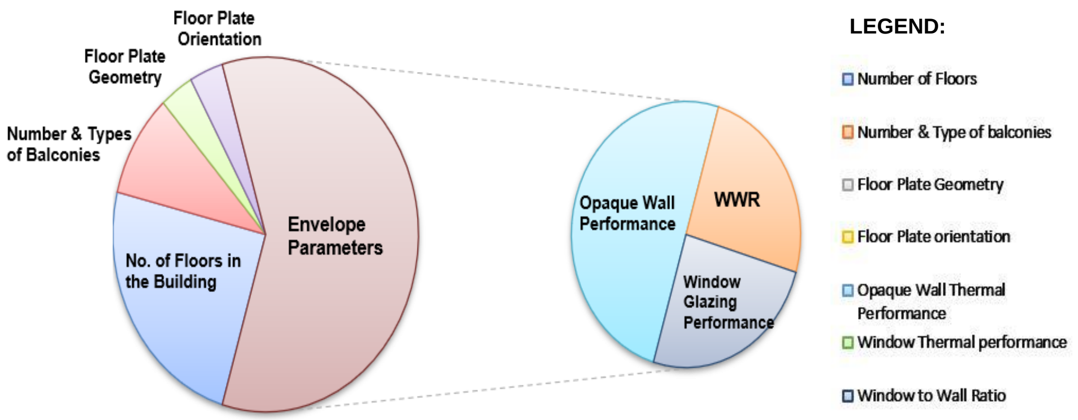


Figure 48: Prioritization of the Parameters in the Early Design Simulation. Source: (By Author, 2020)

4.3 Benefits of Early Phase BES from Project Management Point of View

To understand in-depth the project management point of view, an interview was conducted with an experienced project manager (several international projects), and the following points were highlighted during the discussion that conducting an early phase building simulation could benefit the client and project manager in the following ways:

1. **Unified goals for the different stakeholders of the project.**
   One of the significant benefits for the project manager and client is that the discussion of sustainability before designing motivates the whole design team to work towards the energy goals of the project in alignment. Which further helps the clients and project managers to prioritise assets in the strategies that deliver energy-efficient buildings. Further, it helps architects and engineers to set similar energy goals and stay coordinated to achieve energy efficiency in the project.

2. **The Client and the project manager are more informed about the whole process.**

   The process makes it easier for the project manager and client to be well informed about the scope, requirements, and services the project might need and the implications of the decisions taken in the early phases and the results of it. Simulation not only helps in taking the right decisions but also helps in optimizing the full process. The results of these simulations easily showcase how much can energy usage fluctuates in taking one wrong or not so accurate decision.

3. **Feasibility in achieving GBC certifications.**

   Adopting early-stage simulation helps in setting GBC goals early in the project, which in return helps the project in attaining the certifications easily in the later phases.

4. **Minimizing the risk of re-designing in the later phases.**

   Another benefit of integrating early-stage simulation is the prediction of various setbacks, delays, and risks that can be evaluated in the earlier phases. Thus, minimizing the risk of redesigning once the construction process has begun. Hence, helping in selecting the cost-effective optimized option early in the building process.

5. **The opportunity to test various alternatives before finalizing one**

   Early-stage simulation not only helps in selecting the optimized option but also facilitates the project manager in providing several design variations to select from. Thus, providing the client and project manager with a variety of options and even suggesting the most optimized one.

6. **Choosing the right size and type of building systems**

   The measure of heating, cooling demands, and lighting requirements assist in taking the right decisions and predicting the right size and type of building systems to be installed in the project. This also facilitates the project in achieving the GBC goals as the systems can be selected as per the building satisfying GBC criteria.

7. **Future energy usage predictions**

   It is estimated that adopting early-stage energy simulation helps in reducing the energy demands if the building by 50% (Franconi *et al.*, 2013). The entire simulation process assists in determining the future energy usage of the building and how to satisfy the needs and requirements of the building sustainably and cost-effectively.

8. **Assists project manager in achieving projects triple constraint (scope, schedule, and budget)**

   Therefore, the benefits of conducting and carrying out the early-stage simulation do not only limit to the sustainable and financial outcomes but also aids in bringing sustainability in the whole building process. It streamlines the scope and schedules of the projects and helps the team in assisting and evaluating the best-optimized design option for the project.

4.4 Generating Standard Reference Template

The parameters are more or less standard, but the workflow can be varied depending on the type of project, timeline of the project, software used, location, certifications, etc. so it is not possible to generate a standard template as a model. However, it is possible to generate a standard list of parameters that should be incorporated by the architects in the early phases as architects come early in the design process and are the primary stakeholders. Also, the requirements of architects and engineers are different from the simulation engines as they need different result for their processes

4.5 Research Objectives and Results

The Below mentioned objectives were set as the research objectives at the beginning of the master thesis. The aim was to distribute the primary objective of the study into a sequence of secondary objectives:

1. To study and identify different phases of design and construction, referring to GBC & LOD - **Achieved (See chapter 2).**

2. To summarize and generate the parameter list based on the inputs received from energy simulation experts and also address the practical issue manifest in retrieving the required parameters. **Achieved (See chapter 3).**
3. To list the parameters and attributes that exist in the model or can be accurately exported to the ones that cannot be. Furthermore, to evaluate the prioritization of these parameters. **Achieved (See chapter 3).**
4. To explain the practical process of retrieving parameters, that exists in the BIM model but can be extracted only with the help of external software (programming tools). **Achieved (See chapter 3).**
5. To generate a standard list of parameters required for early-stage energy simulation to be referred by the project manager. Additionally, elaborating the benefit for the project manager and project overall.**Achieved (See chapter 3 & 4).**

4.6 Research Gap

With the advancement in technologies and software, new updates are being generated approximately daily still, the whole process of BIM-BEM consists of a significant research gap. The major ones impacting the full process has been discussed below:

1. **Early stage difficulties**

The early incorporation of the simulation software is not as feasible as said; the whole process is time-consuming with contradictory requirements. As the design is a collective process with different stakeholders involved such as client, architect, engineers, consultants, end-user, etc. there are different requirements from each, and the design changes are very swift in the early phases. In addition to carrying out the simulation, lots of assumptions and uncertainties are inserted, which makes the whole process inaccurate and unreliable.

2. **Workflow unpredictability**

Integrating building information modelling (BIM) and energy analysis tools with green building certification system to conceptually design sustainable buildings (jalaei and jrade, 2014). The transfer is not a direct path between BIM and energy simulation. The step "Link between BIM Tools and Sim. Software is developed separately for each case study (not general) Although the paper says “Develop interface” in a unique process, it was not precisely explained what should happen because the overriding focus here is on certification.

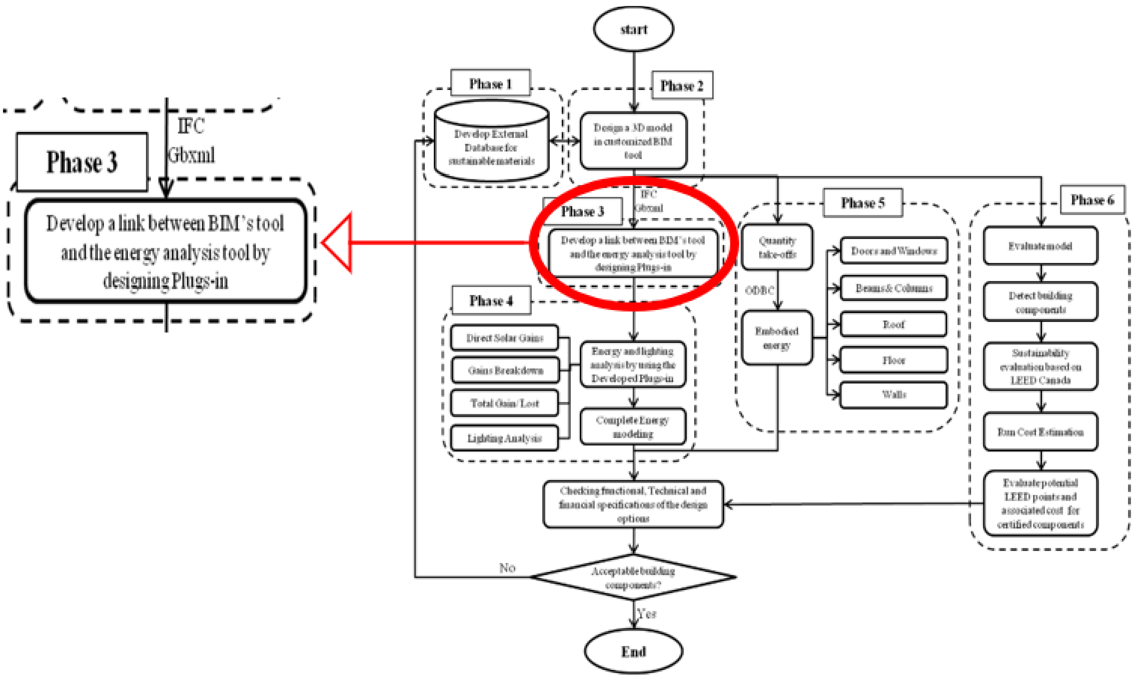


Figure 49: Status of Transfer from BIM to BEM.
Source: Adapted from (Jalaei and Jrade, 2014).

3. Early stage difficulties

The early incorporation of the simulation software is not as feasible as said; the whole process is time-consuming with contradictory requirements. As the design is a collective process with different stakeholders involved such as client, architect, engineers, consultants, end-user, etc. there are different requirements from each, and the design changes are very swift in the early phases. In addition to carrying out the simulation, lots of assumptions and uncertainties are inserted, which makes the whole process inaccurate and unreliable.

4. Programming issues

The current simulation tools existing in the market are highly involved with a complicated programming language. Skilled people are required to understand a tools procedure and work on it as architects are not programmers which makes it difficult for them to customize the software and use it for a specific purpose. There is a gap between the programmers who program the software and the user's Architects who use it. As the whole design process is collaborative, it is highly needed that the software is more flexible to adapt and easy to learn and work on by different parties(architect, engineers, consultants, etc.) having different expertise for having a transparent workflow.

5. **Reliability issues- software issues or energy simulation tools issues**

The whole energy simulation suffers through many software issues such as interoperability, no seamless exchange of data and thus, the results suffer from inaccuracy and unreliability.

- According to (Batueva and Mahdavi, 2015), The research conducted by the U.S Department of Energy states that out of the current estimated 400 simulation tools only 8% have the potential to carry out early-stage energy analysis.
- The growing number of tools with different formats and inputs makes it difficult for the user to select a tool.
- As the full design process is so fast-paced and unpredictable timely prediction of energy in the early stage is of utmost importance but has researched the current tools lag in estimating the energy performance in speedy or real-time.
- Also, the modelling process for simulation is time-consuming, and none of the software presents currently promises reliable and accurate data transfer.

Thus, making it difficult to rank the design variations. A study conducted on around 230 architects regarding selecting a simulation tools ranked that the intelligence and usability of the software are more critical for them than the accuracy and interoperability (Attia, Gratia, *et al.*, 2012).

6. **Architects and Engineer issues**

As per the literature study and the researcher’s personal work experience, there is a considerable gap in architects' and engineers' demand when selecting a simulation tool. The architects are concerned with the simulation tools that deal with design concerns such as Building shape, geometry, orientation, ventilation, shading, heating, and cooling, etc. and the engineers are concerned with the building systems predictions such as thermal comfort, system control, insulation, openings, HVAC and other building systems.

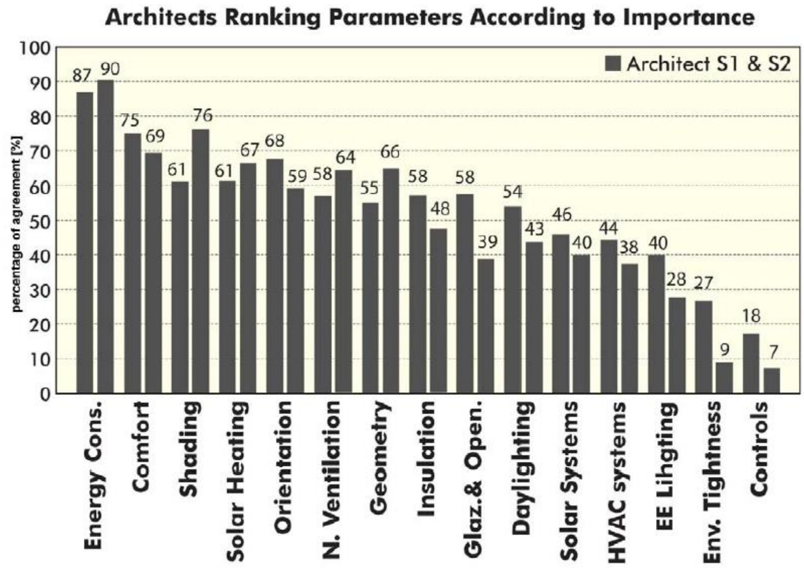


Figure 50: Parameters Priority Ranking by Architect.
Source: (Attia, Hensen, *et al.*, 2012).

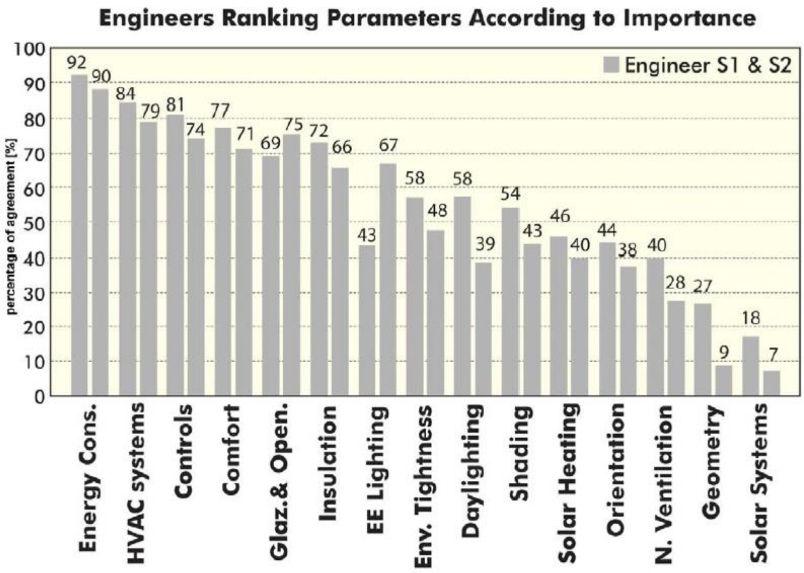


Figure 51: Parameters Priority Ranking by Engineers.
Source: (Attia, Hensen, *et al.*, 2012).

Since architects are more involved in the early stage, BES and factors such as building systems are not decided in that phase. The simulation tools should be selected as per the architect's concern, or integrated design should be used so that architects and engineers can set similar energy efficiency goals.

4.7 Research Questions

1. **What are the major issues and challenges related to retrieving the parameters in different LOD's?**
   The major issues and challenges associated with extracting the parameters in different level of development has been discussed in detail in chapter 3, Research methodology. Through the help of a pilot project the author has established a deep insight into the issues concerning the extraction process of parameters from a Revit Model.

2. **How can one retrieve the parameters? What tools are used in this process and how efficient are the results?**
   In the context of this research, dynamo is used for retrieving the parameters (see chapter 3.2).The workflow associated with extraction of parameters using dynamo has been explained stepwise (see heading 3.2.3). Despite the accuracy of results being high, it is still not efficient enough to extract and export all 56 parameters (see figure 36) needed to perform energy simulation with certainty and accuracy.

3. **Why has BIM not been actively used for building energy simulation? What are the research gaps that exist?**
   One of the prominent reasons of why BIM has not been actively involved for BES is due to lack of consideration made in the early phases to integrate both the processes.Other significant factors are limited knowledge and interoperability issues.The research gaps concerning has been highlighted (see sub-chapter 4.6).

4. **Is it possible to develop templates with a standard inventory of parameters to be used by the project manager for different types of the project? And how accurate are the results?**
   Yes, it is possible to have a standard inventory of parameters as suggested from the research conducted above. Since, the template lists out the basic yet effective parameters it can be used for almost all types of projects regardless of its type & usage. The accuracy of the simulation is directly proportional to the accuracy of the information delivered by the parameters. In the research conducted, the author is able to extract 12 parameters out of the needed 15, which ensures a high accurate & reliable result (see figure 47).

5. Discussion

Currently, there is much misconception regarding energy modelling practice and process. It is termed as a process to be used by the engineers for code compliance and to view energy data. However, slowly the AEC industry has started using energy modelling to measure building performance and its energy demands and requirements in terms of heating and cooling loads but after the completion or in the later phase of the project. The integration of early-stage design simulation is still a new concept in the AEC industry.

5.1 Identifications of the Problem

Despite the widely acclaimed and much-researched benefits of early phase energy simulation, the widespread integration of early phase design simulation is still not prevalent majorly because of the vagueness related to the below-mentioned factors:

1. Rapid change of design in the initial phases.
2. Uncertainty related to the early phase energy modelling process and software.
3. The ambiguous role of project manager in the whole simulation process.
4. Lack of awareness regarding the benefits of the whole process.
5. No standardization of approach.
6. An overwhelming number of software and programs with no proper guidance and instructions.
7. Limited reuse of knowledge.

1. **Rapid change in design in the initial phases.**

   The fluid setting of the design phases in addition to constant and rapid changes of design in the initial phases makes it a challenging process to assimilate energy simulation and deliver reliable results.

2. **Uncertainty related to the early design phase energy modelling process and software.**

   Detailed building energy models that are inserted with actual building information can deliver and predict energy usage and requirements. Even with these factors taken into account, the results of predicted energy usage might differ from the actual ones for valid reasons as the process of simulations allow the software to assume specific parameters regarding occupants, types of equipment, building systems. Whereas, the types of equipment may be default in terms of placement or operation as opposed to what was predicted in design. However, the assumptions can be refined, and the model calibrated once the building is constructed and performance information can be gathered.

In the case of early phases of design, the available parameters are less in number due to which the software and the simulator expert have to input much data manually and make assumptions. This leads to ambiguity and uncertainty in results. The presence of a professional simulator and use of early design phase software (see table 8) can minimize this error to a certain point.

3. **The ambiguous role of project manager in the whole simulation process**

In the current era of digitalization, the role of the project manager is continually evolving. The emerging trends and needs of the construction industry have advanced the position of the project manager from the traditional one. The project manager now needs to be aware of interoperability, knowledgebase integration, and adaptability of different design phases. It is the task of the project manager to aware of the project team and client regarding the emerging energy concepts in the market. Thus, the project manager needs to stay updated with the current GBC guidelines, market trends, and upcoming tools in the AEC industry. It is the vital responsibility of the project manager to select a licensed architect or engineer to work on the simulation software and to select the right tool for the optimization of the process. At the same time, calculate the economic benefits of simulating which phase with the questions as what, when, and why?

4. **Lack of awareness regarding the benefits of the early-stage simulation process.**

At present early phase design simulation is termed as a time-consuming and not cost-effective option for the projects, due to uncertainty and ambiguity involved with the results. Nevertheless, with the incorporation of the right tools, skilled team, and good workflow, the simulation conducted at an early phase can hugely benefit the client and the project manager. However, at present, the construction industry is not fully aware of the advantages and benefits. The simulation tool is viewed mostly as a compliance modelling tool, which is to be incorporated at a later stage once the building is constructed for benchmarking, quality control and code compliance.

5. **No standardization of approach.**

   The absence of any standard approach and parameter list makes it difficult for the users and the project managers to have guidance to rely on. The project teams do not know what to look for and what will help the simulation process. Hence, proposing a standard approach/template or parameter list to refer to can help the professionals in motivating them to use the simulation process in their projects much early in the building process.

6. **An overwhelming number of software and programs with no proper guidance and instructions**

   Lack of guidelines, instructions, and an overwhelming number of software tools make it confusing for the professionals to understand which software to use in which phase. A lot of the software is not free and is expensive to use hence choosing the wrong one cannot only provide inaccurate results but also demotivate the professionals to use it later. The different file formats, multiple software integration, and the complex programming of the software are not too inviting for the construction professionals to adapt too. The whole design process is very lucid and time-restrict, which demands highly developed software to adapt and easy to use for the professionals.

7. **Lack of re-use of Information**

   At present, there is no knowledge database provided for the simulators to share their experience or have a forum to re-use the information already proved by other experienced simulators. Thus, the presence of such a database can help in optimizing the time invested into modelling,and increase the input reliability.

5.2 Limitations of the Study

BIM and BES are a topic of broad-spectrum and technological advancements in the AEC industry and are being updated continuously. This constant change represents a limitation for the research since it is transforming the way the professionals and software companies understand the design and construction process and their professional work (Allen, 2016). The workflow involved in the data stage and interoperability issues of the software are being updated daily, and hence the outcome may become outdated or cannot be generalized beyond a scope.

Another limitation is that the overwhelming breadth of software present for carrying out energy simulation with different input and output file formats. The number of software available makes it challenging to try and test each of the software in practice to deliver the result. Also, most of the software is not freeware. The author observed that dynamo updated a new plug-in monthly. Hence in such a context, it is challenging to stay updated with the results achieved. The given below figure highlights five different technologies were introduced in a duration of ten years (see the year 2010-2020)

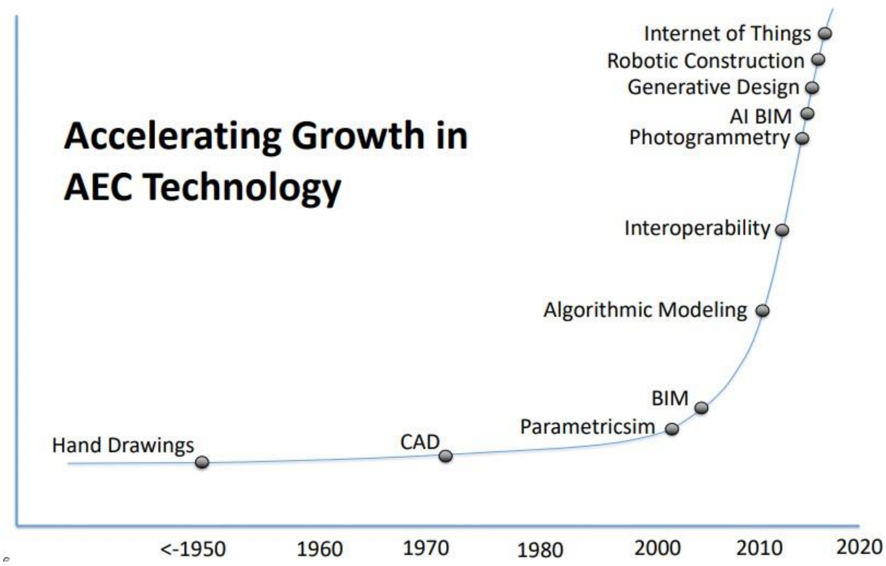


Figure 52: Growth in the AEC Industry.
Source: (Allen, 2016).

Also, the project was carried out in a limited time, despite the best efforts made, the outcome can have internal and external limitations, and on the tool side, the complex structure and programming of this software can proof to be of hindrance without proper expertise in the information technology department. Hence, the focus of the research is based on academic literature, methodology, and current use of the software according to the design and simulation process not in the programming or invention process.

The exchange between BIM Models and simulation software is limited and exhibits gaps on the road to seamless cooperation and lossless data exchange. (Bazjanac, 2008). The import/export processes using standard IFC (Industry Foundation Class) Format are not seamless (Kamel and Memari, 2018). The simulation is manually conducted based on key-spaces. Here it is lavish to having to input the model data in every new simulation. Thus, a simulation of the whole building without manual adjustments is still ruled out (Benz *et al.*, 2018). Among many export/import methods, an external database serves as an interface for manipulating the exported data rows into the appropriate Files.

Also, the complex programming language and multiple file-formats limits the capability to fully understand the workflow of software and how to modify it as per the needs of a project as every project is unique and standardized the assumptions can be a risky task to incorporate.

5.3 Recommendations and Future Research Topics

There are countless opportunities for further research on this topic, as the construction industry is continually progressing, and new technologies and software are coming in the market daily. Additionally, several exciting topics came across while conducting the interview of industry professionals and researching the literature, which forms a good base for recommendations. Future studies and research on this topic should focus more on how to take a holistic approach to adopt early-stage energy simulation as a common practice. Below mentioned are some of the recommendations to be adopted to provide the society with better value and more energy-efficient buildings.

1. **Involvement of energy modeller and simulator in the design process.**

Construction is a collaborative process where coordination and involvement of the right stakeholders at the right time is of key importance. To utilize the full potential of BEM, the energy modeller and simulator should be included in the project’s energy dialogue.

They should take an active part in project discussion, meeting, establishing performance targets, etc. With their expertise, they can provide technical suggestions in incorporating integrated design solutions. They should be involved and updated about the change orders when it comes to performance targets and energy models. The complete design documentation set and detail should be provided to them to establish a clear understanding of the design process.

2. **The mandatory requirement to include early phase energy simulation in projects (Included in the contracts)**

Another vital factor to be considered which was also highlighted in discussion with the project manager is to include the energy simulation process in the contract and pay the project manager for it. Apart from including it in contract, it should be made mandatory as a guideline by the government to perform simulations of all the new construction buildings in its early phase to contribute to the upcoming demand of NetZero and energy-efficient buildings.

3. **Conducting workshops for the team to inculcate early design process and its benefits**

One of the other important consideration would be to conduct regular workshops and certification courses to make the teams and construction professionals aware of the gains and advantages of incorporating these processes into the building process. It is also essential to teach and guide the software available in the markets and suggestions on what to use to determine the requirements of the project.

4. **Model adjustments should be carried out to improve the simulation results.**

A qualitative jump can be observed between LOD 200 and 300. Window elements are responsible for the geometry and properties that affect building behaviour. The components are defined in LOD 200 but without specific product and material specifications, which only occur in LOD 300. With LOD 400, the element information is deepened and execution relevant, which is subject to the minimum difference to LOD 300.

A shift of the model quality to the earlier work phases of the HOAI is necessary for functional simulation. The model quality achieved by LOD 200 is not sufficient for this to make sense to use the simulation model when designing.

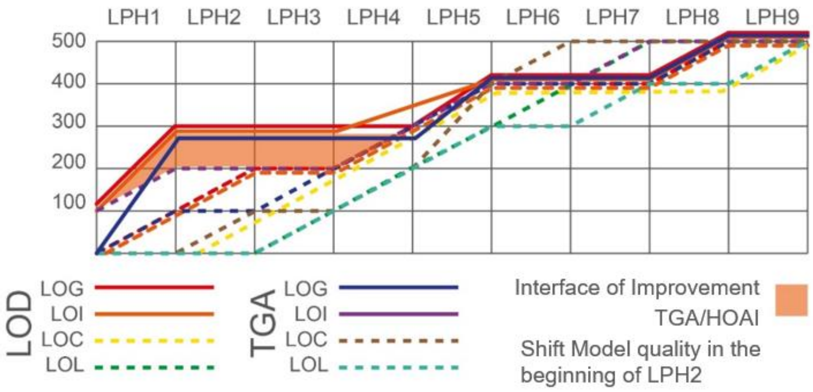


Figure 53: Simulation Result of Different LOX on Shifting Parameters from LOD 300 to LOD 200. Source: Adapted from the case study (By Author, 2020).

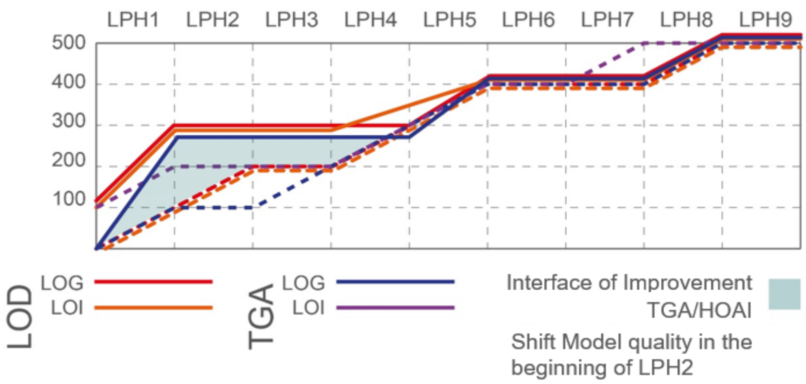


Figure 54: Simulation Result of Different LOX on Shifting Parameters from LOD 300 to LOD 200. Source: Adapted from the case study (By Author, 2020).

As seen from the graphs above, it is evident that the model adjustment affects the early phase design simulation process. Thus, the process of determining the parameters of LOD 300 in LOD 200 can hugely impact the results of the simulation process.

5. Generation of a knowledge sharing database platform

At present, lack of knowledge sharing database makes it challenging for the simulators or modellers to share their knowledge, expertise or refer a platform with already successful simulations file. Hence, generating an online library or platform will help in saving time while increasing the reliability of the input information and reusing the expertise of professional simulators.

Conclusion

The overall objective of this study was to propose a template for the project manager required for conducting early design phase energy simulations. Additionally, to determine the feasibility of adopting early-stage energy simulation by identifying the main perceived barriers and benefits. The aim is to integrate the early phases of design with technology for generating unified and environmentally responsive design outcomes.

With the digital design becoming knowledge-intensive, the current need of the hour is to integrate design and simulation to work in coordination to develop strategies for unified energy efficient design. The current thesis contributes to the growing body of research conducted in accelerating the traditional AEC industry in adopting ahead of the current practices and leverage the technological advantages to its maximum potential. At present identified challenges like (see chapter 5) missing/lack of information, uncertainty, fuzziness, expanding level of detail, interoperability issues, time- exhausting modelling, massive design space and quick change of design contribute to the inaccuracy and complications in conducting early stage building simulations. Considering the broad-spectrum, difficulties influencing all phases of building process incorporates lack of proper reuse of information, interoperability issues, limited simulation guidance, overwhelming number of software, contradicting and sterner requirements, different file formats, and inconsistency between simulations and real-life measurements.

Despite of the challenges the benefits of performing early-stage design simulations overtake the obstacles, and through the research, the author has established an inventory of parameters required for conducting the early design phase energy simulation. In the inventory (see table 19) out of these fifteen parameters, twelve are attainable, which further leads to high accuracy and reliability in the energy predictions.

Though the industry is still far from utilizing the energy simulation tools to its full potential and is struggling with the issues like interoperability, loss of data, manual inputs and errors, the parameter inventory promises a good start for the project stakeholders to use it as a base in locating the parameters required in the early phases.

In the era where energy efficiency is not a requirement but a need, it is critical to incorporate the energy simulation since the beginning of the project to deliver significant value to the project and society in general by constructing a high-performance energy-efficient building.

Declaration of Authorship

I hereby declare that the attached master’s thesis was completed independently and without the prohibited assistance of third parties, and that no sources or assistance were used other than those listed. All passages whose content or wording originates from another publication have been marked as such. Neither this thesis nor any variant of it has previously been submitted to an examining authority or published.

Berlin, Germany. 30.10.2020

Location, Date

Richa Srivastava

Signature of the student

Appendix

Appendix A

Variable	Description	Found	Source in Revit	Affiliation	Export / converted
[absolute filepath]		-			-
[LayerName]	List of project materi-als used	X	Material List	All Elements	E / U
Conductivity		-	thermal proper-ties - Material Browser	"	-
Capacity		-	"	"	-
Density		-	"	"	-
[INPUT]	defined in TRNSYS	-			-
INPUT	defined in TRNSYS	-			-
[Schedules]	Can be defined in Revit, but would be easier to load into TRNSYS due to refor-mulation	-	shared parame-ters	Project	-
Name	"	-	"	"	-
Hours	"	-	"	"	-
Values	"	-	"	"	-
[MultiLayerEl-ementName]	List of project ele-ments - multilayer	X		Material Browser	E / U
[LayerList]	Materials in the re-spective element	X		Material Browser	E / U
[ThicknessList]	Material thickness	-		Material Browser	-
[Absorptance]		X	Wall List	Wall evalua-tion table	E
[Emissivity]		-			-
[Win-dowName]	Window: FamilyType Name	X	Window List	Window evaluation table	E
ZONES					
[RoomNameL-ist]	List of project rooms or zones	X		Room Schedule	E

[Direction_AngleH_AngleV]	Orientation / alignment (definition)	X	from dynamo definition list	-	E / U
[RoomName]	N	X		Room Schedule	E
[Element-Name]	Walls in the room	X	Element ID for membership	Wall List	E / U
[Area]		X	Wall List	Wall List	E
[MaterialDescription „Int-Ext“]		X	Material list	Material Browser	E / U
[Orientation-Syntax]	Orientation / alignment	X	Dynamo	-	E / U
[WidowName]	From the window list with affiliation to the room	X	Room-Window ID	Window evaluation table	E
[WindowID]	ID is used as a surf ID in * .bui, a test carried out, it works	X	Dynamo	-	E
[WindowArea]		X	Window-area List	Window evaluation table	E
[MaterialDescription „Int-Ext“]	same as above, s. Connection right	X	Material list	Material Browser	E / U
[Orientation-Syntax]		X	Wall-Orientation List Dynamo	-	E / U
[INPUT]	Defined from TRNSYS, or: any	-		-	-
[Element-Name]	Other elements in the room (walls, floors, ceilings)	X	Wall List	Wall List	E
[ElementIDSurf1]	Inner surface of the wall	X	Element ID +1,2, Dynamo	-	U
[Area]		X	Wall List	Wall List	E
[NextRoom]	Derive the affiliation from the wall list + room ID	X	Room - Wall ID	-	E / U
[ElementIDSurf2]	Outer surface of the wall	X	Element ID +1,2, Dynamo	-	E / U
[DirectionIf „Front_Back“]	Defined by the ElementSurfID	X	"	-	U
[Room-Volume]	Cubature of space	X	Room List	Room Schedule	E
[RoomArea]		X	Room List	Room Schedule	E
[RoomName]		X	Room List	Room Schedule	E

Appendix B

Table Name	Param1	Param2	Param3	Param 4	Param 5	Param6	Param7	Param8
Wall_ID-Room_ID	Wall. Element.ID	Room ID	Room ID	Room ID				
Room_ID-Ceiling_ID	Room ID	Ceiling. Element.ID	Ceiling. Element.ID					
Room_ID-Floor_ID	Room ID	Floor. Element.ID	Floor. Element.ID	Floor. Element.ID	Floor. Element.ID			
Room_ID-Window_ID	Room ID	Window. Element.ID	Window. Element.ID	Window .Element.ID	Window. Element.ID			
Wall_ID-Orientation	Wall ID	Orientation String						
Wall List	Family name	Type	Area	Absorptance	Heat Transfer Coefficient (U)	Thermal Resistance (R)	Thermal mass	Volume
Material list	Family name	Type	Material Name	Material Description	Volume	Area		
Wall_ID-Wall_Type	Wall ID	Wall Type						
Ceiling_ID-Ceiling_Type	Ceiling ID	Ceiling Type						
Floor_Type-Floor_ID	Floor Type	Floor ID						
Window_FamilyType-Window_ID	Window Type	Window ID						
Room Schedule	Number	Room Name	Area	Perimeter	Volume	Level		
Wall_ID-Window_ID	Wall ID	Window ID	Window ID	Window ID				
Room_Name-Room_ID	Room Name	Room ID						
Wall_ID-Wall_Area	Wall ID	Wall Area						
Window_ID-Window_Area	Window Type	Window Area						

(Green cells) Exported directly from Revit

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