DIPLOMARBEIT

USABILITY STUDY OF A WEB-BASED BUILDING PERFORMANCE OPTIMISATION TOOL

ausgeführt zum Zwecke der Erlangung des akademischen Grades einer Diplom-Ingenieurin

unter der Leitung von

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Kurzfassung

Die Energieeffizienz von Gebäuden wird von vielen Menschen aus verschiedenen Gründen gemessen und analysiert. Das Interesse daran reicht von der Betrachtung im globalen oder regionalen Rahmen bis zum Fokus auf einzelne Gebäude oder separate Energiesysteme. Daten zur Energieeffizienz eines Objekts werden von einer Vielzahl von BenutzerInnen aus dem öffentlichen oder privaten Sektor, wie beispielsweise politischen EntscheidungsträgerInnen, BesitzerInnen oder BetreiberInnen von Gebäuden, DesignerInnen, sowie auch in der Gebäudebewertung und Forschung benötigt. Aufgrund der bestehenden Nachfrage wurde ein breites Spektrum an Werkzeugen und Herangehensweisen entwickelt. Diese zielen auf verschieden Arten der Analyse ab und unterscheiden sich im Ausmaß der möglichen Präzision sowie der konkreten Planungsphasen, in denen sie angewendet werden können. Mit jedem dieser Werkzeuge wird die Energieeffizienz auf unterschiedliche Weise dargestellt, um den Ansprüchen der BenutzerInnen möglichst genau zu entsprechen.

Die SEMERGY genannte web-basierte Optimierungs- und Entscheidungsunterstützungsplattform für die Planung von neuen Gebäuden und Gebäudesanierungen ist ein Instrument, welches ProjektteilnehmerInnen auf effiziente Weise hilft, mögliche Gebäudekonfigurationen zu identifizieren. Sie wird zur Evaluierung von Design-Strategien und Materialkombinationen genutzt, welche im späteren Verlauf des Projekts für eine optimale Energieeffizienz von Neubauten und Nachrüstungen bestehender Gebäude sorgen sollen. In einer frühen Entwurfsphase, wo sich grundlegende Parameter von Bauwerken mehrmals ändern können, liefert die Analyse der Energieeffizienz wertvolle Daten, aufgrund derer Entscheidungen getroffen werden können, welche später die optimale Funktion des Objekts sicherstellen.

Die vorliegende Arbeit präsentiert das Ergebnis einer Studie über dessen BenutzerInnenfreundlichkeit. Der TeilnehmerInnenkreis setzt sich aus einer repräsentativen Anzahl von Laien, StudentInnen des Bauwesens und professionellen AnwenderInnen aus den Bereichen Architektur sowie Ingenieurs- und Bauwesen zusammen. In 36 Einzelversuchen wurde die Interaktion der BenutzerInnen mit den verfügbaren Werkzeugen beobachtet, während diese vorgegebene Aufgaben lösten. Die dabei gesammelten Bildschirmaufnahmen wurden analysiert, um Daten zu den Parametern Effektivität, Erlernbarkeit, Effizienz, Einprägsamkeit, Fehleranfälligkeit und Zufriedenheit im Zusammenhang mit der Verwendung des Programms zu erlangen.

Als Resultat zeigt sich eine positive Aufnahme von SEMERGY durch alle BenutzerInnengruppen. Die web-basierte Lösung bietet auf effektive Weise Unterstützung bei Entscheidungen in einer frühen Phase des Designs. Sie unterstützt sowohl Laien durch einfache Erlernbarkeit und Einprägsamkeit als

auch professionelle AnwenderInnen durch effiziente Arbeitsabläufe. Allen Versuchspersonen gemein ist eine gutes Resultat im Bereich Zufriedenheit. Unterschiedliche Vorkenntnisse haben jedoch zu abweichenden Erwartungshaltungen gegenüber den vorhandene Werkzeugen geführt. TeilnehmerInnen mit Erfahrung in der Verwendung von Planungssoftware tendieren zu einer höheren Fehleranfälligkeit beim Zeichnen von Gebäuden als Laien. Letztere widmen dem Erlernen der Abläufe in SEMERGY mehr Zeit anstatt das Vorhandensein bestimmter Funktionen vorauszusetzen.

Abstract

Energy performance of buildings is measured and analyzed by many individuals for a variety of purposes. Interests in the energy performance of objects can range from a global or regional scale to single buildings or even individual energy systems as smallest units. Data of energy efficiency is required by a wide range of users in the public and private sectors, such as policy makers, owners, designers, operators, building raters and researchers. As a result of the existing demand, many tools and approaches have been developed. They aim to analyze building energy performance in different ways, at different levels of effort, with varying degrees of precision and also at different stages in the process of planning and constructing a building. With each of these tools, the building energy performance is quantified in a different manner and customized to fit the users' requirements.

SEMERGY web-based building performance optimization tool is a decision support tool that assists stakeholders with a broad range of backgrounds in identifying potential building configurations efficiently for their projects. It is employed to evaluate design strategies and material combinations that further on in the project will optimize the performance of the final design in new construction and retrofit projects. In the early stages of design, where geometry and semantic properties of buildings constantly change, energy evaluation can provide valuable data that leads to smart decisions to ensure an optimal performance of the building.

The present work reports the result of a study to measure its usability in different situations. Participants consist of a representative number of non-professionals, Building Science students and professional users from the fields of architecture, engineering, and construction. In 36 usability study sessions, their interaction with SEMERGY's user interface was observed while they performed given tasks. The resulting screen recordings were analyzed to obtain data regarding the effectiveness, learnability, efficiency, memorability, the susceptibility of errors and satisfaction associated with the usage of the program.

Results are positive and satisfying for all user groups. SEMERGY is a very effective tool that helps to provide support for decisions in an early stage of design. It provides great learnability and memorability to non-professional users as well as an efficient workflow for professionals in different fields. All groups respond with positive satisfaction results. Nonetheless, diverse backgrounds of users lead to different expectations of the behavior of tools. Participants with drafting tool experience tend to cause more errors in drawing geometry than participants without any drafting tool background. The non-professional users spend longer time acquiring information of the tool than expecting a certain function.

Acknowledgements

I would first like to thank my thesis advisor Prof. Dr. Ardeshir Mahdavi and my thesis co-advisor Dipl. Ing. Dr. Ulrich Pont, who are patient and considerate, and have kindly guided me in the right direction toward the completion of this study.

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CHAPTER 1

Introduction

1.1 Overview

Web-based energy performance optimization tools give an alternative to current users of conventional tools for stakeholders in architecture, engineering, and construction (AEC) field. Nevertheless, the tools should be in an uncomplicated environment along with instant availability and accessibility.

Semergy, a web-based energy performance optimization tool, supports users to experiment with different building configurations and their modification on buildings functional, ecological and economical performance. The conventional method regarding collecting related issues' data is complicated, time-consuming and error-prone. The aim of this tool is to support the building's design phase related architecture, engineering and construction contributors regarding cost reduction, occupants comfort, and productivity. Therefore, an attempt for the design of energy efficient buildings is reduced.

This thesis is to examine its usability to optimize the usage of the tool beneficial to achieve its decent function and focuses on developing ideas in optimizing the current design during the early-stage process as well as alternative building design and retrofit options.

In the first part of this thesis, literature will be reviewed to analyze different optimization techniques. In the second part, the use of the tool will be investigated with the questions of how the tool is used, what possible flaws are and what should be improved.

1.2 Motivation

In the past years, the importance and availability of computers have changed radically. Computers are not expert-only systems, but they have a profound impact on every person's daily life. Under these circumstances, it is crucial that computers, software and interactive systems as a whole be simple to use and to learn. In addition, there is a change of user groups, in the past typical users were computer experts using highly customized and custom-made software after having special software training. Today the target group of a software product is much greater and more heterogeneous; users are often not very experienced in using computers (Thurnher 2004).

Web-supported tools for knowledge inquiry and problem solving have been well known during the last decade. The increasing availability of web-based sources of consultive information and decision-making support tools promptness advantages stakeholders in many areas of expertise. The ease of use and application instant updates are characters that grow the use of the tools (Byrne et al. 2009).

Usability and user interfaces in building performance simulation tools are seemingly positioned farther back from commercially computational tools (such as operating systems, popular applications, games). Early simulation tools developers are not specialists in human-computer interaction (HCI) but engineers and physicists. Concerning its usability, building performance simulation applications were not meant for broad usage as research tools. Certainly building performance simulation tools usability has improved in the last decades, but there is still significant potential for enhancement (Mahdavi 2011).

Because significant functional requirement and detailed design document do not by themselves guarantee that a programmer's final code will be correct, so in advance usability guidelines do not by themselves guarantee a usable end product. In both cases, a specific validation process is required. Usability testing is the process by which the human-computer interaction characteristics of a system are measured, and weaknesses are identified for correction. While the amount of improvement is related to the effort put in usability testing, all of these approaches lead to better systems (Levi and Conrad 2008). By that means, the results can guide the process of requirement specification for user interface designs for the tool.

Decisions taken during conceptual design have a disproportionate impact on the final building performance, relative to time and effort consumed (Domeshek et al. 1994). During early stage design phase, 20% of the design decisions taken afterward, influence 80% of all design decisions (Bogenstätter 2000). Furthermore, in the later design phase, the cost of implementing changes during the early design stage is extensively lower (McGraw-Hill 2007).

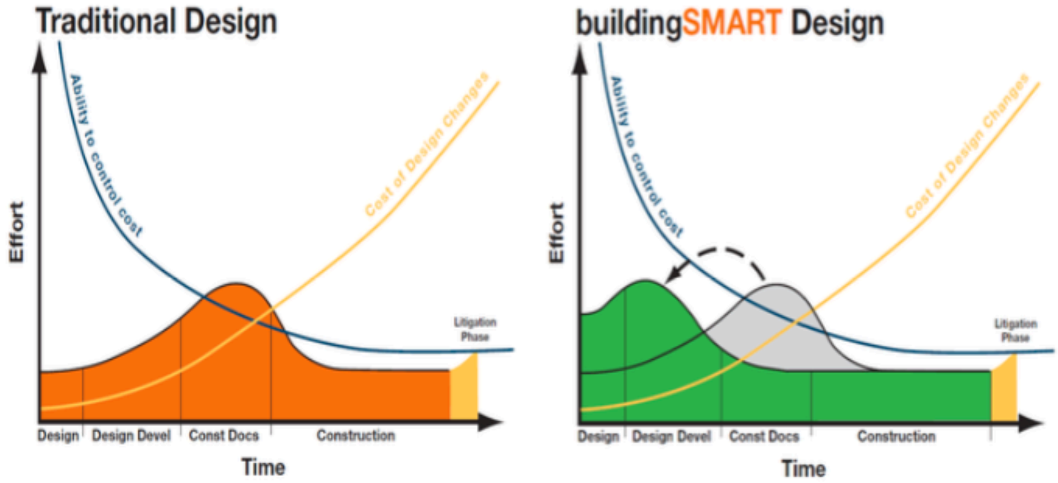


Figure 1: Earlier decision making improves ability to control costs (McGraw-Hill 2007)

If building performance assessments and optimization redundancy took place earlier in the process rather than traditional evaluation and optimization towards the end of architectural design, it can benefit from design and development costs. These tools need to be accustomed to the requirements and preferences of stakeholders who are accountable in the early stage design decisions to support the integration of performance assessment tools in the design process (Ghiassi 2013).

Efficient building performance simulation can decrease the environmental impact of the built environment, improve indoor quality and productivity, and promote future innovation and technological progress in construction (Hensen 2011). Nonetheless, relatively few systematic efforts have been made to observe and analyze patterns of such user-system interactions with building performance optimization tool. Specifically, the necessary requirements for the design and testing of hardware and software systems for user-system interfaces have not been formulated in an accurate and reliable manner (Chien and Mahdavi 2009).

CHAPTER 2

Background

Buildings environmental systems complexity is increasing as a result of interacting economical, ecological and social development, such as awareness and demand for better indoor environment quality as well as integrated functions of buildings (Hensen 2011). Computer modeling and simulation arise an approach to design and performance assessment.

2.1 Building Performance Simulation Tools

Generating a model of a complex system, and using the model to analyze and forecast the behavior of the primary system. An iterative process involving the creation of the model, including analysis of buildings and model calibration. Together with simulation with design relevant perimeter conditions and various analysis of simulation results and extraction of design related information (Hensen 2011).

2.1.1 Conventional Building Performance Simulation Tools

Conventional building performance simulation (BPS) tools demand accurate information of building geometry such as properties of construction material, heating and cooling system information, building location as well as orientation to perform accurate simulations. Therefore, weather data of expanded locations and building material libraries are essential (Cetin 2010).

Advantages

BPS visualizes the dynamic and complex behavior of buildings that allows analysis of complicated environments. It introduces to form before the complexity of mathematics that creates a qualitative experience that leads to intuitive understanding.

Disadvantages

Users might encounter technical difficulties. Most of them cost license fees.

2.1.2 Web-based Building Performance Simulation Tools

Web-based Simulation Tool has grown in the last two decades (Luo et al. 2000) the advantages and disadvantages of such tools have been explored (Cetin 2010).

Advantages

Web-based simulation tools in comparison to conventional simulation tools provide accessibility promptly via web browsers without software installation requirements. As well with a familiar interface, ease of navigation and ease of use as decent Internet applications. Internet-based tools have instant updates to the latest option available.

Disadvantage

Web-based simulation tool depends on the network traffic. Greater server is required for a large number access. The graphical user interface (GUI) is limited comparing to desktop applications.

Table 1 shows the comparison between web-based and conventional energy simulation tool by their general features.

	Web-based simulation tool	**Conventional simulation tool (Desktop application)**
Advantages	• Availability • Ease of use/Navigation • Better environment for project management • Platform, hardware and system independence • Instantly distributed updates • Reasonable charges	• Visualizes dynamic and complex behavior • Analyze complicated environment • Detailed algorithm • Efficient GUI • Advanced software security
Disadvantages	• Network traffic • GUI limited • Unstable web environment • Vulnerable security	• Technical difficulties • License fees • The platform, hardware and system dependent.

Table 1: Comparison between Web-based Building Performance Simulation and traditional simulation tools. (Cetin 2010) (Hensen 2011)

In building design and construction field, effective web-based BPS tools can provide a proficient choice. Primary users are small firms, students, architects, and engineers, which are broader user groups than the current users of conventional tools. The essential characteristics of web-based BPS tools are the user-friendly environment and low maintenance. The immediate accessibility via a web-browser promotes the availability. These broad aspects, therefore, increase usages of the tools. Web-based building performance simulation tools have the potential to overcome the complication of traditional simulation technologies (Cetin 2010, 14-16)

2.2 SEMERGY

Energy performance of buildings is measured and analyzed by many individuals for a variety of purposes. Interests in the energy performance range from global to regional, individual buildings, and finally individual systems. Users of energy performance data include policy makers, owners, designers, operators, building raters, and researchers. Many tools or approaches have been developed to analyze building energy performance in different ways, at different levels of effort and precision and different stages in the life of a building. With each of these tools, the building energy performance is quantified in a manner that fits the needs of the users (Deru et al. 2005).

Common use cases of building performance simulation involve the evaluation of alternative building design and retrofit options. Toward this end, simulation tools must be supplied with immense amounts of information. Such information primarily includes buildings' geometry, building components' technical properties, occupants' presence and actions, microclimate data. Therefore, SEMERGY project intends to provide semantic links between real-world products and building model's abstract concepts and elements (Mahdavi et al. 2012).

Architects and designers have difficulties in the usage of energy performance optimization tools even though the number of tools has been increased in the last decade since the tools are complicated and difficult to use and are not compatible with their working methods and needs (Punjabi et al. 2005).

Semergy will be used to evaluate design strategies and material combinations that optimize the performance of the final product in new construction and retrofits projects. In the early stages of design where the geometry and semantic properties of buildings constantly change, energy evaluations can lead to decision making that influence building performance (Ghiassi et al. 2012).

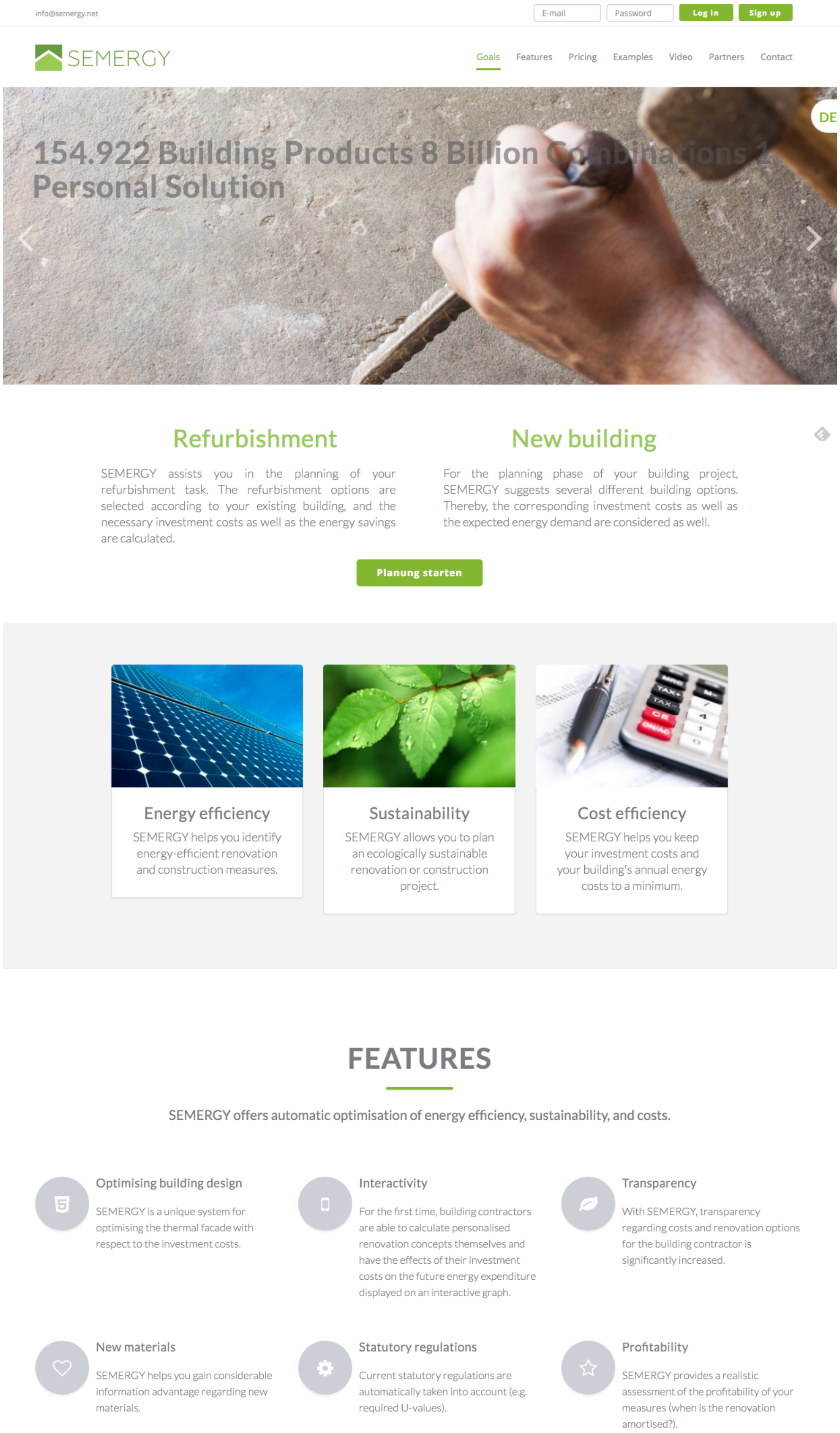


Figure 2: SEMERGY start page screenshot

To integrate performance assessment tools in the design process, these tools need to be crafted to the requirement and preferences of users, which are designers, architects to the layman, who are decision makers at the early stage of design.

According to Figure 3 not only an intelligence of a design support tool that plays an importance role in building performance simulation selection criteria. Usability of a tool that can provide the ease of use and clear guidelines is as well on high-priority criteria of selecting building performance simulation tools of architects.

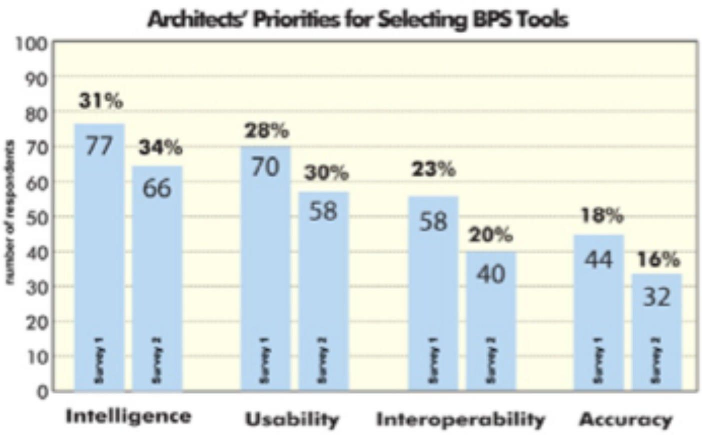


Figure 3: Architects' priorities of selecting building performance simulation tools (Attia 2011).

Although the emphasis on usability has grown in the past fifteen years since software designers and developers attempted to incorporate principles of human-computer interaction into their work, some designers have suggested that concerns for usability not be truly integrated into the design and development software (Levi and Conrad 2008).

CHAPTER 3

Usability Engineering

3.1 Definition

"Usability: the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use." (ISO 9241)

Such as an appropriate for a purpose, comprehensible and learnable, ergonomic and high-performance, and reliable and robust (Thurnher 2004).

"Usability is a quality attribute that assesses how easy user interfaces are to use. The word "usability" also refers to methods for improving ease-of-use during the design process." (Nielson 2003)

The measurable usability attributes defined by ISO [1998] are:

- **Effectiveness**: accuracy and completeness with which users achieve specified goals.
- **Efficiency**: resources expended about the accuracy and completeness with which users achieve goals.
- **Satisfaction**: freedom from discomfort, and positive attitudes towards the use of the product.

According to Jakob Nielsen, usability has five quality components:

- **Learnability**: How easy is it for users to accomplish basic tasks the first time they encounter the design?
- **Efficiency**: Once users have learned the design, how quickly can they perform tasks?
- **Memorability**: When users return to the design after a period of not using it, how easily can they reestablish proficiency?
- **Errors**: How many errors do users make, how severe are these errors, and how easily can they recover from the errors?
- **Satisfaction**: How pleasant is it to use the design?

Combining the three ISO usability attributes with Jakob Nielsen's five usability attributes, results in the following six usability attributes:

- **Effectiveness**: completeness with which users achieve their goal.
- **Learnability**: ease of learning for *novice users*.
- **Efficiency**: steady-state performance of *expert users*.
- **Memorability**: ease of using system intermittently for *casual users*.
- **Errors**: error rate for minor and catastrophic errors.
- **Satisfaction**: how satisfying a system is to use, from user's point of view.

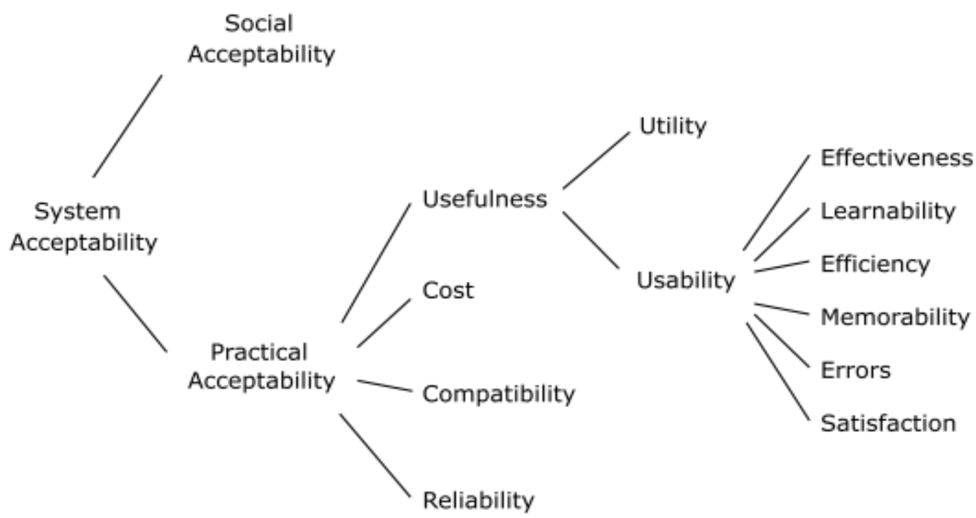


Figure 4: A model of the attributes of system acceptability (Andrews 2012)

3.2 Measuring Usability Attributes

According to Andrews (2012).

- **Effectiveness**: decide on the definition of success. For example, some substitution words spotted in a text, or binary measure of success (order completed or not).
- **Learnability**: pick novice users of system, measure time to perform certain tasks. Distinguish between no/some general computer experiences.
- **Efficiency**: decide the definition of expertise, get sample expert users (difficult), measure time to perform typical tasks.
- **Memorability**: get sample casual users (away from the system for a certain time), measure time to perform typical tasks.
- **Errors**: count minor and catastrophic errors made by users while performing some specified task. For example, a number of deviations from optimal click path.
- **Satisfaction**: ask users' subjective opinion (questionnaire), after trying system for real task.

Usability Attributes	Measuring
Effectiveness	Success rate
Learnability	Novice users' tasks performing time
Efficiency	Expert users' tasks performing time
Memorability	Time users perform tasks
Errors	Error counts
Satisfaction	Post use questionnaire

Table 2: Usability attributes measuring (Andrews 2012)

3.3 Usability Evaluation Methods

Usability studies are necessary for developing applicable products, identifying usability problems likely to compromise the user experience. Usability problems take many forms, possibly time-consuming users performing tasks, error-prone, decreasing learnability. Usability studies include two general forms: In practical usability testing, users are observed performing tasks within a controlled environment, and in usability inspections, experts analyze the system, attempt to forecast flaws that users might encounter. Variations of usability testing and expert inspection have been proposed (Schmettow 2012).

The methods of usability evaluation can also be classified according to who performs them. Usability inspection methods inspection of interface design by usability specialists using heuristics and judgment without test users. Usability testing methods empirical testing of interface design with real users (Andrews 2012).

3.4 Usability evaluation purpose

The purpose of usability evaluation is to determine performances of websites or services. By acknowledging if users are able to complete tasks, considering task performance time, and approach that users attempt to use, also if the approach attempted to meet their preferences. Including if users encounter any usability problems as well as if the user gets disoriented (Haj-Rashid 2001).

3.5 Usability Engineering Benefit

According to Bettina Thurnher (2012) system reliability and efficiency improvement will lessen user support costs and time-consuming training investments. Technology development time and costs will be reduced, as later usability problems detections will lead to additional re-engineering time which results in increased project costs.

Users' benefit	Providers/producers/developers' benefit
• Experience satisfaction instead of frustration • Achieve goals more effectively and efficiently • Not waste time and energy • Easily learn to handle the system	• Reduced financial costs • Efficient design that adds value, not frills • Fewer revisions • Reduction of support costs • Increased productivity • Increased accessibility to maximize the potentials audience • Increase in use • Happy and loyal customers • Reduced development times • Avoidance of unnecessary features

Table 3: Usability engineering benefit according to Thurnher (2012)

CHAPTER 4

Methodology

To demonstrate a controlled experiment approach and taste under controlled conditions with exploited variables. Results are statistically analyzed accordingly. The effectiveness of SEMERGY will be assessed. Users will perform energy optimization tasks. Task performance, error and success rates as well as qualitative data about participants' experiences using the site will be collected.

4.1 User Groups

User characteristics, which represents a general view of a particular user profile, a description of a specific person who is a target user of a system being designed, providing demographic information, requirements and preferences have been developed from known information about the audience of the simulation tool. To prevent designing for the average user who does not exist, and instead to ensure that the tool will work for specific user groups, user characteristics have been developed (Thurnher 2012).

Determining the target users of Semergy, by analyzing the interested participants of building and retrofit processes. SEMERGY supports energy-efficient planning, targeting users with consideration about energy-related decision-making (Pont 2014).

User groups for SEMERGY are; novice user, who has little knowledge of the building sector so that a helpful guidance through the data entry process is necessary. Architects and building designers who data transfer via known formats such as CAD or BIM is of great importance and municipalities, developers and other authorities who are interested in the toolbox for fast evaluation of building at a larger scale, such as neighborhood or town (Pont 2014).

In this thesis, user groups are interested participants for energy efficient planning, with consideration about energy-related decision-making. The users are classified according to the level of expertise and the professional experiences.

Professional users:

- In the architecture, construction and engineer (ACE) field by profession
- Have advanced experience in using one or more of these tools
  -Drafting, 3D visualization, BIM, and energy evaluation tools.

Building science student users:

- Building science and/or architecture student
- Have adequate experience in using one or more of these tools
  -Drafting, 3D visualization, BIM, and energy evaluation tools.

Non-professional users:

- Have non-related to ACE field professions
- Interested in energy efficient planning and energy-related decision-making
- Have no or little experience of these tools
  -Drafting, 3D visualization, BIM, and energy evaluation tools.

4.2 Sample size

Usability studies are an essential task for developing a usable product. The effectiveness of a usability study depends on the sample size. A particular number of tests must be conducted to discover a certain proportion of problems at least 80% (Schmettow 2012).

83 usability-consulting projects from Nielsen Norman Group have been summarized below.

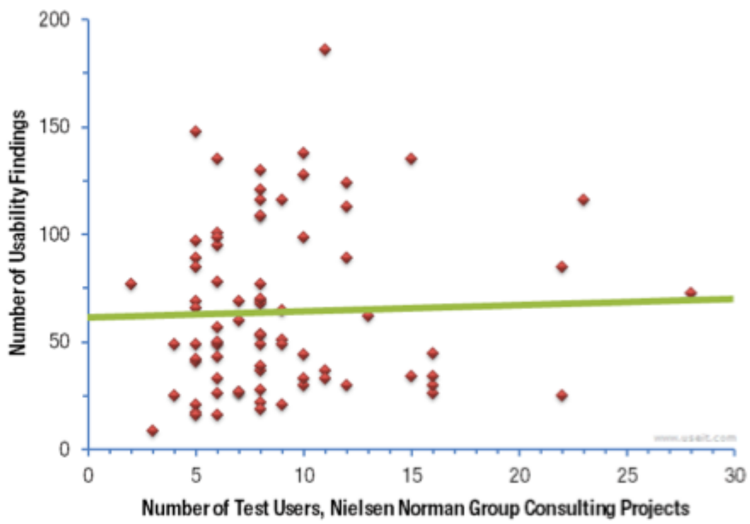


Figure 5: Correlation of number of usability findings and number of users (Neilson 2000)

The figure illustrates the minor correlation across many projects, testing more users does not necessarily results in more problems finding.

Tom Landauer and Jakob Neilsen earlier research show the number or usability problems found in a usability test with *n* users is:

$$N(1-(1-L)^n)$$

N is the total number or usability problems in the design . *L* is the proportion of usability problems discovered while testing a single user that have a typical value of 31% from their study. The graph *L*=31% is shown below.

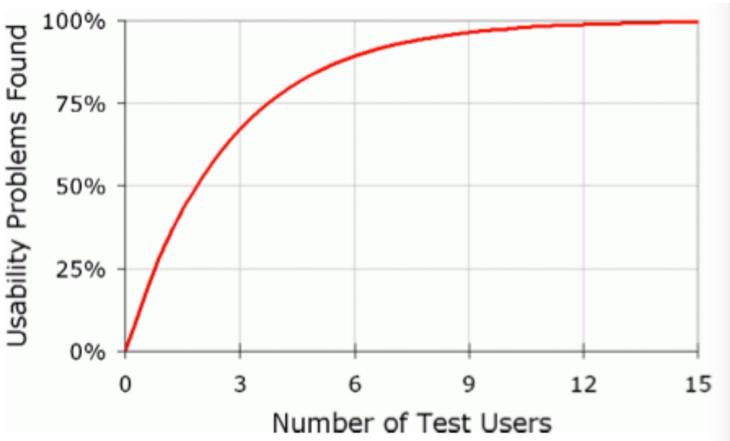


Figure 6 : Correlation between usability problems found and test users number (Neilson 2000)

The graph shows the more users tested, the fewer problems found, as the same problems will be found.

In conclusion, twelve participants per user group will be recruited. With one pilot, and one backup user per group.

	Non-professional	**Student**	**Professional**
Participant Type	Number of Participant		
Pilot	1	1	1
Regular	12	12	12
Backup	1	1	1

Table 4: User groups and sample size.

4.3 Tool Description

According to Pont (2014) following paragraphs describes the optimization workflow for a building retrofit as implemented in the SEMERGY environment.

The user draws the floor plans of a building design or retrofit in the SEMERGY graphic user interface. Using particular drawing tools to define different drawing line type as various building component functions, for example, exterior wall, interior wall, window, and door. For each line type, the user will specify a construction type from a provided list that is based on the user's preferences regarding the main construction method. Accordingly, the user is requested to enter additional information influential for calculation of compatibility values and reduction of the solution space. For instant, the definition of the north offset, which rules on the solar gains and heating demand. Moreover, defining the maximum investment cost that correlates the number of solutions, as unaffordable solutions will be omitted.

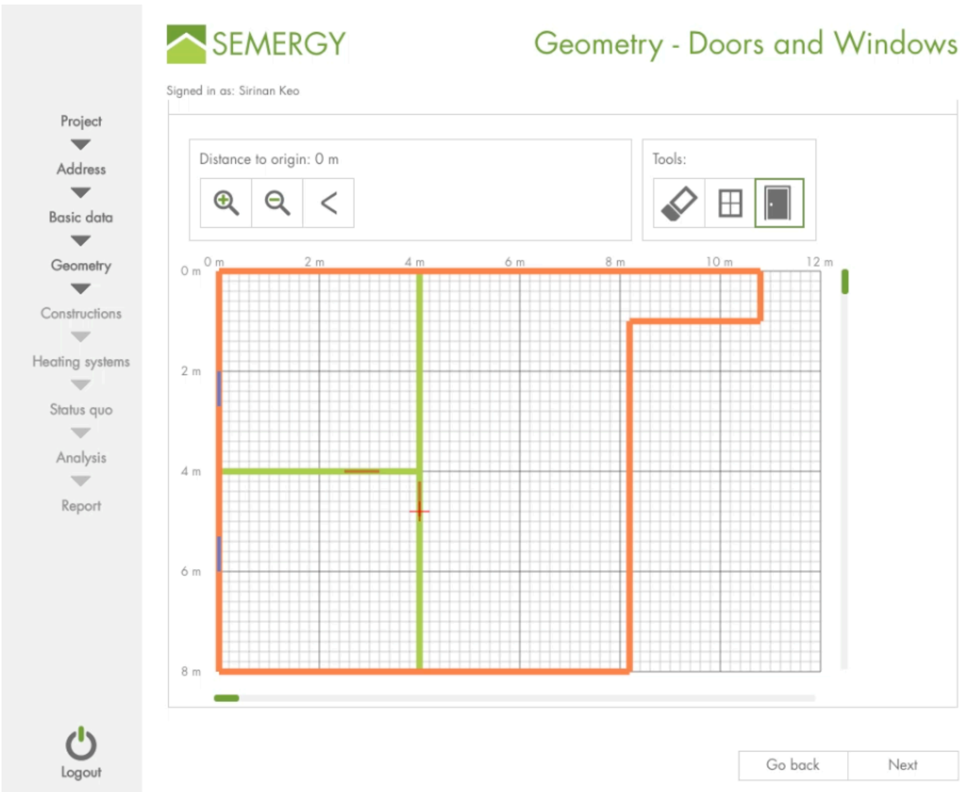


Figure 7: Inputting geometry in SEMERGY

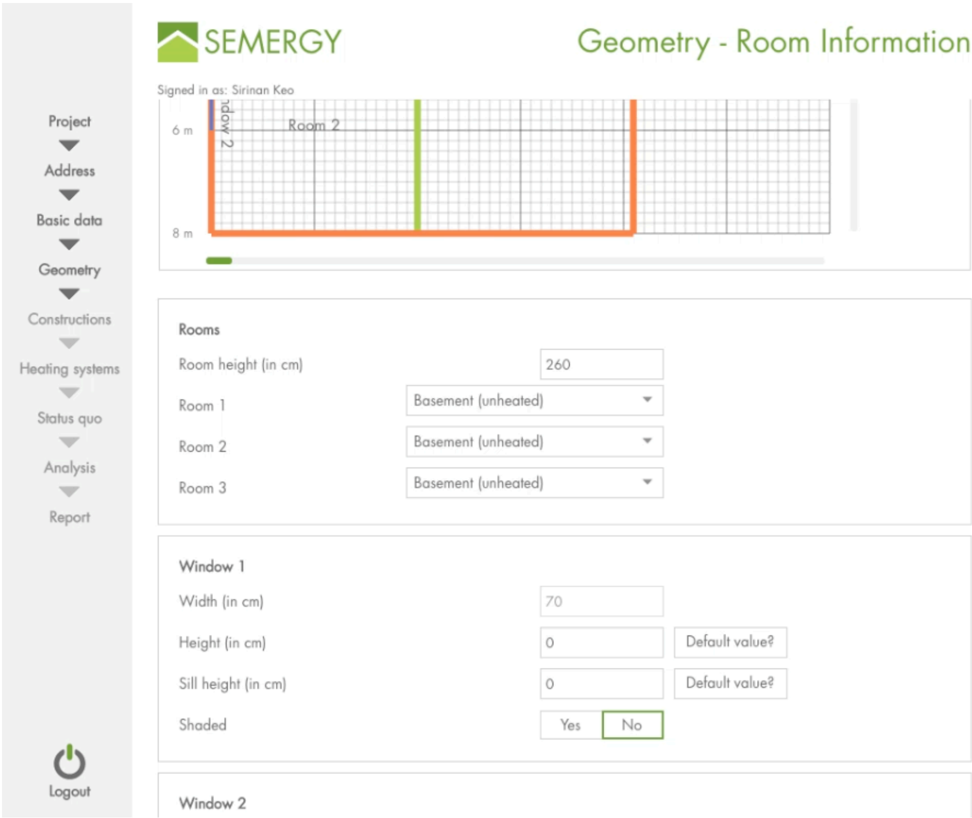


Figure 8: Defining room functions in SEMERGY

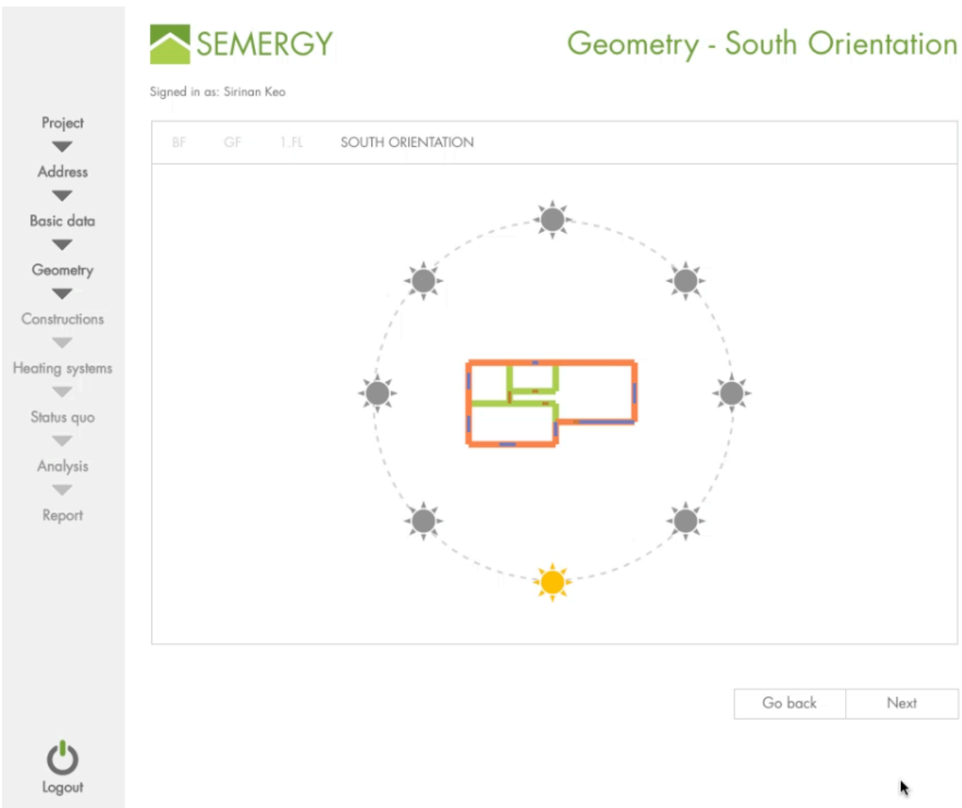


Figure 9: South orientation

The semantic interface analyses all applicable building material/building products from the product ontology based on the preferences and by different pre-defined required characteristics for each layer within each specific building component template. The identified products are used to supply the layers of the template employed in the optimization. Default materials generate layers with minor effect on the overall construction performance.

The generated possible choices of constructions are analyzed concerning their compliance with the particular requirement, which is minimum U-Value and condensate calculation. Valid alternatives create the gene pool in the optimization process, while alternatives with the incompatible check are ruled out. Then the constructions are combined to create complete design solution packages, including the construction alternatives for all building components.

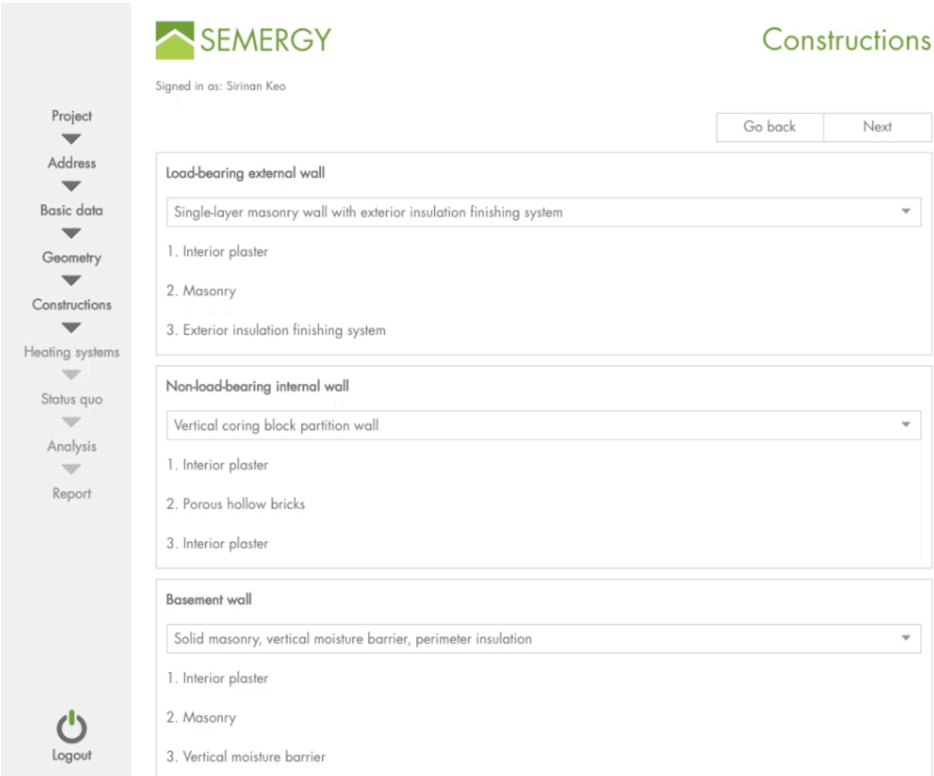


Figure 10: Construction packages

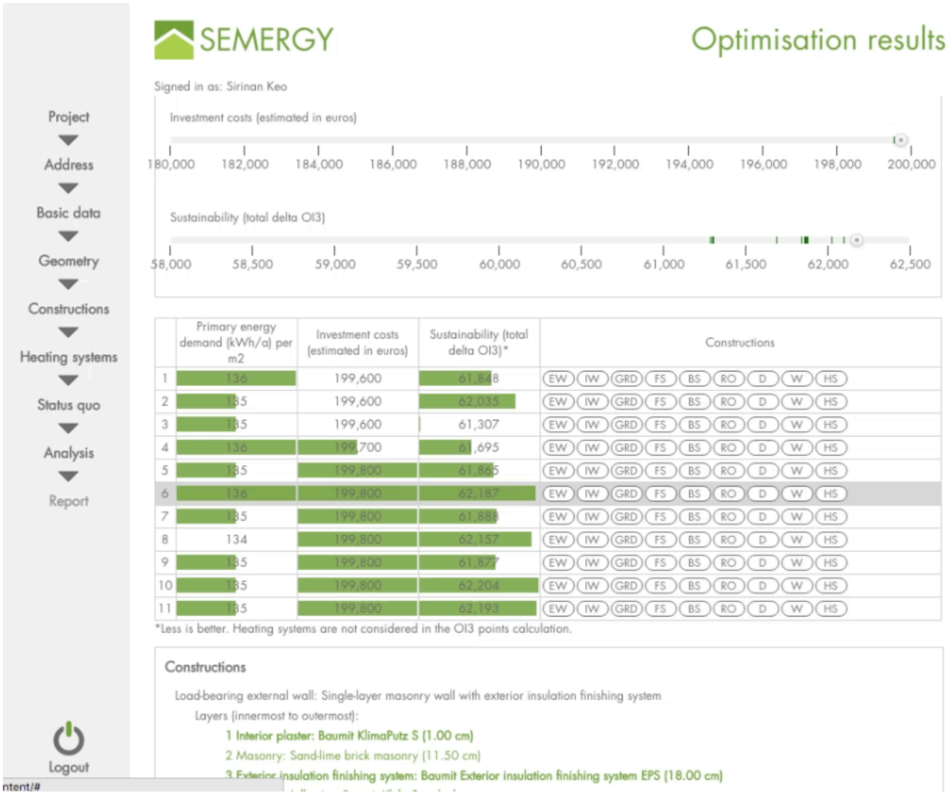


Figure 11: Optimization results

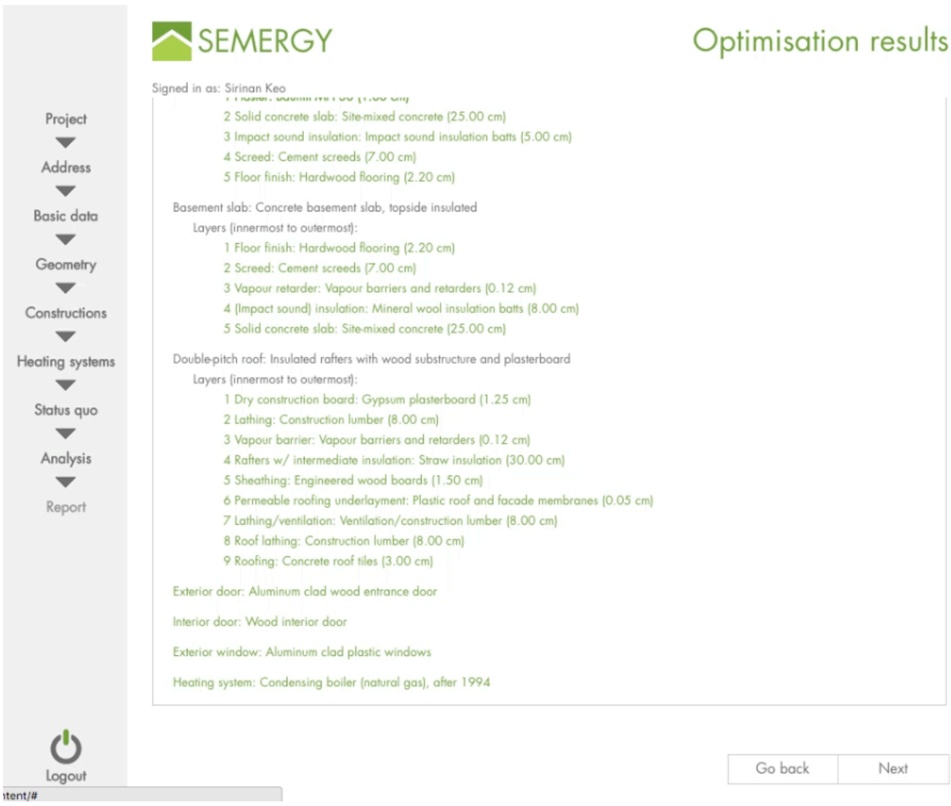


Figure 12: Optimization results, building material suggestions.

4.4 Usability tasks

4.4.1 Typical use-case

SEMERGY supports decision-making of alternative building design and retrofit in an early design stage in ACE field. Information input regarding building purpose, for instance, construction of a new building, renovating of an existing structure. Users provide building information such as location, geometry, principle construction method and background information for example budget and performance aim. Information input regarding users area of expertise and experience. Based on users preferences, SEMERGY generates building performance alternations such as energy efficiency, sustainability or cost for preliminary design. Alternations suggested are considered from users requirements and applicable laws, standards, and guidelines. For example, compiled windows collections, external wall compositions, and roof construction are diversifying integrated to generate series of achievable design selections (Pont 2014).

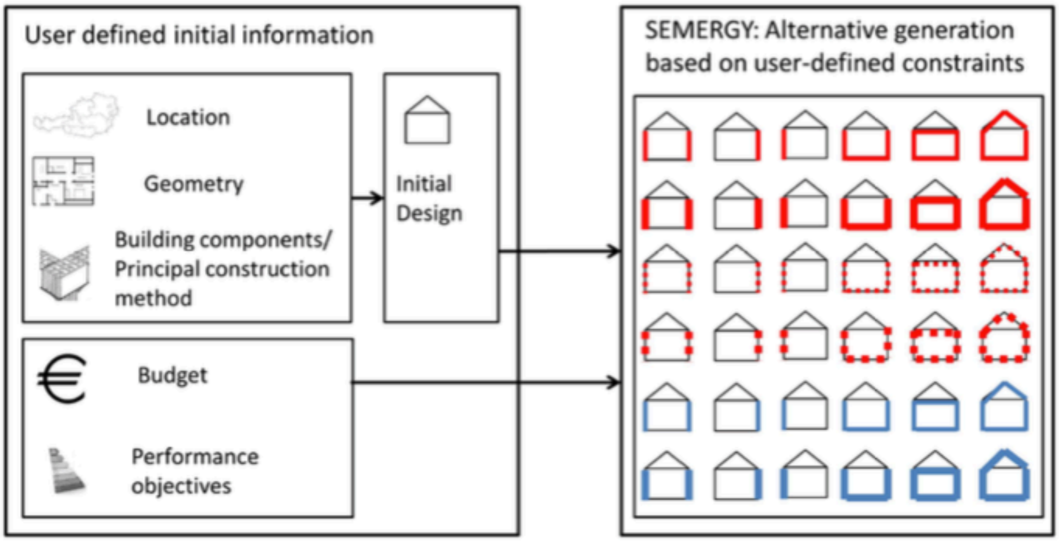


Figure 13: Principle use case for the SEMERGY environment. User defined information concerning location, geometry, principal construction method, available budget, and performance objectives are utilized for permutative generation of design alternatives (Pont 2014)

4.4.2 Test scenarios

Test scenarios emerged from use cases with prerequisite from developer team. The tasks with average and comparatively complex that are sufficient for entire aspects of the workflow are developed under the consideration for participants time limitation availability (U.S. Department of Health & Human Services 2016).

4.4.3 Tasks

Participants will draw a building geometry of a 2-story single-family house with loft living area, a basement, rooms on the attic floor with a gable roof construction. As well, users will input all required information about the building and optimize energy consumption by altering buildings components and the system then selects the preferred result.

4.5 Developing questionnaires

Questionnaires provide a quantitative method of data gathering that is expressed in numerical terms. Structured questionnaires base on closed questions that responds collected can be analyzed quantitatively for patterns and trends. The incentive is studied and proposed by an evaluator (Cohen et al. 2000).

In this project, structured questionnaires consist of two parts, background, and level of expertise questionnaire and post use questionnaire.

4.5.1 Background and level of expertise questionnaire

Background questionnaire contributes historical information about the users that will help to understand their behavior and performance during the use. It is constructed of questions regarding user's basic information, experience, attitudes, and preferences in the area of computer-based tools usage in their profession, resourcing construction product information and their information about subsidy incentives.

Background/Level of expertise Questionnaire

What is your age?

______

What is your gender?

○ Female

○ Male

What is your current occupation?

○ Architecture Student

○ Building Science Student

○ Computer Science Student

- ○ Engineering Student
- ○ Architect
- ○ Building Scientist
- ○ Computer Scientist / Engineer
- ○ Structural / Civil Engineer
- ○ Construction expert (Craftsmen, Contractor)
- ○ Facility Manager
- ○ Mechanical Engineer or HVAC Expert
- ○ Other, Please specify______________________

Have you ever used any of these tools?

Drafting Tools	***3D-Modeling / Visualization Tools***	***BIM Tools***	***Image Processing and Graphic Design Tools***
○ AutoCAD ○ Draftsight	○ Rhino ○ 3DS Max ○ Maya ○ Cinema 4 D ○ Sketch Up	○ Revit ○ Archicad	○ Adobe Photoshop ○ Adobe Illustrator

Other, Please specify______________________

Which building energy evaluation tools are you familiar?

Energy Certification Tools	***Dynamic Thermal Simulation Tools***
○ EcoTech ○ Archiphysik ○ GEQ ○ PHPP	○ Energy Plus ○ TAS ○ Ecotect

Other, Please specify______________________

For which purpose do you use computers regularly?

- ○ Architectural design (educational or professional)
- ○ Browsing the web/checking e-mails

- ○ Social networking/Blogging
- ○ Editing Word/Excel/Power point documents
- ○ Gaming
- ○ Programming
- ○ Web design
- ○ Others, Please specify____________________

Have you ever looked for constructing products information in the past?

- ○ Yes
- ○ No

When looking for construction product information, which resources do you usually use?

- ○ Printed folders (Architektenordner)
- ○ Data storage devices (USB, CD, DVD)
- ○ World Wide Web (Websites)
- ○ Building centers and hardware stores (Baumärkte)
- ○ Salespeople (Representatives of building materials/construction companies)
- ○ Others, Please specify____________________

Have you ever looked for information about building regulations?

- ○ Yes
- ○ No

When looking for building regulations which resources do you usually use?

- ○ Printed documents (standards, laws, guidelines)
- ○ World Wide Web (Websites)
- ○ Others, Please specify____________________

Are you familiar with subsidy incentives for building construction and retrofit?

- ○ Yes
- ○ No

When looking for information about subsidy incentives, which resources do you usually use?

- ○ World Wide Web (Websites)
- ○ Bank & Insurances
- ○ Recommendations by architects or building companies
- ○ Others, Please specify____________________

Figure 14: Background Questionnaire

4.5.2 Post-use questionnaire

Post-use questionnaire employs five-point Likert rating scales to evaluate post usage of the tool. The Likert scale has five potential choices to ascribe quantitative value. A numerical value is assigned to each potential option. A mean figure for all responses will be analyzed. The questionnaire runs through the contexts on the site. Each context grouped by functioning of the tool. The questionnaire starts with general building information, creating of building model/drafting, the semantics of building components, analysis of results, general features, and user interface. Furthermore, suggestions and comments boxes are added. The qualitative data will be collected regarding this post use questionnaire.

Post Use questionnaire

General Building Information:

Specification of the building locations	Very difficult	○—○—○—○—○	Very easy
Selection of general construction method	Very difficult	○—○—○—○—○	Very easy
Definition of number of floors	Very difficult	○—○—○—○—○	Very easy
Specification of roof properties	Very difficult	○—○—○—○—○	Very easy

Creation of Building Model / Drafting:

Placing walls	Very difficult	○—○—○—○—○	Very easy
Placing windows/doors	Very difficult	○—○—○—○—○	Very easy
Specification of Space functions	Very difficu	○—○—○—○—○	Very easy

Dimensioning of Windows / Doors	Very difficult	○—○—○—○—○	Very easy
Setting Default Dimensions for Windows and Doors	Very difficult	○—○—○—○—○	Very easy
Specification of shades	Very difficult	○—○—○—○—○	Very easy
Determination of building orientation	Very difficult	○—○—○—○—○	Very easy

Semantics of Building Components:

Identification of correct templates for opaque building components	Very difficult	○—○—○—○—○	Very easy
Modification of chosen templates for opaque building components	Very difficult	○—○—○—○—○	Very easy
Selection of building parts to be optimized for opaque building components	Very difficult	○—○—○—○—○	Very easy
Identification of correct templates for transparent building components	Very difficult	○—○—○—○—○	Very easy
Selection of building parts to be optimized for transparent building components	Very difficult	○—○—○—○—○	Very easy

Analysis of Results:

Navigating through results	Very difficult	○-○-○-○-○	Very easy
Selection of the individual preferred solution	Very difficult	○-○-○-○-○	Very easy
Perceivability of Results	Very good	○-○-○-○-○	Very bad

General Features:

Help tab visibility	Hardly noticeable	○-○-○-○-○	Very easy to notice
Help tab contents	Unhelpful information	○-○-○-○-○	Helpful information
Calculation time	Very slow	○-○-○-○-○	Very fast
Results visualization	Hardly understandable	○-○-○-○-○	Very easy to understand
Downloading the results report	Very confusing	○-○-○-○-○	Very convenient

User Interface:

Navigation through the SEMERGY environment	Easily to get lost	○-○-○-○-○	Logical/intuitive
Overall usability	Very Difficult to use	○-○-○-○-○	Very easy to use

What additional features would you suggest for integration within the SEMERGY environment?

Which feature of the tool did you find most useful?

What feature of the tool you find least satisfactory?

Additional Comments (are welcome):

Figure 15: Post- use questionnaire

4.6 Testing Methods

An overall look at the complete web-based energy optimization tool to gather objective data usability measures.

4.6.1 Objective for the study

The goals of this study are to assess the overall effectiveness of SEMERGY for different types of users performing base-case tasks, measures users performance and determining design flaws to improve the efficiency of the tool by identifying design inconsistencies and flaws of user interface and content areas involving;

- **Navigation errors** when users fail to locate functions and follow workflow.
- **Presentation errors** when users fail to locate and fail to respond to information in screens and have selection errors due to unclear descriptions.
- **Control usage problem** with improper toolbar or data inputting area usage.

4.6.2 Location and setup

A controlled setting will be used to conduct the sessions. The study will take place at BST seminar room and at users' locations. Participants will use a Windows laptop with a connection to the Internet. The laptop that the participant uses will also have a recorder installed on it. A screen recorder application - Camcorder will record what happens on the screen.

4.6.3 Recruiting participants

We will select participants who are interested in energy efficient planning, with consideration about energy-related decision-making. The users are defined by the level of expertise and the professional experiences.

	Non-professional	Student	Professional
Participant Type	Number of Participant		
Pilot	1	1	1
Regular	12	12	12
Backup	1	1	1

Table 5: User groups and sample size.

4.6.4 Methodology

The usability study will be exploratory and will also gather assessment data about the effectiveness of SEMERGY. Participants are professionals, graduate students of Building Science and Technology and non-professional users. The participants will perform the main task, which is to optimize an energy consumption of a given building. Error and success rates, as well as qualitative data about participants' experiences using the site, will be collected.

Each participant will work through tasks path. Usability study sessions will be conducted. Each participant will perform a task using SEMERGY.

4.6.5 Session outline and timing

The test session will be minimum 60 minutes long. The session will take place in the department's seminar room and at users' locations.

4.6.6 Pre-test arrangements

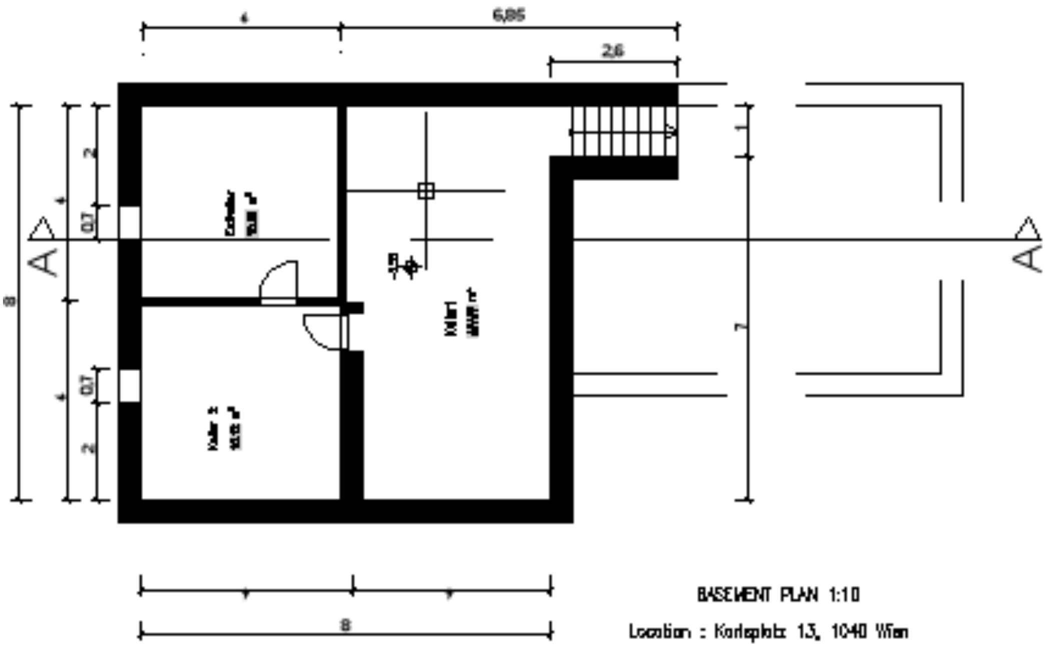
- Fill out background questionnaire
- Task explanation

4.6.7 Task

Participants will draw a building plan and optimize energy consumption, minimizing building operation cost or maximizing occupants' comfort by altering building materials of the given building.

4.6.8 Test material

A 2 stories single-family house with unheated basement and heated attic space is used as the test material for this usability study project.



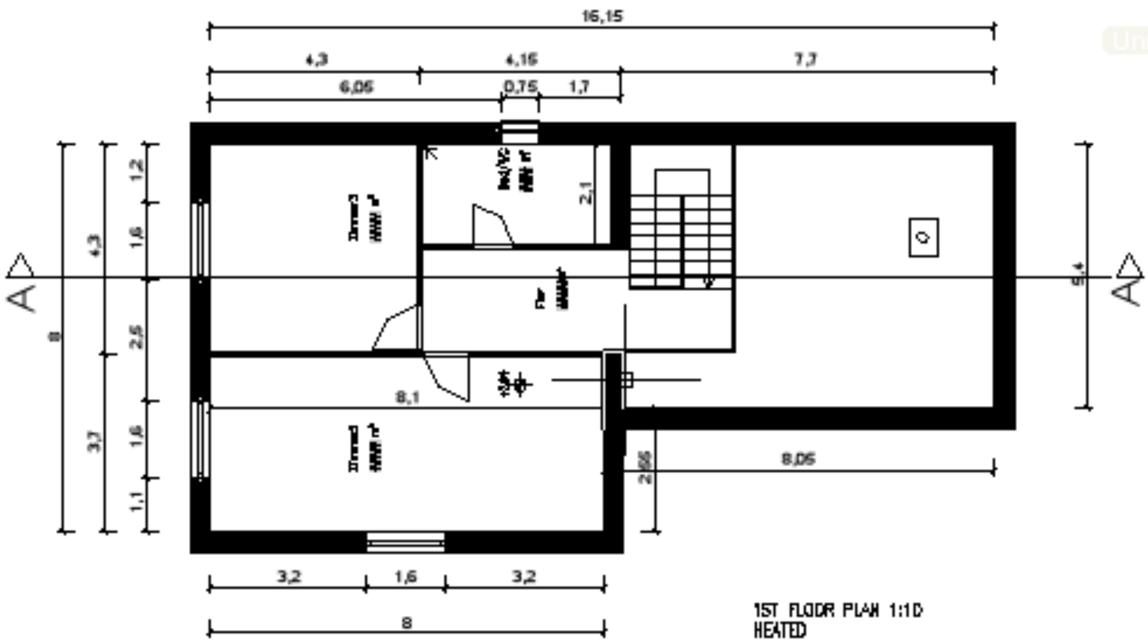


Figure 16-17: Test materials

4.6.9 Post-test debriefing

- Post-test questionnaire
- Follow up on any particular problems that came up for the participant.

4.6.10 Task lists

Task description	Success criteria
Start a new project, entering an address and basic data	A new project is started. Building location is established and required data is filled
Draw geometry	Building plans; external wall, interior wall, and windows and doors are created
Edit room profiles	Rooms information are entered and prepared to be calculated
Place building orientation	Building orientation is set
Review 3D visualization model	User examine the 3D model and possibly correct, alter the geometry
Specify buildings construction, heating, and ventilation systems	The series are considered and is selected
Optimize energy demand, navigate through results, select preferred solutions and download the report file	User selects preferred solutions and downloads the report file

Table 6: Task lists

4.6.11 Identifying Test Metrics

Metric collected during testing:

- Successful Task Completion
- Errors
- Subjective Measures
- Like, Dislikes and Recommendations

4.6.12 Data Analyses

At the end of the sessions, error in entering data, error in drawing geometry, error in analyzing the results and if users can complete tasks at all will be collected as quantitative data. As well as qualitative data from the post-test questionnaire.

Performance Data	Preference Data
• Task time • Success rates • Error rates • Satisfaction questionnaire ratings	• Problem experienced • Comments/recommendations • Answers to open-ended questions

Table 7: Performance data and preference data collected

CHAPTER 5

Result

5.1 Users background and level of expertise

Background and level of expertise questionnaire present information that helps understand users behavior and their performance during the application.

The data visualized consists of users' occupation, their computer-based tools usage background, their purpose for using computers, whether users look for construction product information and which resources they use, if users look for building regulation information and which resources they use as well as if users are familiar with subsidy incentives for building construction and retrofit and which resources they use.

Data collected from fill-in questionnaire from 3 sample groups with 12 samples number in each group.

Drafting tool background:

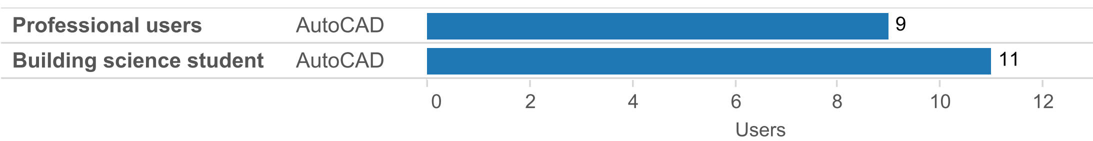


Figure 18: Drafting tool background

3D-Modeling/Visualization Tools background:

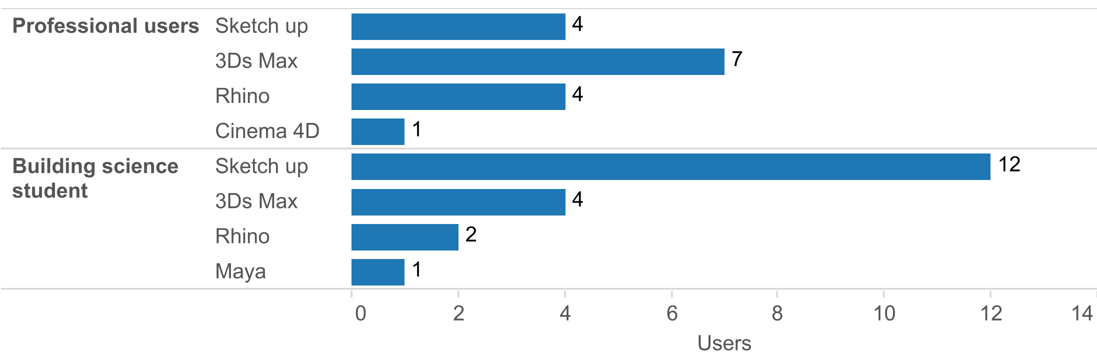


Figure 19: 3D-Modeling/Visualization tools background

BIM Tools background:

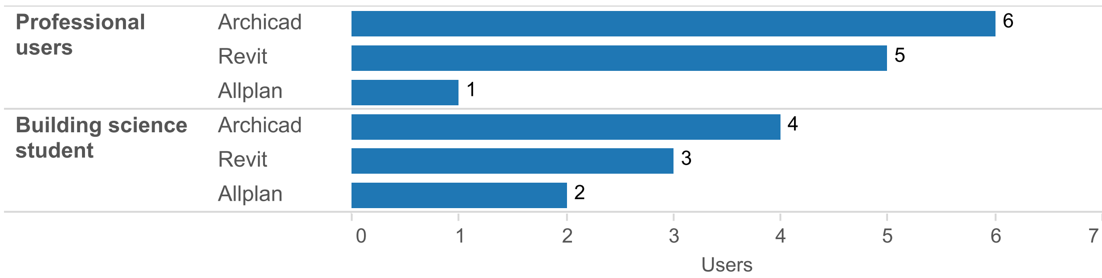


Figure 20: BIM Tools background

Energy certification tools background:

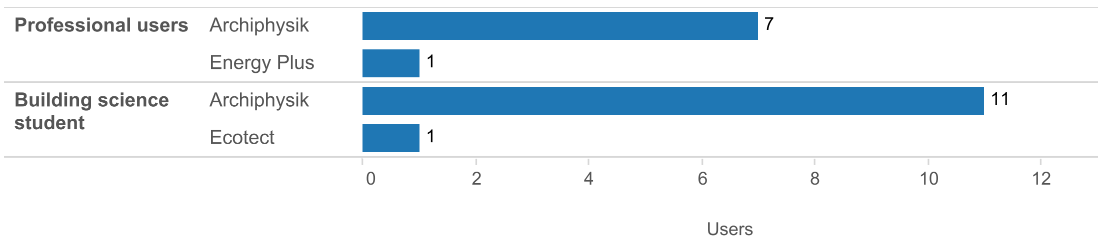


Figure 21: Energy certification tools background

Dynamic thermal simulation tools background:

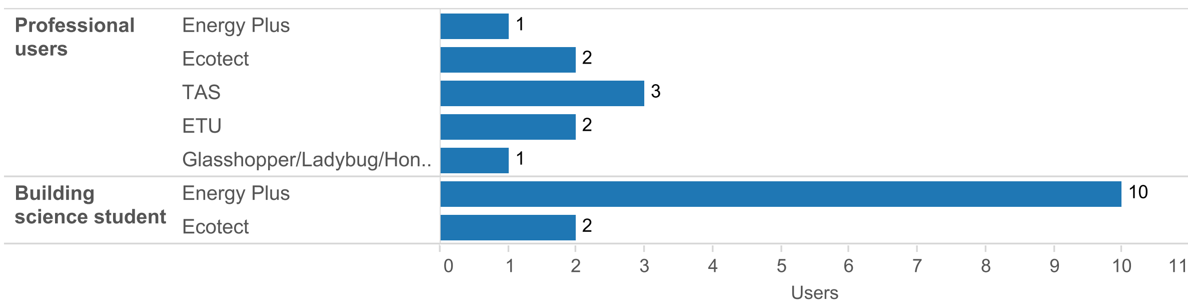


Figure 22: Dynamic thermal simulation tools background

Image processing and graphic design tools background:

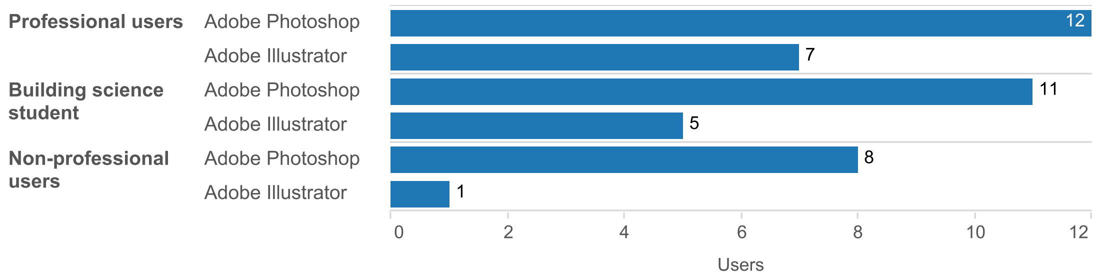


Figure 23: Image processing and graphic design tools background

Computer using purpose:

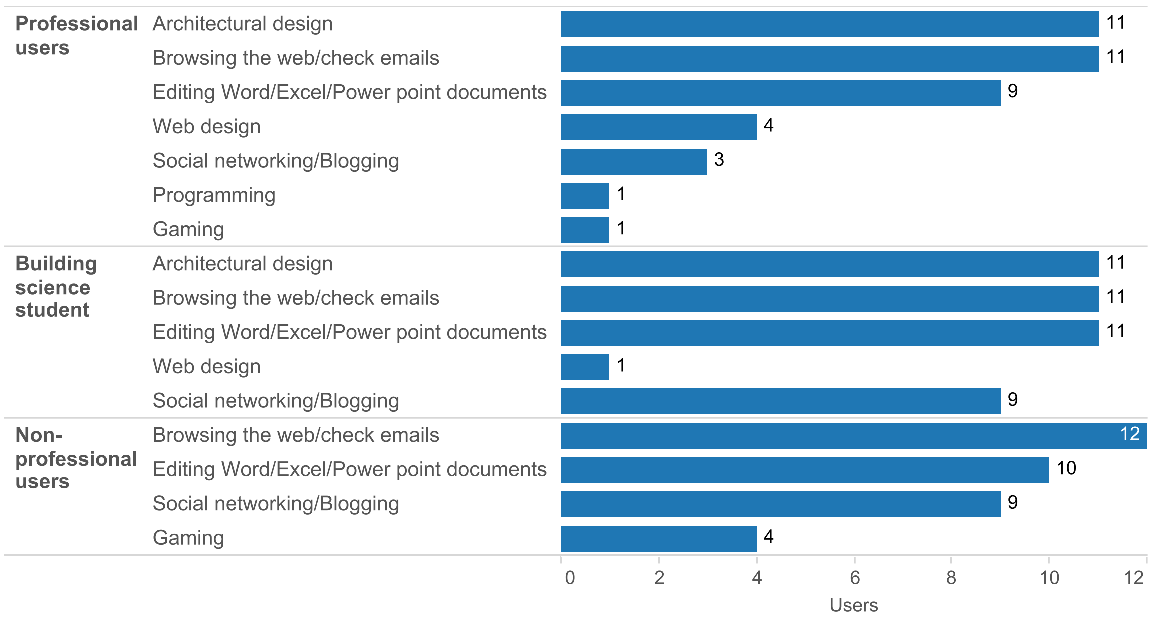


Figure 24: Computer using purpose

Looked for product information:

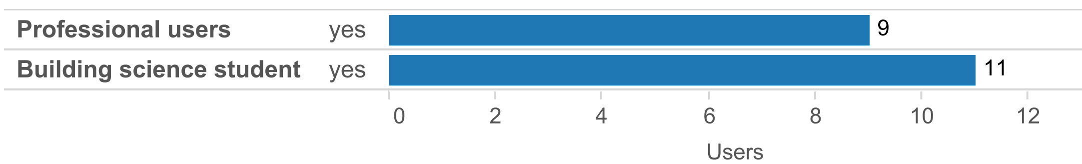


Figure 25: Looked for product information

Product information resources:

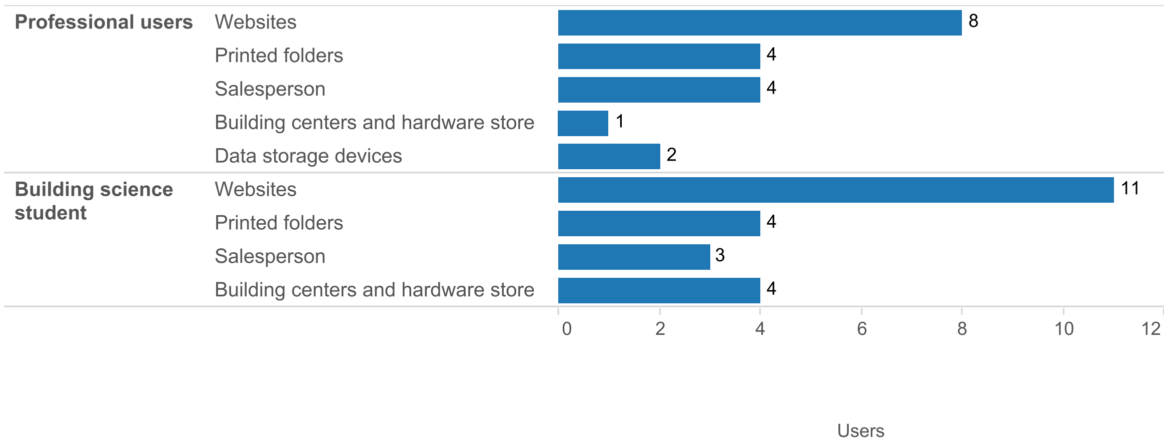


Figure 26: Product information resources

Looked for building regulation information:

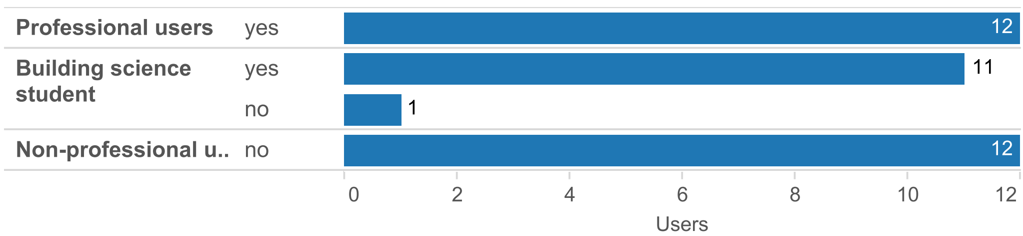


Figure 27: Looked for building regulation information

Building regulation information resources:

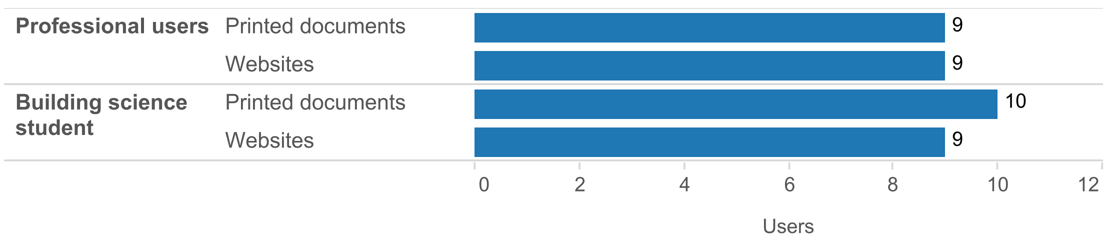


Figure 28: Building regulation information resources

Subsidy incentives for building construction and retrofit familiarity:

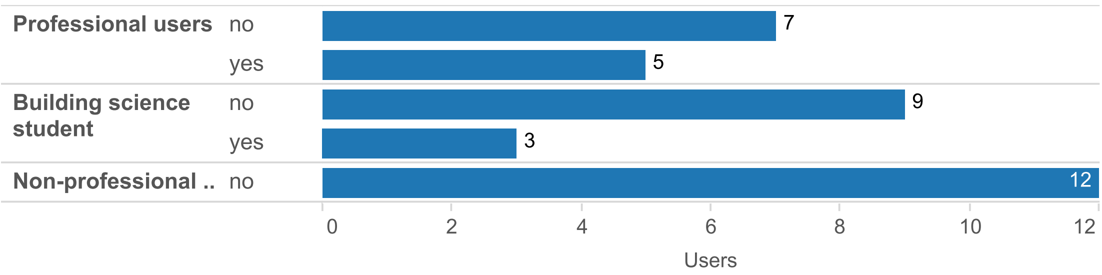


Figure 29: Subsidy incentives for building construction and retrofit familiarity

Subsidy incentives resources:

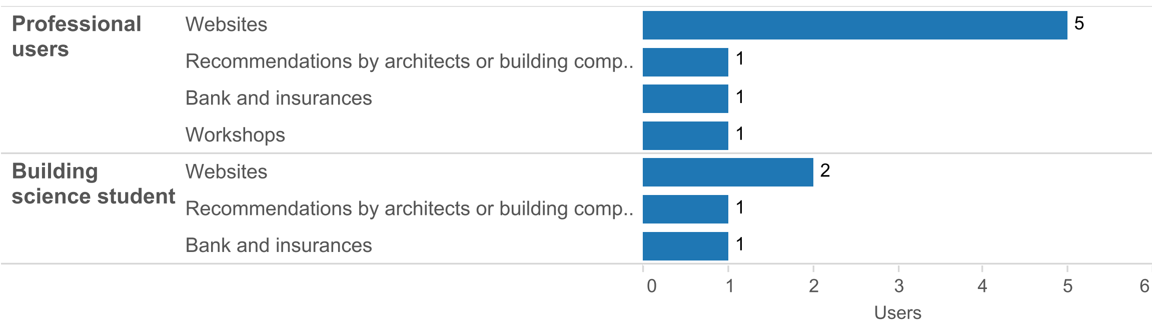


Figure 30: Subsidy incentives resources

5.2 Summarize Performance Data

Summarize performance data regarding task timing, errors and task accuracy using descriptive statistics to support seeing patterns that review problems or insights.

5.2.1 Task Timing

Time participants require completing each task and time using for the entire session.

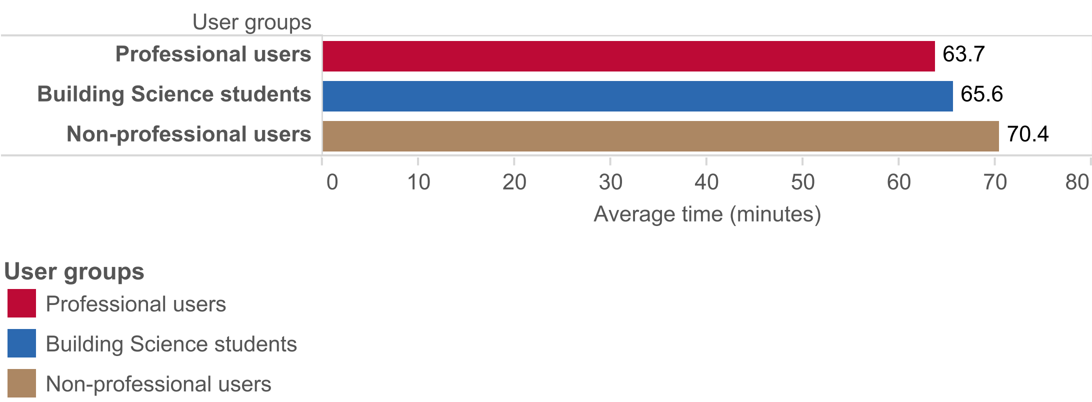


Figure 31: Users task session timing

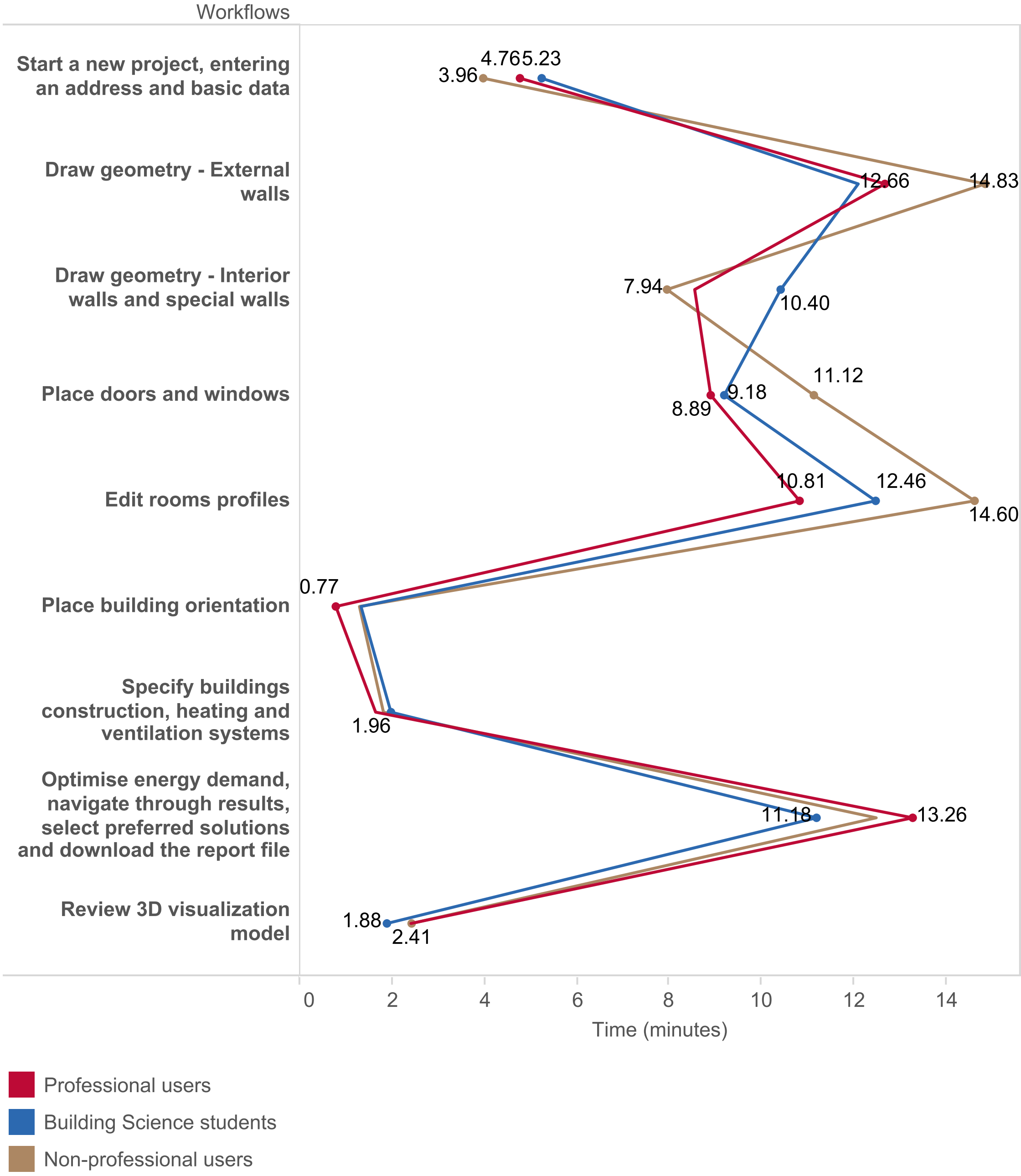


Figure 32: Comparing between users group task average performance timing by workflows sequence

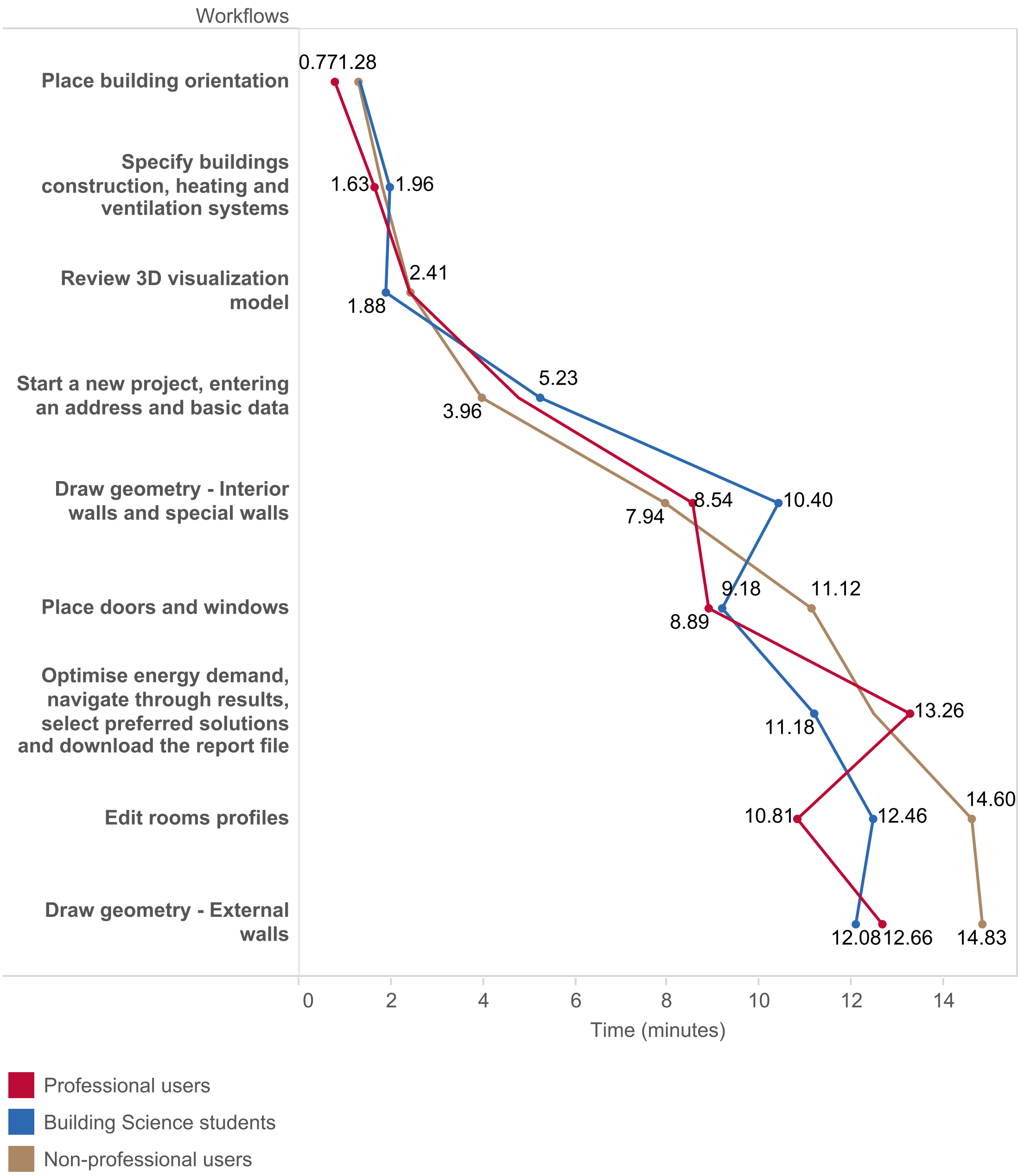


Figure 33: Comparing between users group average task performance timing ascending sorted

5.2.2 Success rate and help tap usage

Indicates the percentage of participants who were at least able to muddle through the task well enough to complete it successfully. If the participants made errors, they were eventually able to correct themselves and perform successfully.

User group	Success rate	Help tap usage
Professional users	100%	33.3%
Building Science student	100%	41.66%
Non-professional users	100%	58.33%

Table 8: Success rate and help tap usage

5.2.3 Error Analysis

Identify errors that caused the incorrect performance. Frequency is counted as well as an estimation of the frequency of occurrence that accounts the percentage of total users affected and the probability that a user from that affected group will experience the problem.

Tasks	Errors	Source of errors	Error counts
Draw geometry	• Did not follow the workflow path	• User prefers to have the overview of the tool by skipping steps and move forward • Users prefer to browse around for the overview before doing the task	3
	• Simply omitted a step - Completely skipped drawing 1st-floor plan	• User skipped drawing geometry detail due to confusion of drawing tools function • Not used to geometry inputting method and find it hard to draw • User simply gives up, as it might have been too complicated to complete the steps	6
	• Working with an incorrect floor plan	• User simply starts with the ground floor plan without noticing basement plan should be started regarding the tool workflow • Floor plan indicator is too subtle	3
	• Draw with incorrect tools	• User was not aware of the actual function of the tools	6
Place door and window	• Incomplete drawing windows and doors	• User could not find the right measurement to place doors and windows • User got lost and simply moved on to the next step	1
Edit room profiles	• Entering the wrong unit	• Drawing unit is meter but room profiles unit is centimeter	3

	• Entering wrong values	• User does not understand which metric should be entered clearly	2
Optimize energy demand, navigate through results, select preferred solutions and download report file	• System error	• Long calculation time when unable to find a solution, suggested selecting automatic option of heating system • Logged itself out • Shut itself down	4

Table 9: Professional user error analysis

Errors range by error counts:

- **Navigation errors** when users fail to locate functions and follow workflow.
- **Presentation errors** when users fail to locate and fail to respond to information in screens and have selection errors due to unclear descriptions.
- **Control usage problem** with improper toolbar or data inputting area usage.

Error counts	Errors	Error types
6	• Omitted step	Navigation error
	• Draw with incorrect tools	Presentation error
4	• System error	System error
3	• Did not follow the workflow path	Navigation error
	• Working with an incorrect floor plan	Control usage problem
	• Entering the wrong unit	Presentation error
2	• Entering wrong values	Presentation error
1	• Incomplete drawing windows and doors	Control usage problem

Table 10: Errors and its error type range by error counts of professional users

Tasks	Errors	Source of errors	Error counts
Draw geometry	• Did not follow the workflow path	• User prefers to have the overview of the tool by skipping steps and move forward • Users prefer to browse around for the overview before doing the task	2
	• Simply omitted a step - Completely skipped drawing 1st-floor plan	• User skipped drawing geometry detail due to confusion of drawing tools function • Not used to geometry inputting method and find it hard to draw • User simply gives up, as it might have been too complicated to complete the steps	2
	• Working with an incorrect floor plan	• User simply starts with the ground floor plan without noticing basement plan should be started regarding the tool workflow • Floor plan indicator is too subtle	1
	• Draw with incorrect tools	• User was not aware of the actual function of the tools	7
Edit room profiles	• Entering the wrong unit	• Drawing unit is meter but room profiles unit is centimeter	7
	• Entering wrong values	• User does not understand which metric should be entered clearly	1
Optimize energy demand, navigate through results, select preferred solutions and download report file	• System error	• Long calculation time when unable to find a solution, suggested selecting automatic option of heating system • Logged itself out • Shut itself down	2

Table 11: Building Science students' error analysis

Error counts	Errors	Error types
7	• Draws with incorrect tools	Presentation error
	• Entering the wrong unit	Presentation error
2	• Did not follow the workflow path	Navigation error
	• Omitting steps	Navigation error
	• System error	System error
1	• Working with an incorrect floor plan	Control usage problem
	• Entering wrong values	Presentation error

Table 12: Errors and its error type range by error counts of Building Science student

Error analysis of non-professional users:

Tasks	Errors	Source of errors	Error counts
Draw geometry	• Simply omitted a step - Completely skipped drawing 1st-floor plan	• User skipped drawing geometry detail due to confusion of drawing tools function • Not used to geometry inputting method and find it hard to draw • User simply gives up, as it might have been too complicated to complete the steps	2
	• Working with an incorrect floor plan	• User simply starts with the ground floor plan without noticing basement plan should be started regarding the tool workflow • Floor plan indicator is too subtle	1
	• Draw with incorrect tools	• User was not aware of the actual function of the tools	4
	• Misunderstood shading tool's function	• User does not inform what the tool is for and what he/she should proceed on as there is not instruction or guiding	1
Place door and window	• Incomplete drawing windows and doors	• User could not find the right measurement to place doors and windows • User got lost and simply moved on to the next step	1
Edit room profiles	• Entering the wrong unit	• Drawing unit is meter but room profiles unit is centimeter	3
	• Entering wrong values	• User does not understand which metric should be entered clearly	3
Place building orientation	• Place building in a wrong orientation	• User does not understand how to place the building orientation	1
Optimize energy demand, navigate through results, select preferred solutions and download report file	• System error	• Long calculation time when unable to find a solution, suggested selecting automatic option of heating system • Logged itself out • Shut itself down • Bug that slows the drawing process in drawing geometry	2

Table 13: Non-professionals' error analysis

Error counts	Errors	Error types
4	• Draws with incorrect tools	Presentation error
3	• Entering wrong values	Presentation error
	• Entering wrong units	Presentation error
2	• System error	System error
	• Omitting steps	Navigation error
1	• Working with an incorrect floor plan	Control usage problem
	• Incomplete drawing windows and doors	Control usage problem
	• Place building in a wrong orientation	Presentation error
	• Misunderstood shading tool's function	Presentation error

Table 14: Errors and its error type range by error counts of non-professional users

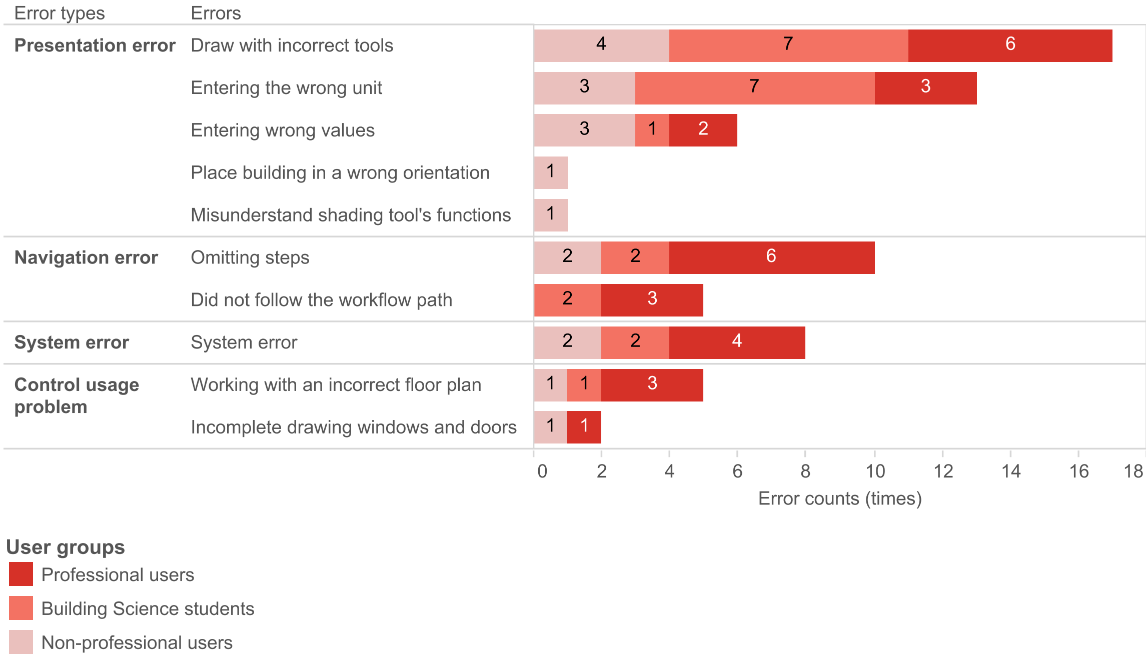


Figure 34: Error counts sorted by error type of the 3 sample groups

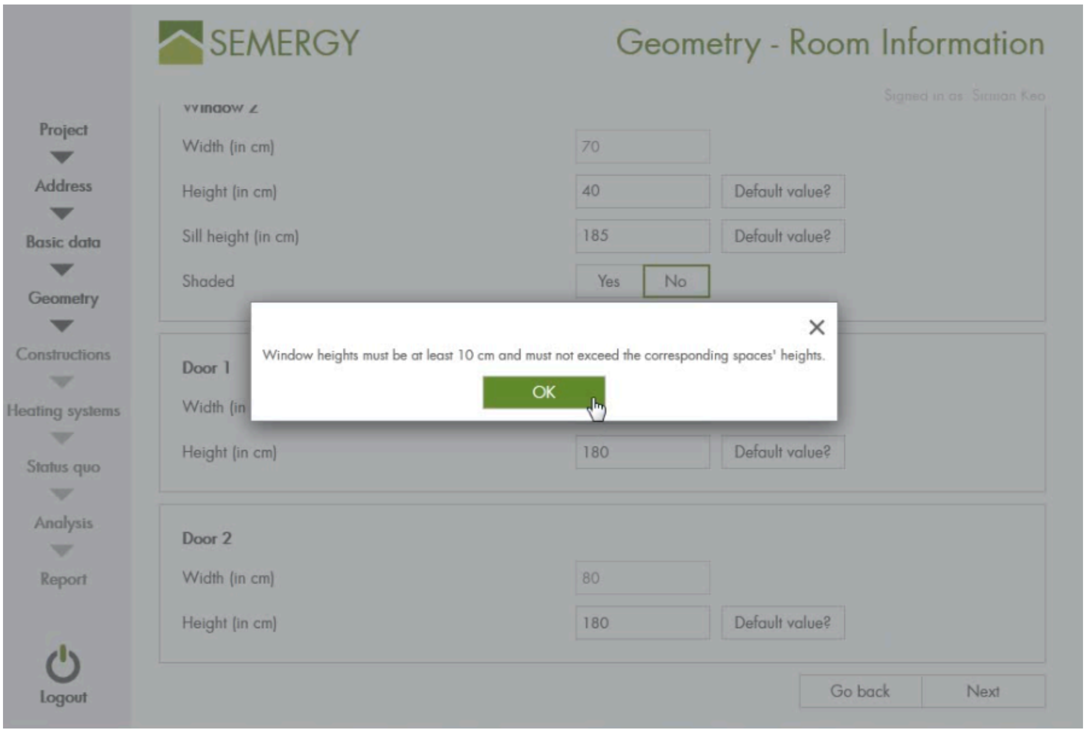


Figure 35: Error from entering wrong value

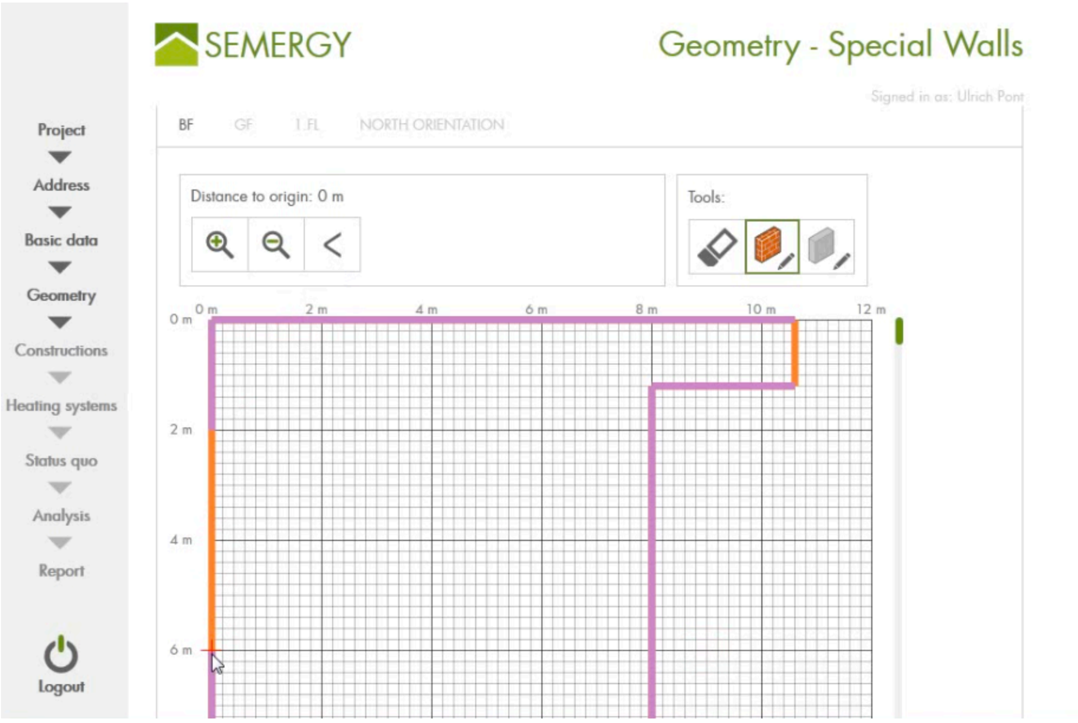


Figure 36: Error from drawing with incorrect tool

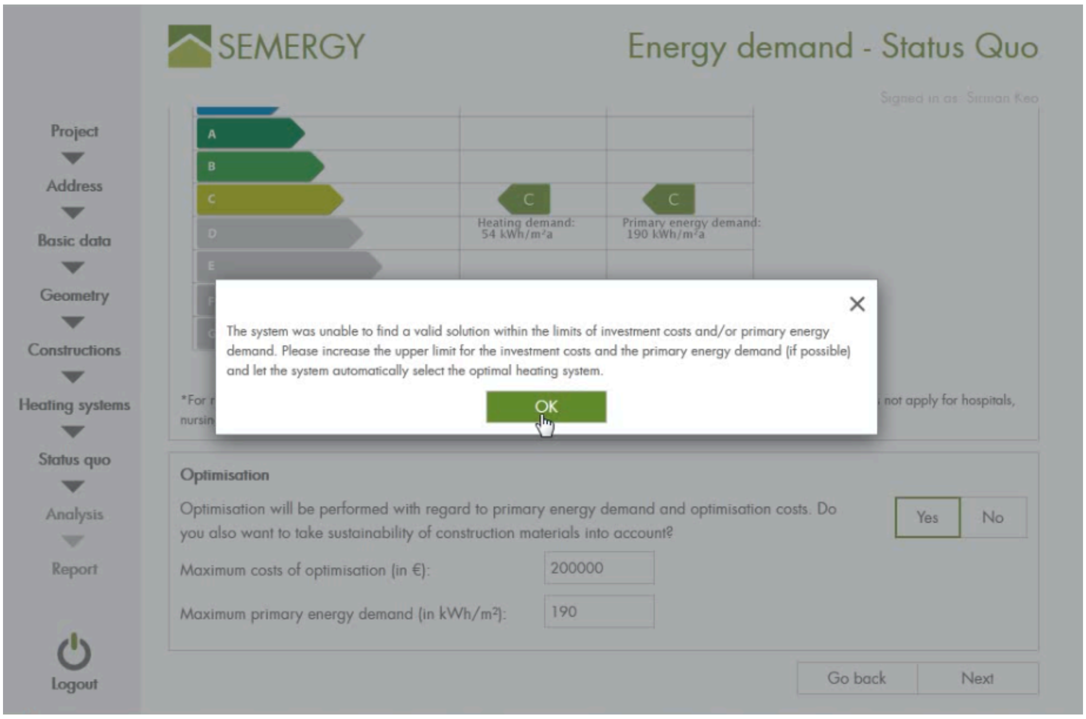


Figure 37: System error

5.2.4 Satisfaction questionnaire ratings

Satisfaction questionnaire rating result of professional users:

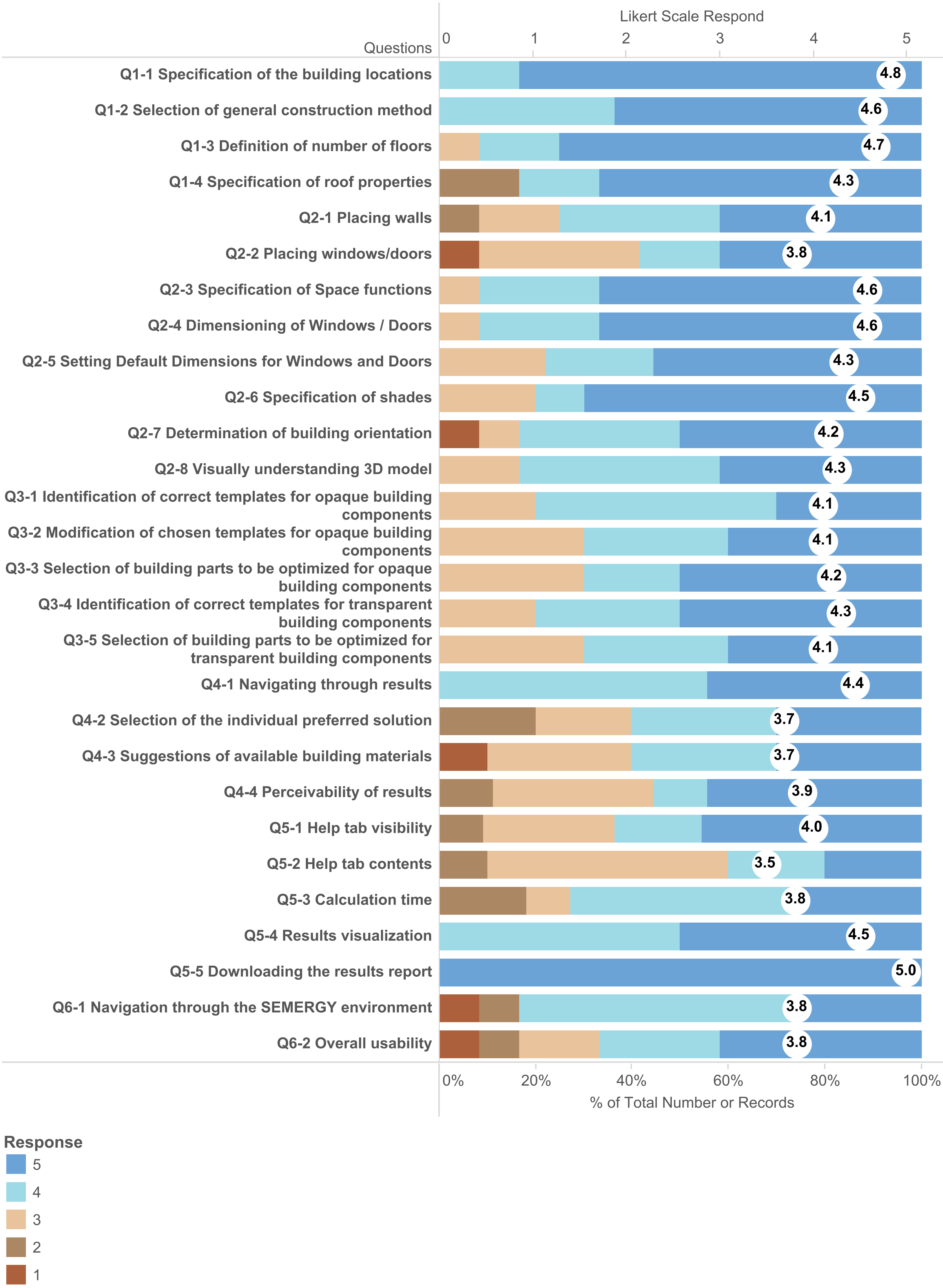


Figure 38: Professional user satisfaction questionnaire rating

Satisfaction questionnaire rating result of Building Science student:

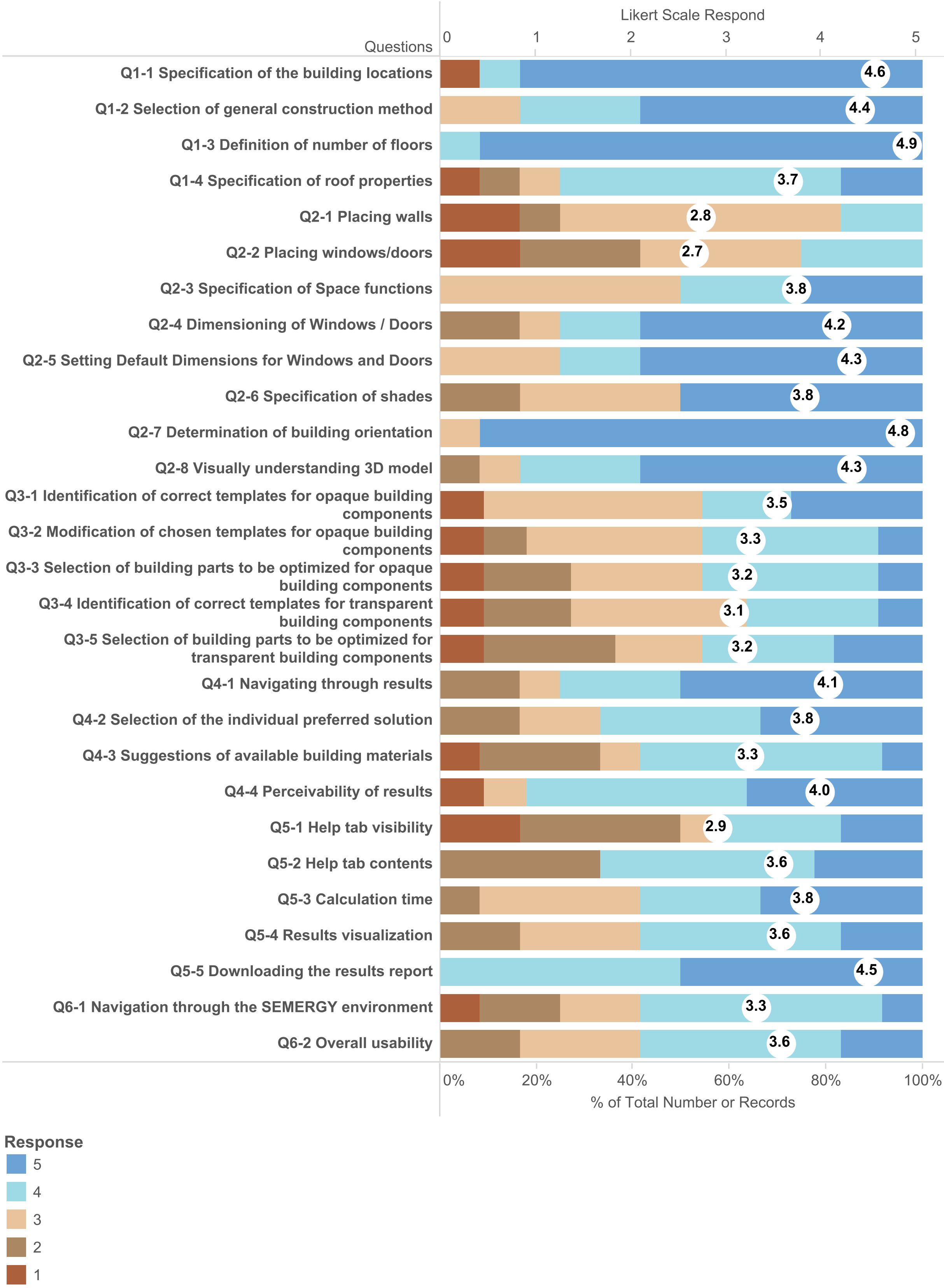


Figure 39: Building Science student satisfaction questionnaire rating

Satisfaction questionnaire rating result of non-professional users:

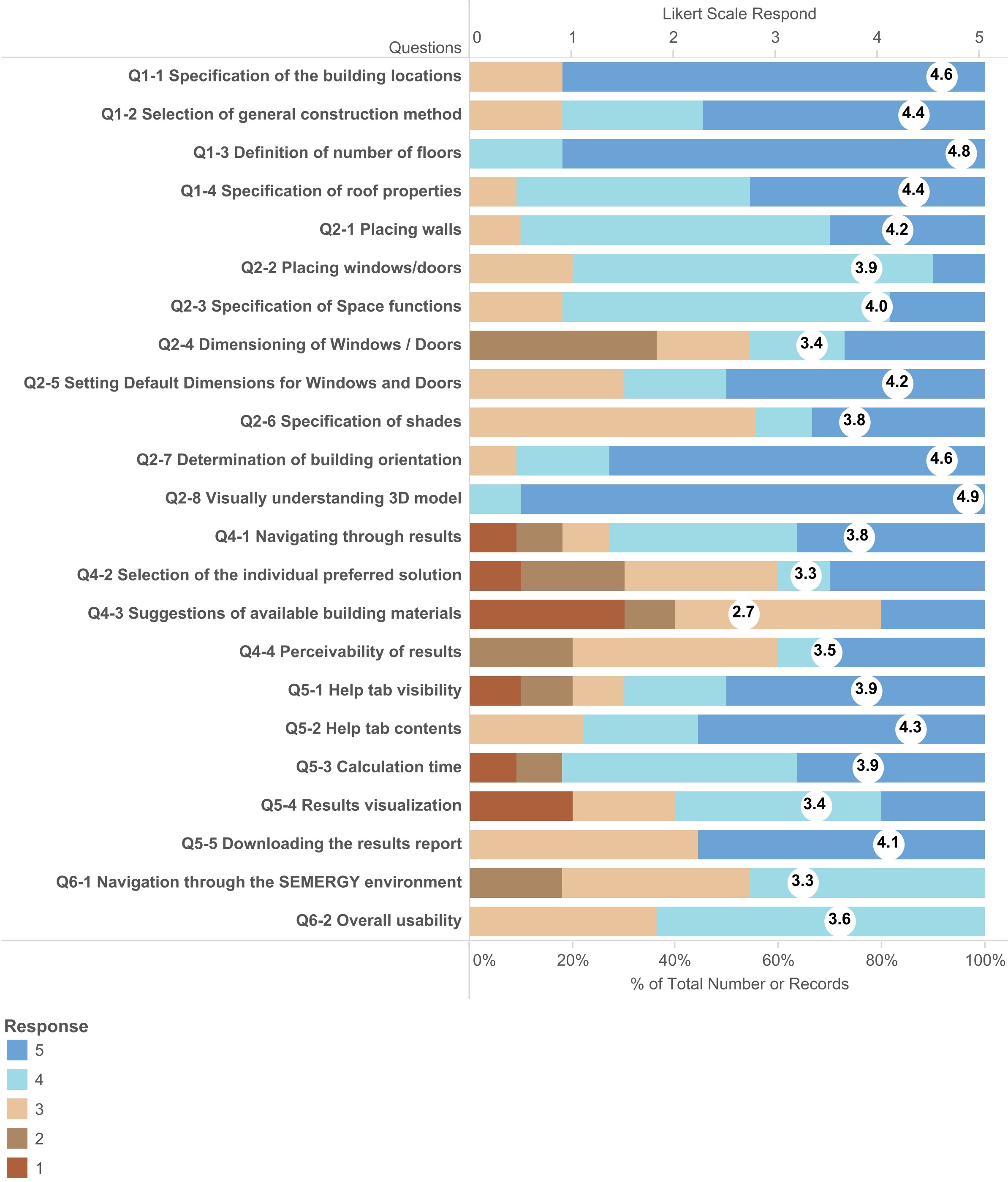


Figure 40: Non-professional users satisfaction questionnaire rating

Average value from all user groups:

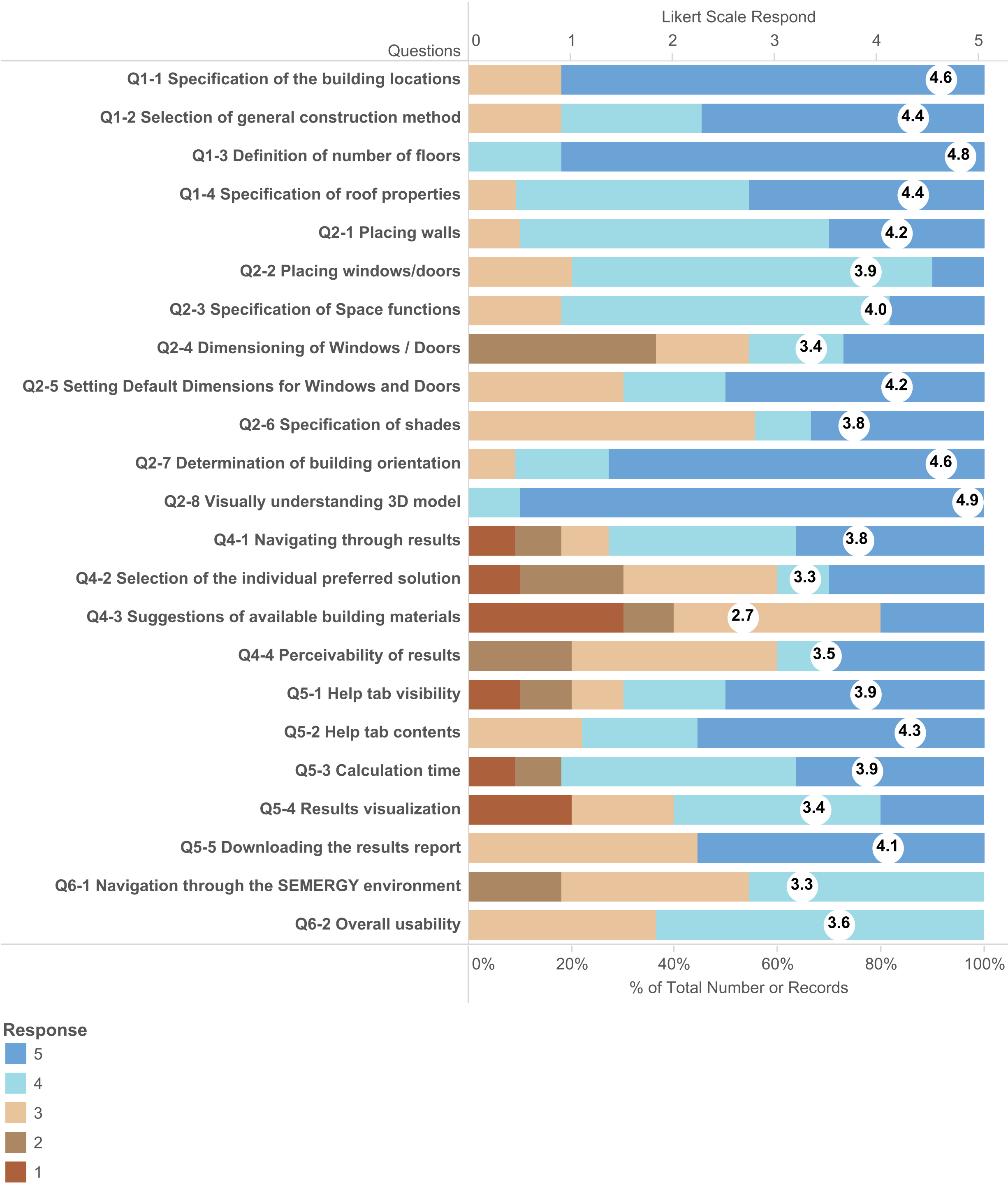


Figure 41: Average value of user satisfaction questionnaire rating

5.3 Summarize Preference Data

Preference data from open-ended questions. Responses are categorized by user groups and are organized in categories.

What additional features would you suggest for integration within the SEMERGY environment?

Navigation and workflow	**Professional users**	• Workflow navigation overview • Fixed on screen of the drawing tool set • Fixed drawing area when entering room profiles • To be able to navigate backward and forward to any section without passing through all the steps • Highlight false input
	Building Science student	• Less scientific language explanation guidance to every step • Next step explanation in texts
	Non-professional users	• It would be helpful not to have to scroll up and down constantly whilst entering room information • Short video tutorial • Mark preferred results as favorites • Be able to navigate to another step without having to pass through every step all over again
Drawing	**Professional users**	• Measurement feature to mark points • Full screen drawing • Elements moving feature • Elements properties tool • Importing CAD drawing files • Snap and stretch features • Continuous zoom feature • Pan tool
	Building Science student	• Better measurement function • Measuring tool
	Non-professional users	• Finer grid • Continuous drawing area visibility
Building components, building system modification	**Professional users**	• To be able to define manually wall construction layers • To be able to define different materials for interior walls for each room • To offer different type of doors for external and interior doors • Rooms heights setting for each room separately

	Building Science student	• More retrofit materials information • More construction options to define construction layers • More heating system choices • Manual construction setting
	Non-professional users	• Illustrated construction details

Table 15: Additional features suggestions

Which feature of the tool did you find most useful?

Overall	Professional users	• The tool is very useful and with a great potential • After the termination of the program due to the error, the plan, and all input data was saved
	Building Science student	• Help tap content • Building orientation setting
	Non-professional users	• All the data is saved when going back and forth • Easy to use with clear instructions • Very useful result comparison
Drawing	Professional users	• Distance from origin indicator • 3D visualization
	Building Science student	• 3D visualization • Deleting walls/windows • Erasing and duplicating floors
	Non-professional users	• Numerical, geometric data inputting • Measurements of windows and doors are easy to use • Copying exterior walls of the previous floor • Easy to draw as long as the walls have an even-numbered length • Draw with effective minimal tools • Excellent 3D visualization

Optimization/ Results	Professional users	• Selection of construction and components • Optimization analysis • Report downloading •
	Building Science student	• Optimization analysis • Optimization according to users' preference • Intuitive results • Good building component selection • Easy to understand construction modification section
	Non-professional users	• Optimization option sliders

Table 16: Most useful features according to users

What feature of the tool did you find least satisfactory?

Overall	Professional users	• The tool was difficult to get through
	Building Science student	• No comment from intermediate user in this section
	Non-professional users	• Drawing function is not easy to handle
Navigation and Workflow	Professional users	• The "Next" button is not convenient to reach
	Building Science student	• Building orientation was difficult to understand at the first view • Visibility of a current floor plan, users find it hard to notice which floor they are working on • Difficult to notice when to navigate to a next step as there is no indicator

	Non-professional users	• Very hard to navigate through geometry panel, get lost easily • Difficult to use the drawing function
Drawing	Professional users	• Difficult to navigate through the drawing panel • Zoom function is not precise and difficult to use • Difficult to place windows and doors • Difficult to input geometry in general • Can't change drawing unit • 3D model is hard to understand at the first glance
	Building Science student	• Difficult to zoom in and out • Only one decimal drawing is allowed • Cannot change floors while drawing • One decimal drawing is simple to do but might be inaccurate • Description of the features of the windows • Zoom function • Got lost because the drawing tools
	Non-professional users	• The zoom function is difficult to use and slows down the whole process • Complicated to edit the drawing • Not being able to move geometries precisely • Great idea with default dimensions for windows and doors but the program overwrote users existed data. • The zoom function only focuses on the middle of the drawing area not exactly where the cursor is • Drawing at the edge of the drawing area makes the program interrupt the line • Origin point gets lost when reaching the end of the zoom area. Auto-scroll is good, but I should be able to continue drawing the line. • It is very annoying to scroll up and down all the time when entering window and door properties.
Building components modification	Professional users	• Less building material option to choose from
	Building Science student	• Description of the retrofit solution • Shading device setting does not have a wide range of choices
Building location	Professional users	• No angle or GPS coordinates input option

Table 17: Least satisfactory features according to users

Additional comments

Overall	Professional users	• Well done, good to use for everyone • Very user-friendly but also could only use for a very simple construction, but it has potentials • Slow calculation time
	Building Science student	• Very useful tool. Better navigation in the geometry section and better responses to the site will be great. • Drawings and room profiles could have used the same unit • It is a smart tool if the drawing tool problem is solved • If organized better, could be useful • Easy to use but to draw geometry and final solution are not understandable
	Non-professional users	• There was a bug for about 30 minutes. The crosshair did not follow the mouse cursor, so it made it impossible to draw anything. Help section does not provide any aid for this problem
Navigation	Professional users	• It is inconvenient to have to pass through every workflow step each time navigating around, should be able to navigate and modify freely
	Building Science student	• The website environment is easy to understand, but it could include workflow explanation or a pop-up help window
Guideline	Professional users	• Drawing guideline, ex. Which building dimension to be used; outer dimensions or inner dimensions • A clearer definition of floors, e.g. is upper store roof-store or full story
Drawing	Professional users	• Difficult to define the exact point from which the windows/doors/ should start • Since users cannot name windows and doors themselves, there should be a better system to define them • The tool did not allow drawing window that was separated by a partition wall • Hard to draw and alter the drawings
	Building Science student	• Drawing tool could be more precise

	Non-professional users	• Drawing environment was difficult to use and at first user did not understand the drawing step • When fixing the error corrected by an error message, the error remained and the user had to redraw the whole part again. • Moving the floors in 3D view cannot be undone completely. The floors do not align properly (bug?) • Uneven decimal numbers (0,10 m / 0,30 m / 0,50 m) can be typed in as a value once I have started to draw a line, but they cannot be drawn with the cursor. This makes it impossible to use them as a starting point, only as an end point they work.
Building orientation	**Professional users**	• Orientation of the building could be set more precisely
Building material	**Professional users**	• Bigger material database should be added including shading options and different window types • Would be good to have access to the database, so you do not depend on pre-defined material only
Optimization	**Non-professional user**	• The results could have extensive explanations for beginners as a link. Right now it would take me very long to research all the terms that are used there. If they were explained somewhere, that would leave a better feeling after using the program.

Table 18: Additional comments

CHAPTER 6

Discussion and Conclusions

This study assesses the overall effectiveness of SEMERGY for three types of users which are professionals in AEC field users, master degree students of the Building Science program and non-professionals in AEC field users. They performed base-case tasks. Users performances are measured to determine design flaws to improve the efficiency of the tool by identifying design inconsistencies and flaws.

Usability Attributes	Measuring
Effectiveness	Success rate
Learnability	Novice users' tasks performing time
Efficiency	Expert users' tasks performing time
Memorability	Time users perform tasks
Errors	Error counts
Satisfaction	Post use questionnaire

Table 2: Usability attributes measuring (Andrews 2012)

6.1 Usability attributes

- **Effectiveness**
  Measuring from success rate, which results in 100%. Even though some users find it difficult to use the tool in the course of time they are capable of finishing the tasks.

User group	Success rate	Help tap usage
Professional users	100%	33.3%
Building Science student	100%	41.66%
Non-professional users	100%	58.33%

Table 8: Success rate and help tap usage

- **Learnability**
  The time that non-professional users perform tasks are not significantly different from other user groups; the tool has an excellent learnability performance to non-professional/novice users. Non-professional users who have no background with drafting or energy optimization tool, tend to follow SEMERGY's workflow path.

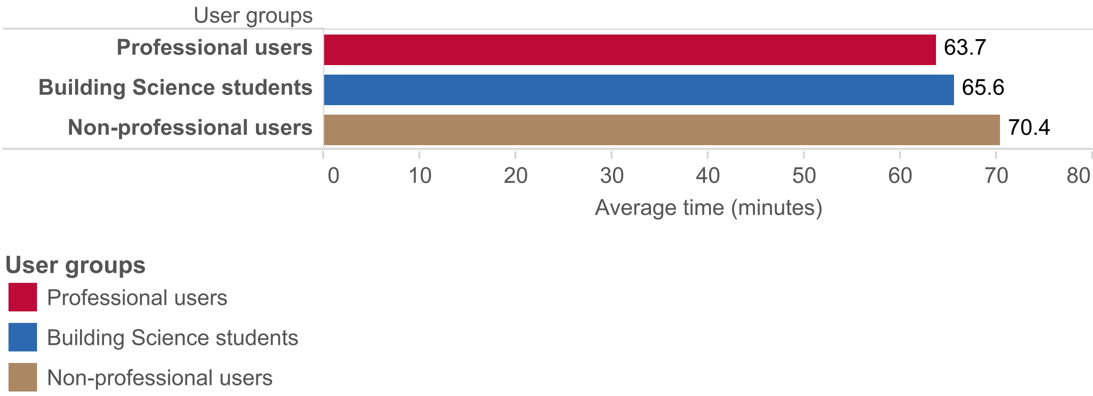


Figure 31: Users task session timing

- **Efficiency**
  Professional users tasks timing is not significantly different than the non-professional user. However, they have more requirements for the function of the tool than other user groups to be able to perform the task more satisfactory and efficiently.

- **Memorability**
  In drawing external walls which is the very first challenge. Users took some time to be compatible with the tool and in the meantime there is a learning process to progress to the next tasks. Users spend less time when drawing another floors' geometry.

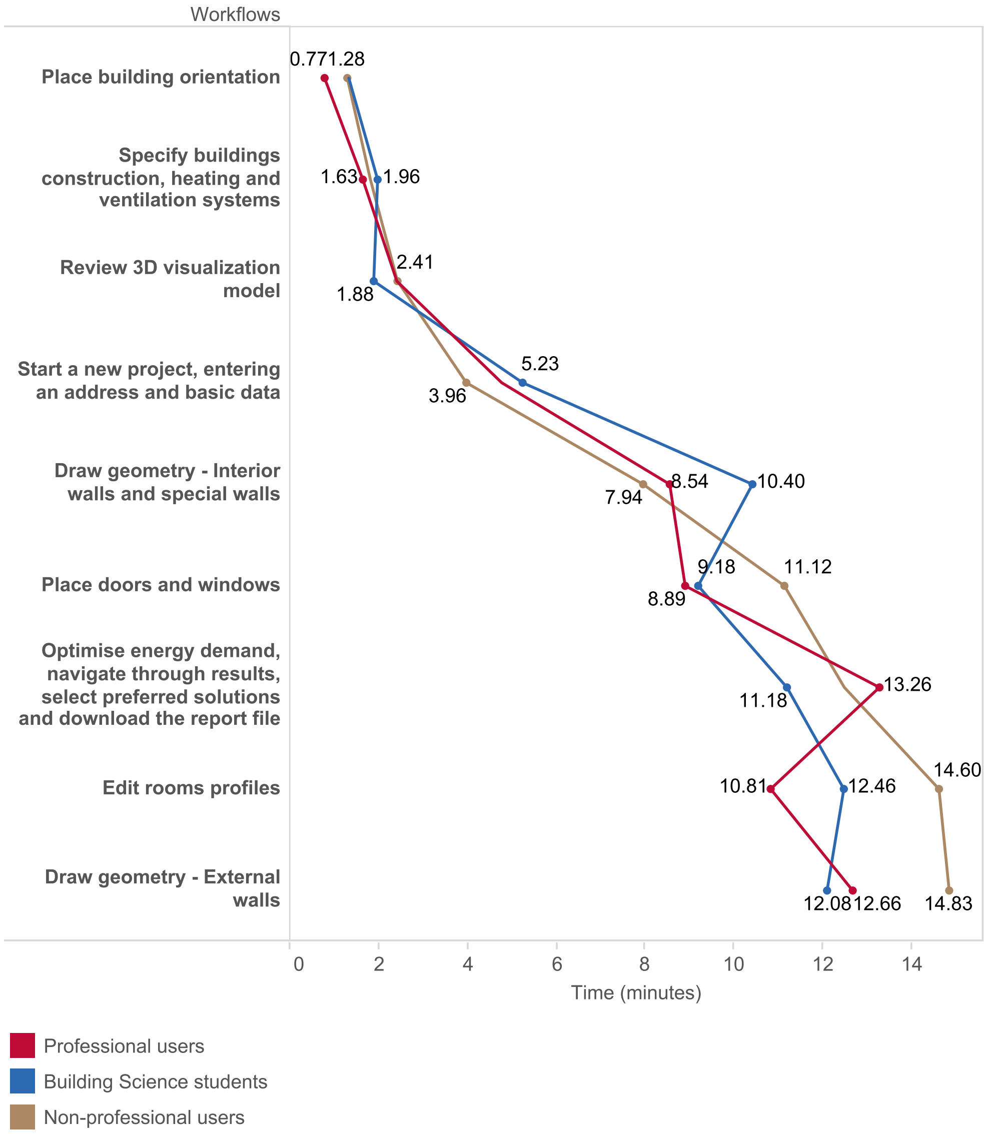


Figure 33: Comparing between users group average task performance timing ascending sorted

- **Error**
  A presentation error is the most error that occurred. It is when users fail to locate and fail to respond to information in screens and make errors because of unclear descriptions. From the twelve sample size of three user groups, professional users have the most error count than Building Science students and non-professional users respectively.

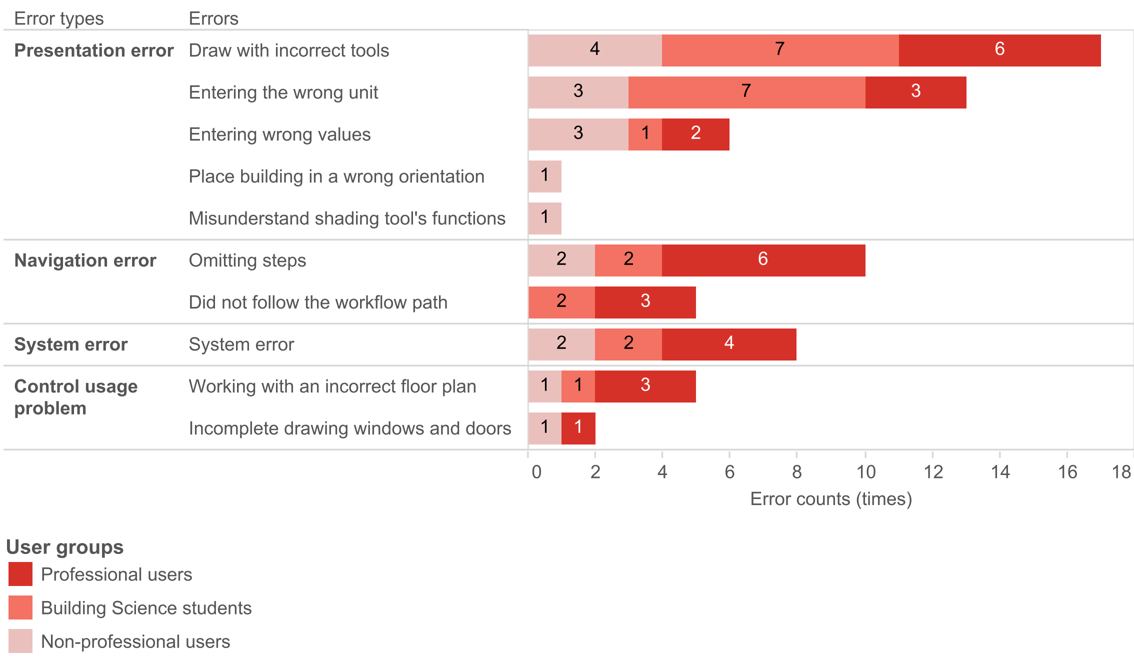


Figure 34: Error counts sorted by error type of 3 sample groups

Professional users who have a background in drafting programs, 3D modeling and building simulation programs are more likely to form errors when they draw geometry. Non-professional users who have no background in the aforementioned tools tend to browse through the tool, reading the labels, trying to get an overview and to familiarize themselves with the new tool before they start to act.

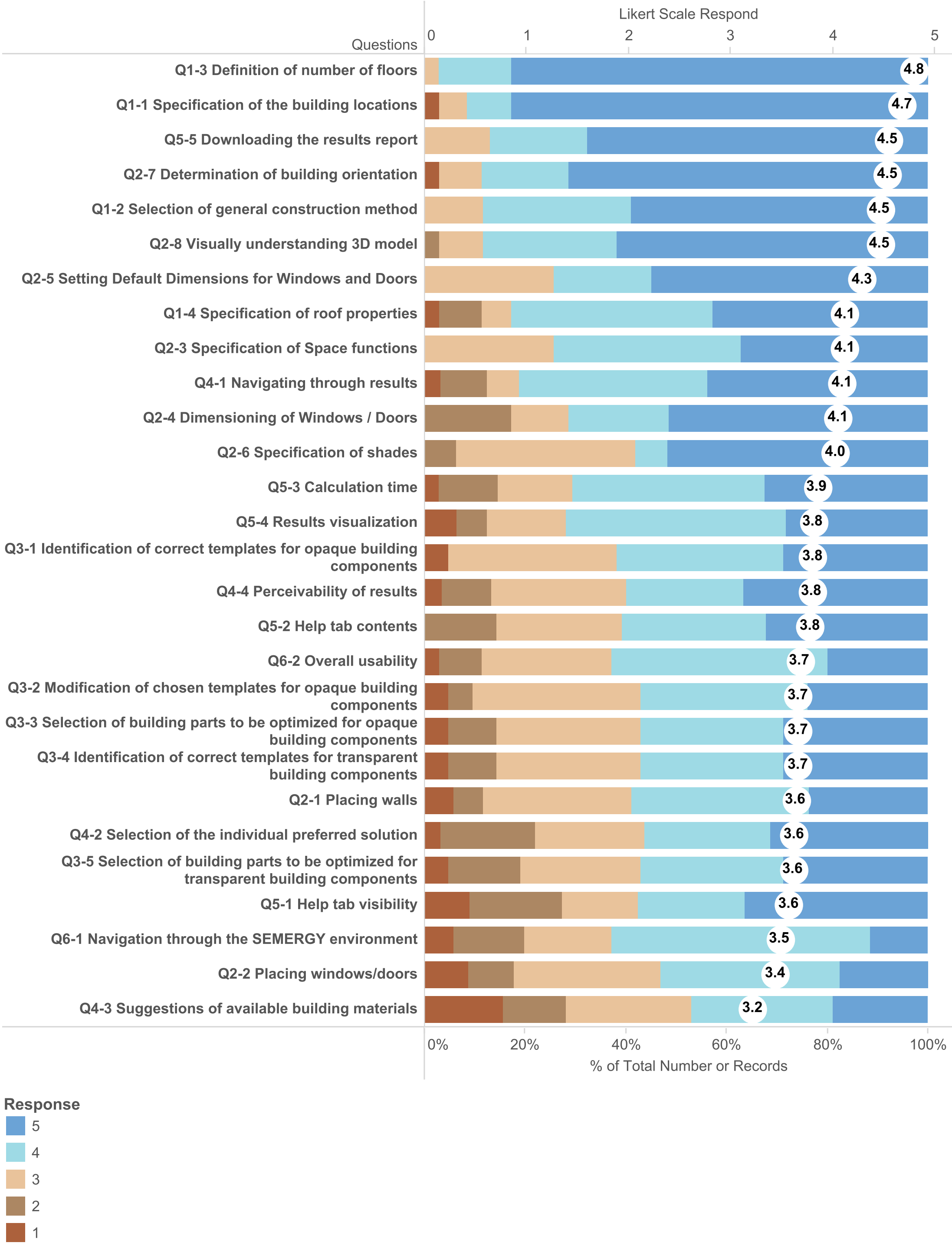


Figure 43: Average Likert scale value sorted descending

- **Satisfaction**
  Post-use questionnaires were gathered to analyze performance data of three user groups with the twelve sample size of each group, to determine user satisfaction from Likert scale respondants. The average response from three user groups range from 3.2-4.8 which are considered a satisfactory result.

  Users find definition number of floors, the specification of building location, downloading the result report, determining building orientation, selection of general construction method and visually understanding 3D model greatly satisfactory. However, participants would suggest more function developments in placing walls, selection of the individual preferred solution, selection of building parts to be optimized for transparent building components, help tap visibility, navigation through the SEMERGY environment, placing doors and windows and finally suggestions of available building materials.

6.2 Conclusion

The study encompassed 36 usability study sessions of 3 groups of 12 users, which are professional users in ACE field, Building Science students and non-professional users in ACE field.

The experiment results in a positive satisfaction from the three user groups. SEMERGY is a very effective tool as a decision support in early stage design. It provides great learnability and memorability to non-professional users as well as excellent efficiency to the professional user. Users respond with competent satisfaction results.

Nonetheless, different backgrounds of users require different usage methods of the tool. Participants with drafting tool backgrounds tend to cause more errors in drawing geometry than participants without drafting tool backgrounds.

Non-professional users who have no background in CAD, BIM or energy performance simulation program tend to follow the tool's workflow. They browse through the menu and read all the labels, informing themselves of the overview and understanding of where specific options and features are positioned. Non-professional users tend to read dialogs and notifications more slowly and try to understand them thoroughly even though they are not assured about acting or canceling specific actions (Cipan 2010). Due to the lack of a specific technical background, users find the tasks complicated to finish but they follow the user-friendly workflow of SEMERGY with a hint of a guideline for the drawing material understanding. All of the non-professional users result in a hundred percent success rate even though it takes a longer time to finish the task than expected.

Non-professional users thoroughly browse through the features of the tool to navigate themselves in an unusual working environment, whereas Building Science students and professional users are familiar with the basics of such tools features. They understand the primary concept and are responsive to the application of the tool; they require reference materials such as help support systems and more functionalities and abilities from the tool.

Participants with drafting tool and energy simulation tools experiences are accustomed to their default tool such as AutoCAD. Such professional tools by all means provide more flexibility and functionality for users. Simplification of SEMERGY tool might hold back the professional users from doing their tasks as they demand more features from the tool and they might be familiar with conventional tools.

CHAPTER 7

User interface design recommendation and Future Research

7.1 User interface design recommendations

Users with different experiences have different requirements. Finding the right balance between designing for different users' backgrounds is an extensively complex and crucial task (Cipan 2010).

Presentation errors occurred when users fail to locate and respond to information on screens. That leads to selection errors by cause of unclear descriptions. To solve presentation issues, we can prevent errors occuring in the first place by eliminating error-prone conditions.

Help and support systems function as a reminder, with reference points not always as starting points. We shall not assume that beginner users will rely strongly on help and support systems. Introducing walkthroughs that appear to guide users through the interface, clarify workflow steps, concepts and overview of the tool are an effective additional user interface design recommendation. The guideline box should offer a turning off alternative as well.

When users start drawing with an incorrect floor plan, for example, instead of drawing basement plans, users draw ground floor plans instead. This usage control problem can be solved by presenting more noticeable information in which floor users are working on.

Non-professional users require drawing guidelines regarding the lack of a technical background; they are not informed which measurements from the floor plan should be drawn. This usability problem can be solved by creating graphical icons that indicate which wall measurements should be drawn, for example when drawing external walls.

The help tap requires more visibility, recommended in a same size icon that is positioned near the drawing tool functions.

Eliminate error-prone conditions by employing a pop-up dialog box directing the overview of the tool and specific tasks explanations.

Back and next buttons informing what users have done and what they are expected to perform, give an overview of the workflow, so that users are orientated and will not get the feeling of losing their steps in the consistency of the tool.

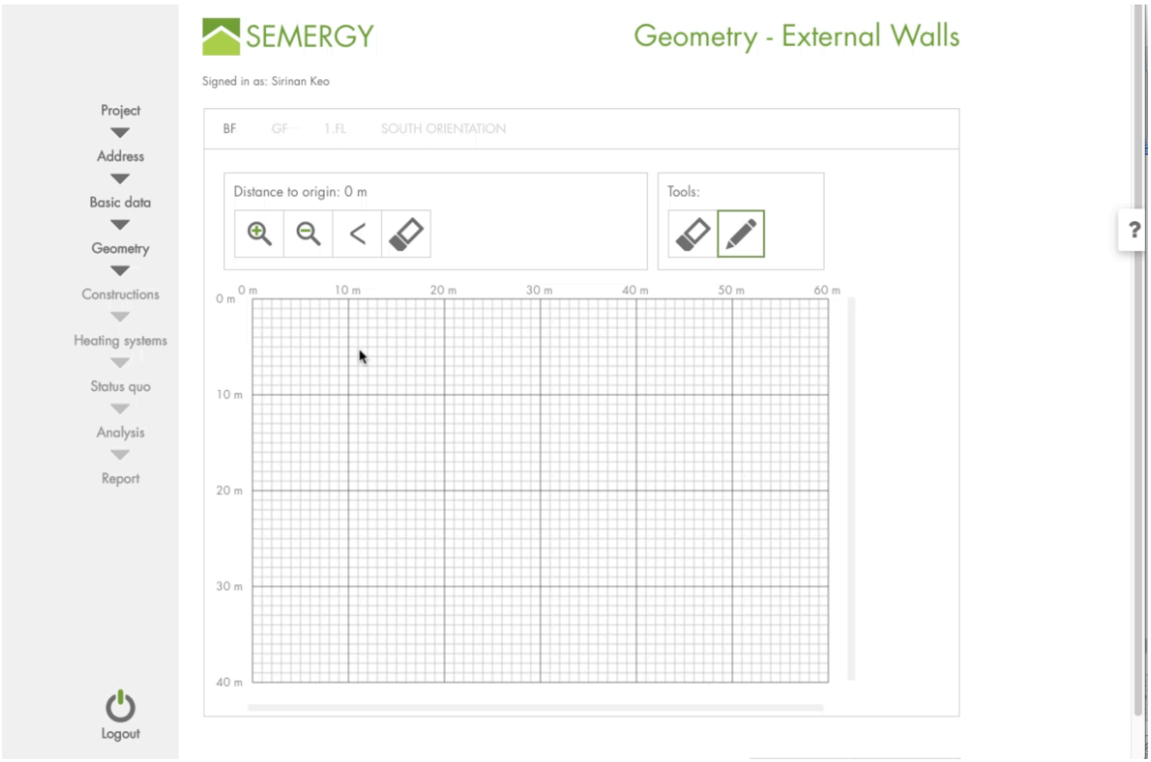


Figure 44: Current SEMERGY user interface.

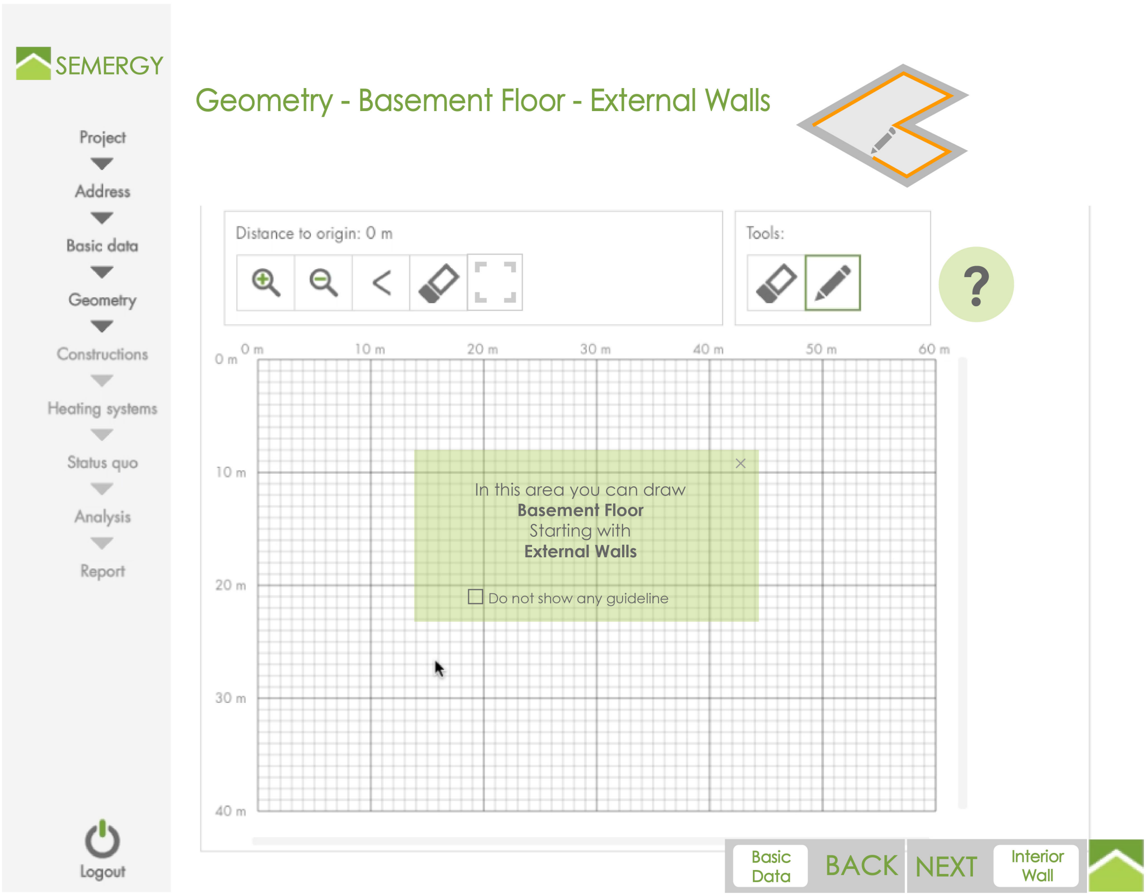


Figure 45: SEMERGY UI external wall section recommended

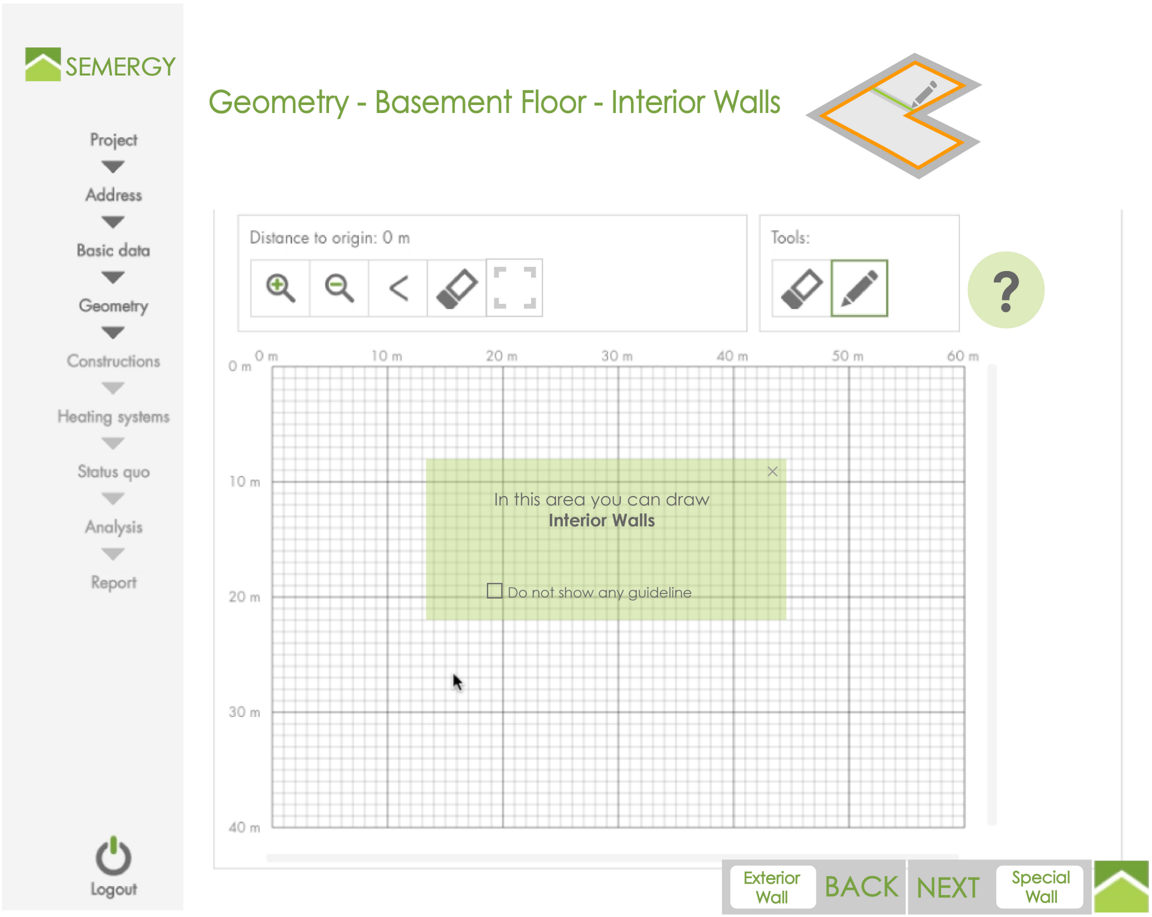


Figure 46: SEMERGY UI interior wall section recommended

Developing UI for non-professional and intermediate users (postgraduate students) to get an overview and user friendliness perception of the tool. It is also important that professional users be satisfied and are being productive while using the tool. Professional users might require some rarely used features for specific scenarios; they need keyboard shortcuts and abilities to manipulate the UI without the mouse. Professional users demand possibilities for significant customizations, automation and some level of extensibility (Cipan 2010). In the use case, full-screen function has been introduced, with highly visible help tap and orientating back and next buttons.

Presentation errors caused by users entering wrong values possibly happen in the Edit Room Profile section. The current method made users scroll up and down to enter each room's information. A fixed screen box of a floor plan has been introduced.

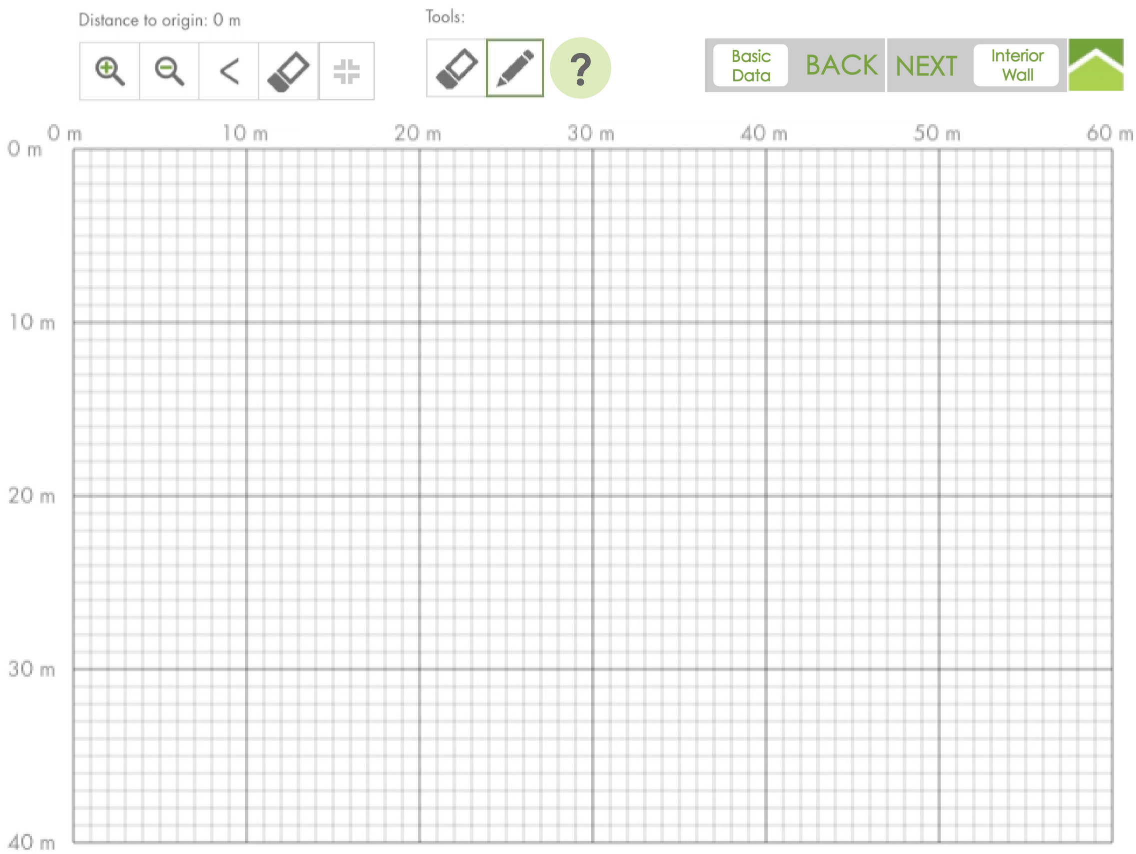


Figure 47: Full screen drawing mode

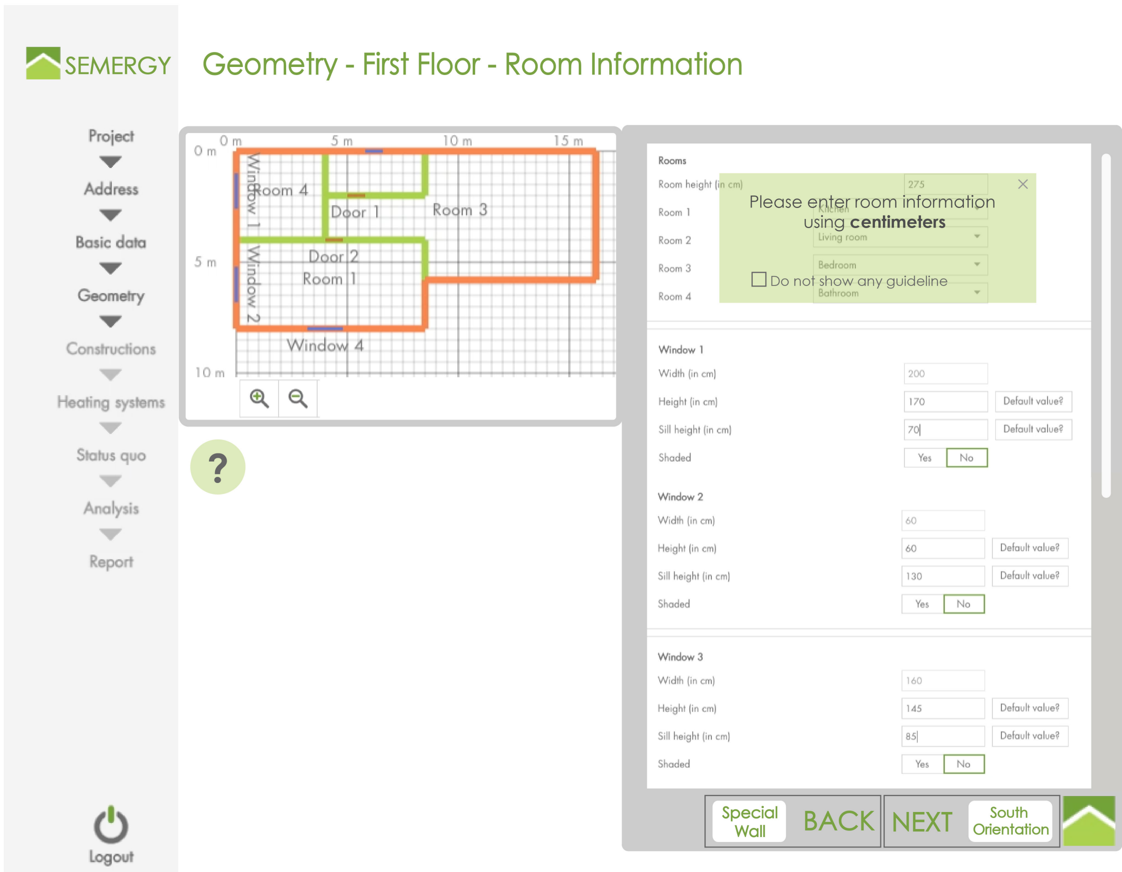


Figure 48: Entering room information UI recommended

7.2 Future research

SEMERGY is a very efficient web-based energy optimization tool. To optimize the user interface that fits user requirements of all user groups is a complex issue. To design for everyone you are designing for no one (Cipan 2010), as different user groups have different requirements. Customized design for each user groups is substantial. The non-professional user requires supplemental features to pilot them through the concept and with the functions of the tool meanwhile, professional users demand functionalities that are rarely or never used by an intermediate or non-professional user. User interface features should be shaped for their specific tasks.

Web-based building performance simulation tools offer an alternative to a desktop-based conventional tool. For non-professional users, this type of tool is convenient to approach via the Internet. In combination with a user-friendly UI, it can help users without a strong technical background in building performance simulation or energy efficiency design to achieve their goals. Future research in specific requirements of professional users could be implemented. We tend to trust expert users for help and advice. Their impact and influence are intensely high and essential (Cipan 2010). A further in-depth study could be implemented regarding expert users' exact usage pattern and behavior of building performance simulation tools as well as in-depth, extensive function requirements toward SEMERGY for future development. Particular features could be developed for specific types of users.

Touchscreen drafting supports ease of use. This method could be introduced uniquely for non-professional users for additional intuitive usage and moreover for preventing errors from an insufficient drafting tool background. For professional users who require extended function, CAD file import function in this development stage has been integrated at present. BIM file import capabilities could be a potential later development process. These added features will support professional users who have to cope with projects at the stage where constant modification of project files is necessary. Furthermore, geographic information systems (GIS) based technology broadens analytical potentials to automatize the calculation of hazards, risk, sensitivity, capacity, proximity, accessibility, vulnerability, and other factors to support design decisions (Ersi 2016). Future research concerning GIS-based design features to integrate the function into SEMERGY could further increase the potential of the tool.

Index

8.1 List of Figures

8.2 List of Tables

Literature

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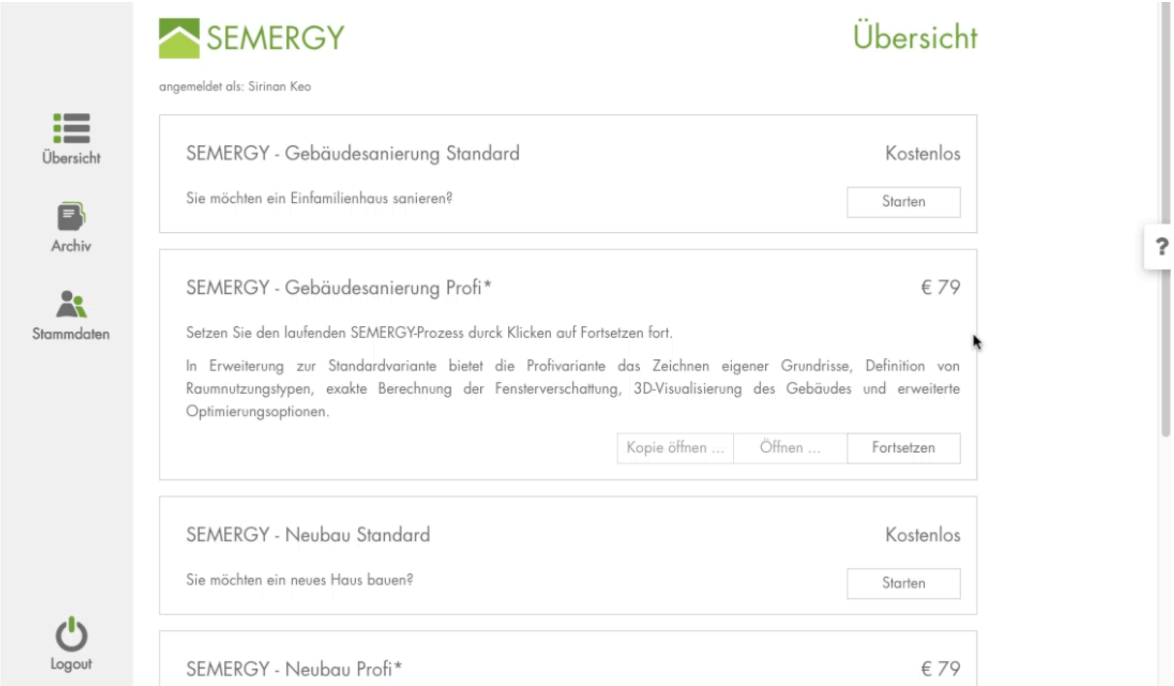
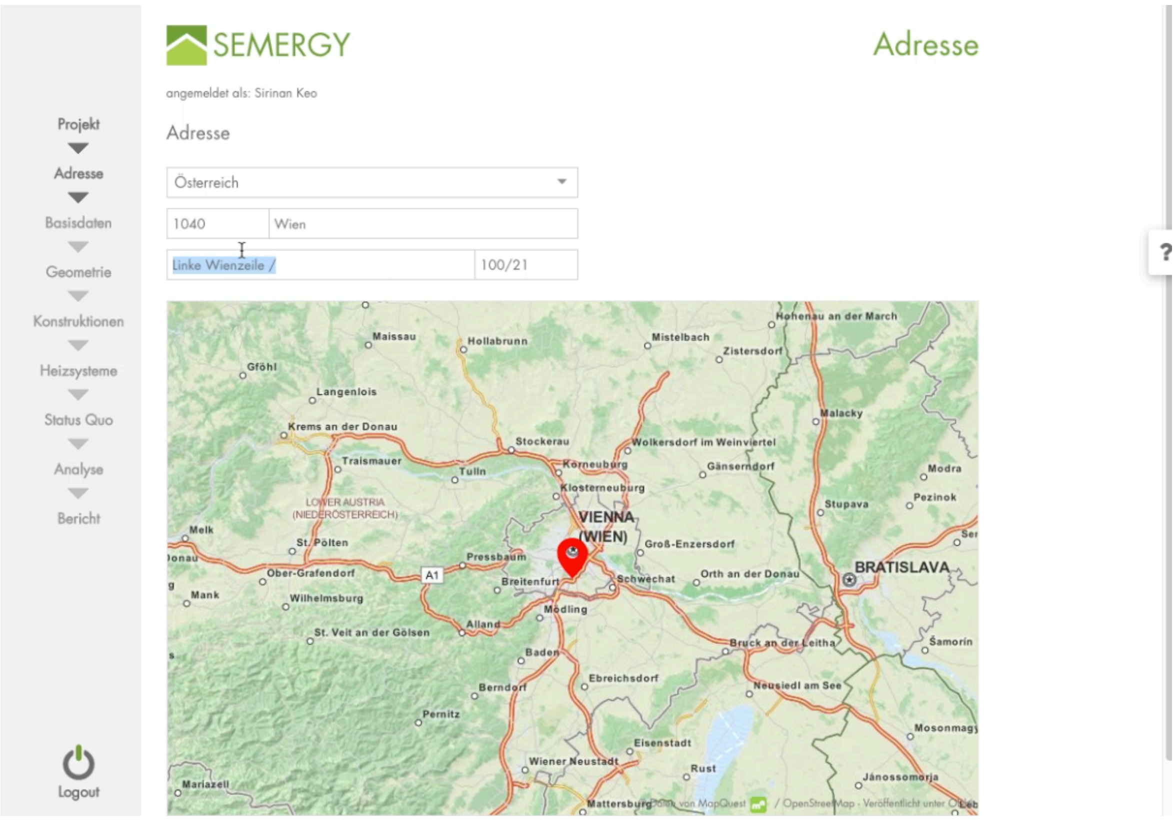
Appendix A: SEMERGY's Screenshots






SEMERGY
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Einfamilienhaus
Bauweise:
Skelettbauweise/Beton
Massivbauweise/Beton
Holzrahmenbauweise
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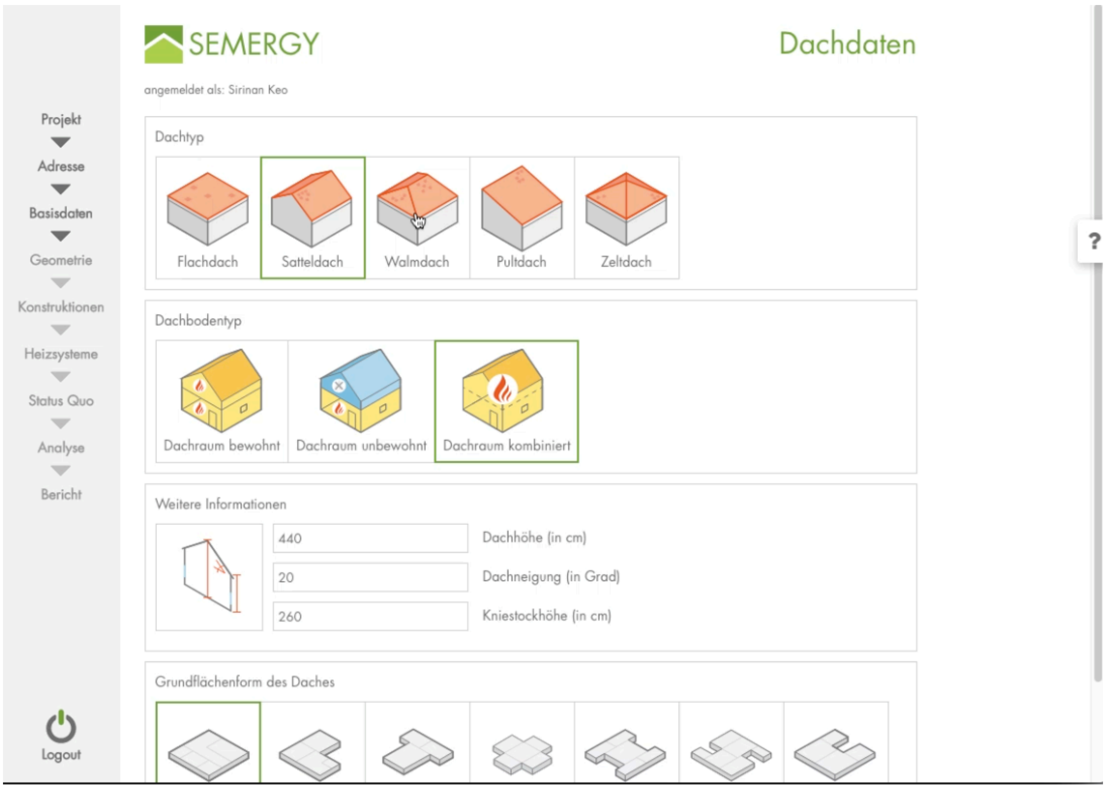
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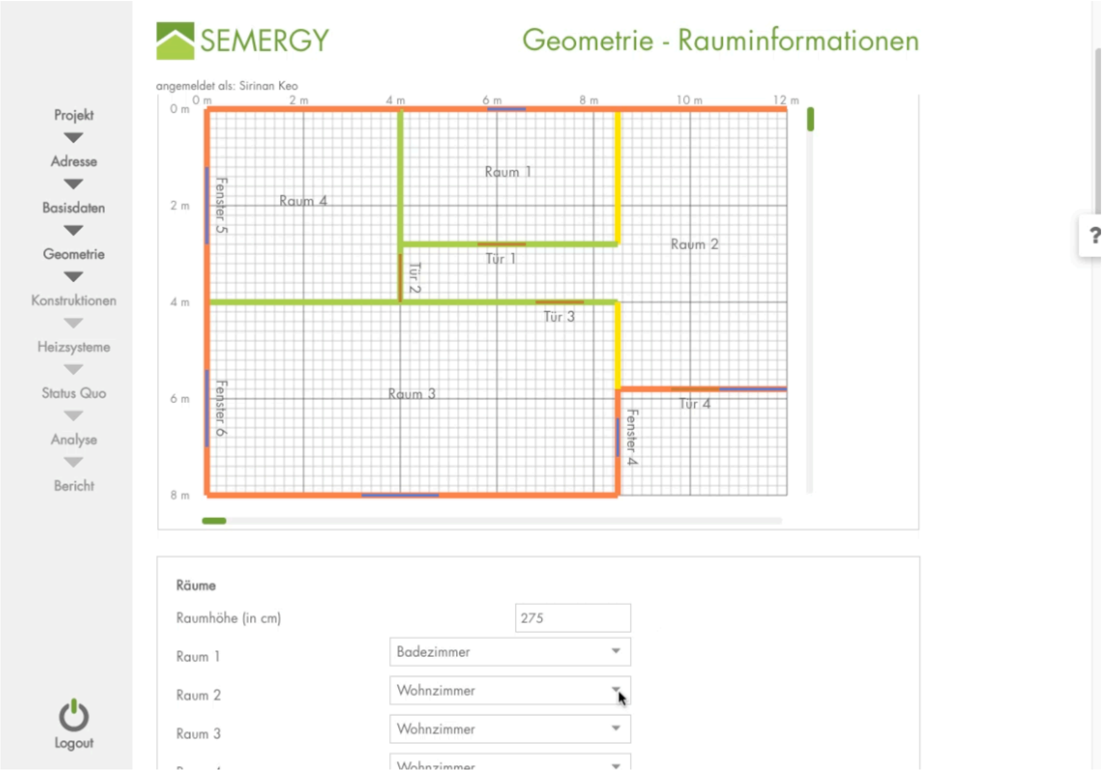
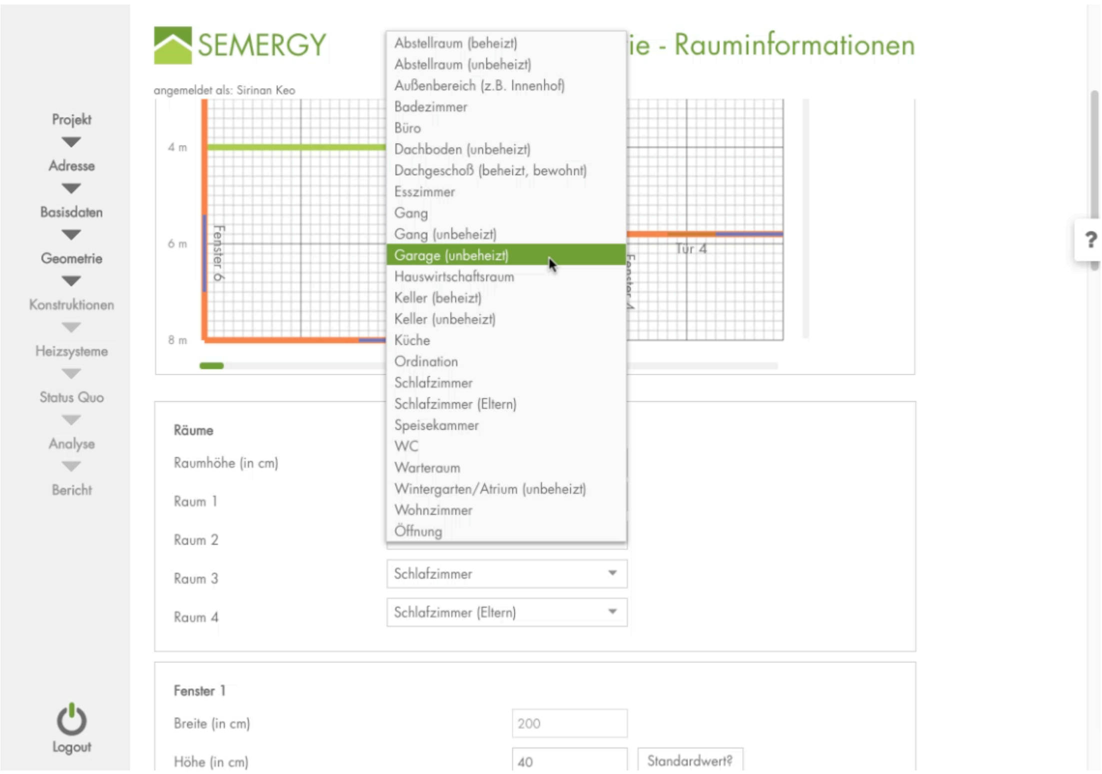
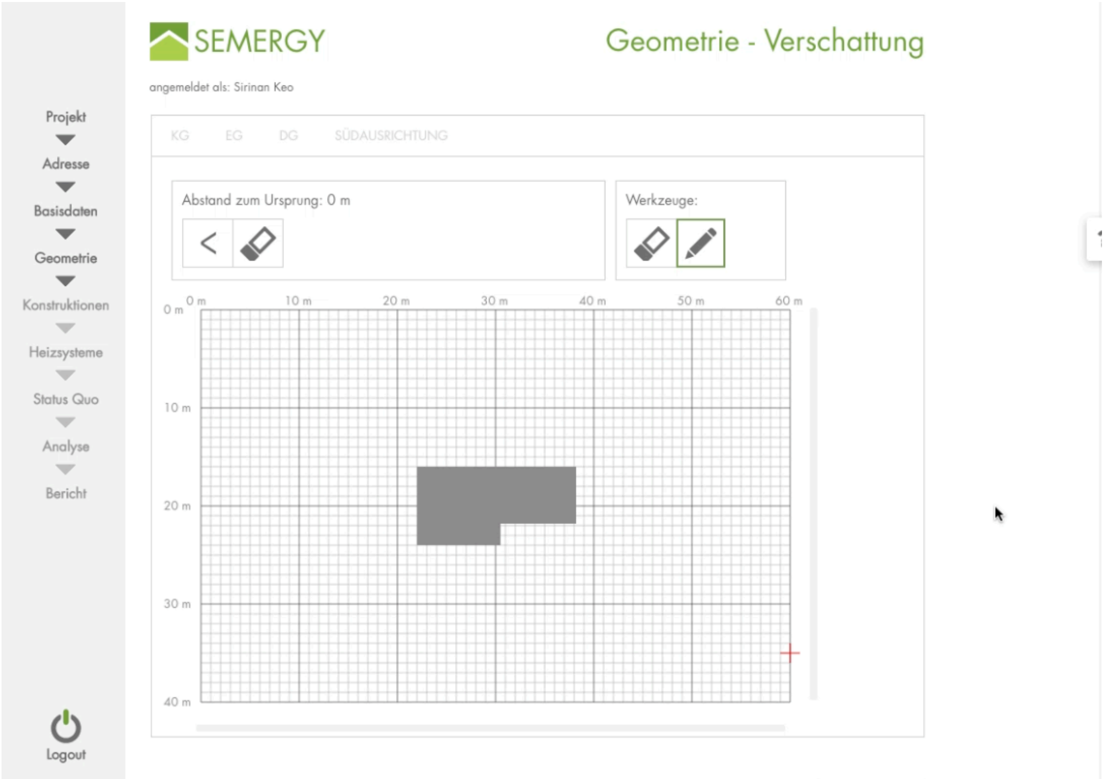
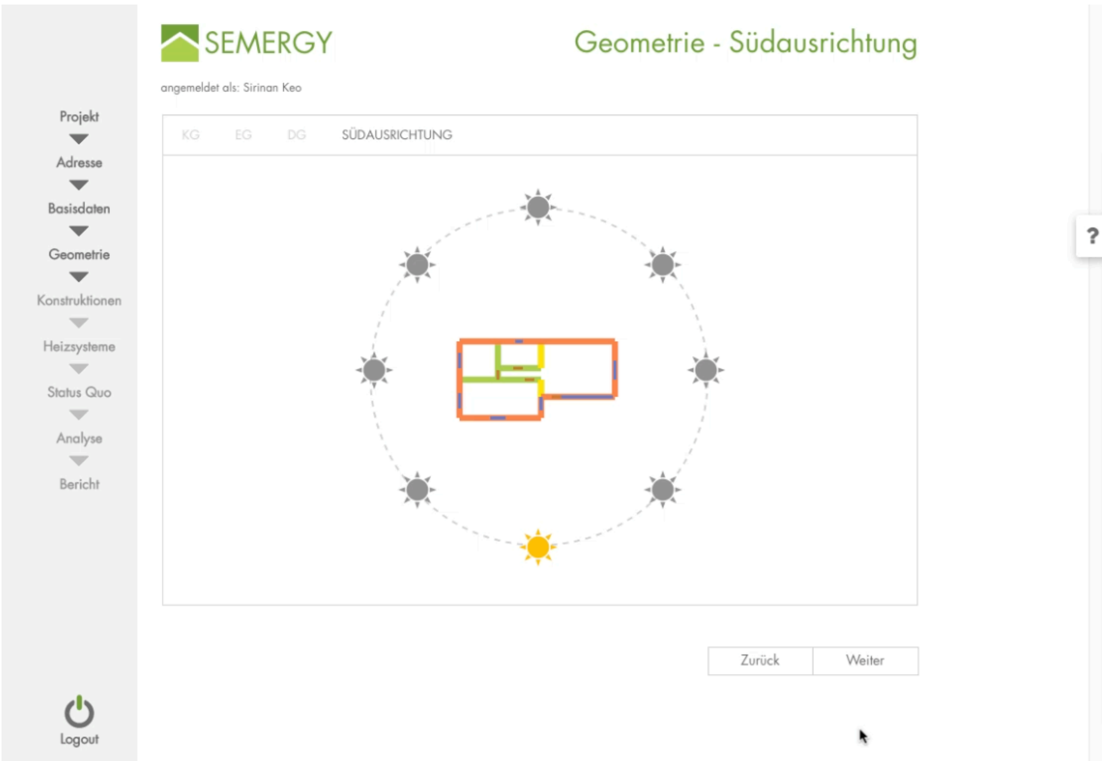
Geometrie
Konstruktionen
Heizsysteme
Status Quo
Analyse
Bericht
Logout
Dachtyp
Flachdach
Satteldach
Walmdach
Pultdach
Zeltdach
Dachbodentyp
Dachraum bewohnt
Dachraum unbewohnt
Dachraum kombiniert
Weitere Informationen
440
Dachhöhe (in cm)
20
Dachneigung (in Grad)
260
Kniestockhöhe (in cm)
Grundflächenform des Daches

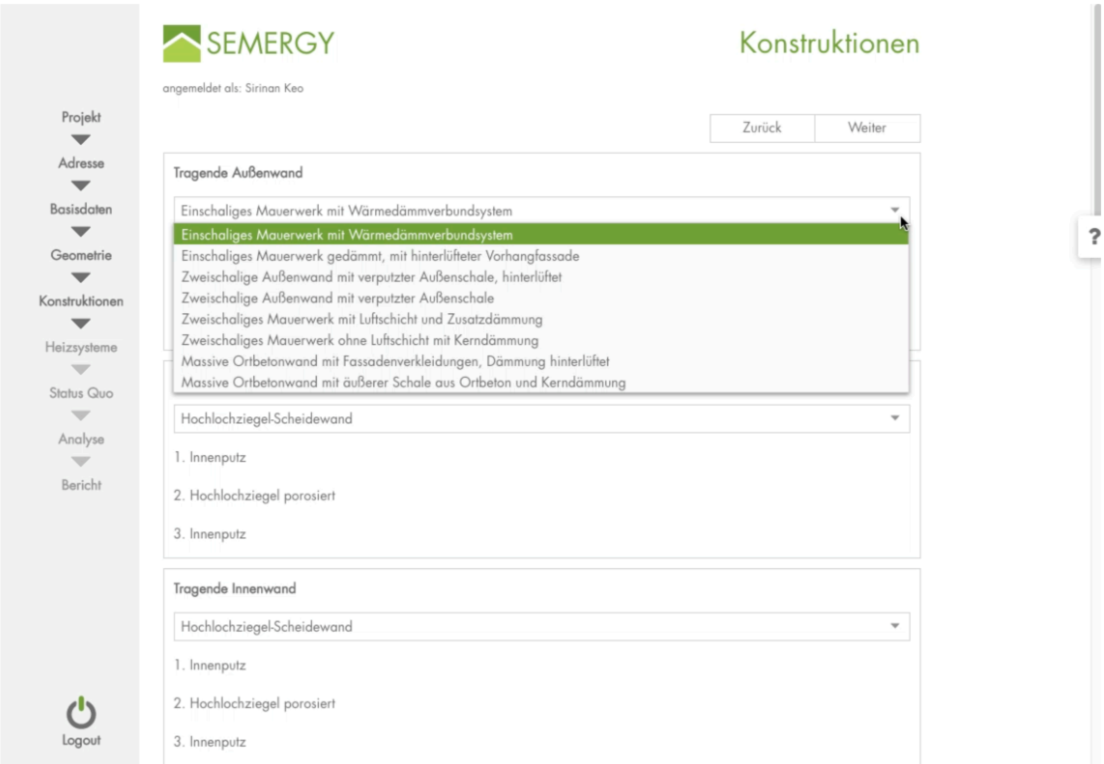

SEMERGY
Geometrie - Rauminformationen
angemeldet als: Sirinan Keo
Projekt
Adresse
Basisdaten
Geometrie
Konstruktionen
Heizsysteme
Status Quo
Analyse
Bericht
Logout
Raum 1
Raum 2
Raum 3
Raum 4
Tür 1
Tür 2
Tür 3
Tür 4
Fenster 4
Fenster 5
Fenster 6
Räume
Raumhöhe (in cm)
275
Raum 1
Badezimmer
Raum 2
Wohnzimmer
Raum 3
Wohnzimmer
Wohnzimmer

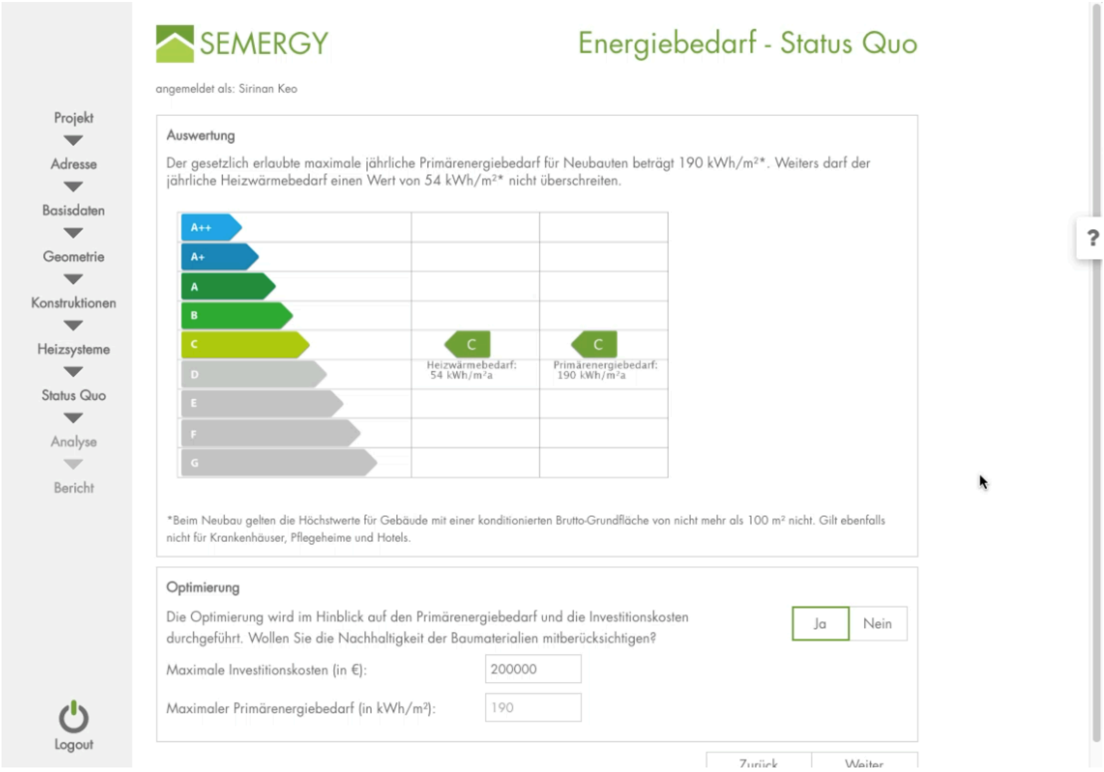

SEMERGY
ie - Rauminformationen
angemeldet als: Sirinan Keo
Projekt
Adresse
Basisdaten
Geometrie
Konstruktionen
Heizsysteme
Status Quo
Analyse
Bericht
Logout
Abstellraum (beheizt)
Abstellraum (unbeheizt)
Außenbereich (z.B. Innenhof)
Badezimmer
Büro
Dachboden (unbeheizt)
Dachgeschoß (beheizt, bewohnt)
Esszimmer
Gang
Gang (unbeheizt)
Garage (unbeheizt)
Hauswirtschaftsraum
Keller (beheizt)
Keller (unbeheizt)
Küche
Ordination
Schlafzimmer
Schlafzimmer (Eltern)
Speisekammer
WC
Warteraum
Wintergarten/Atrium (unbeheizt)
Wohnzimmer
Öffnung
Fenster 6
Tür 4
Räume
Raumhöhe (in cm)
Raum 1
Raum 2
Raum 3
Schlafzimmer
Raum 4
Schlafzimmer (Eltern)
Fenster 1
Breite (in cm)
200
Höhe (in cm)
40
Standardwert?

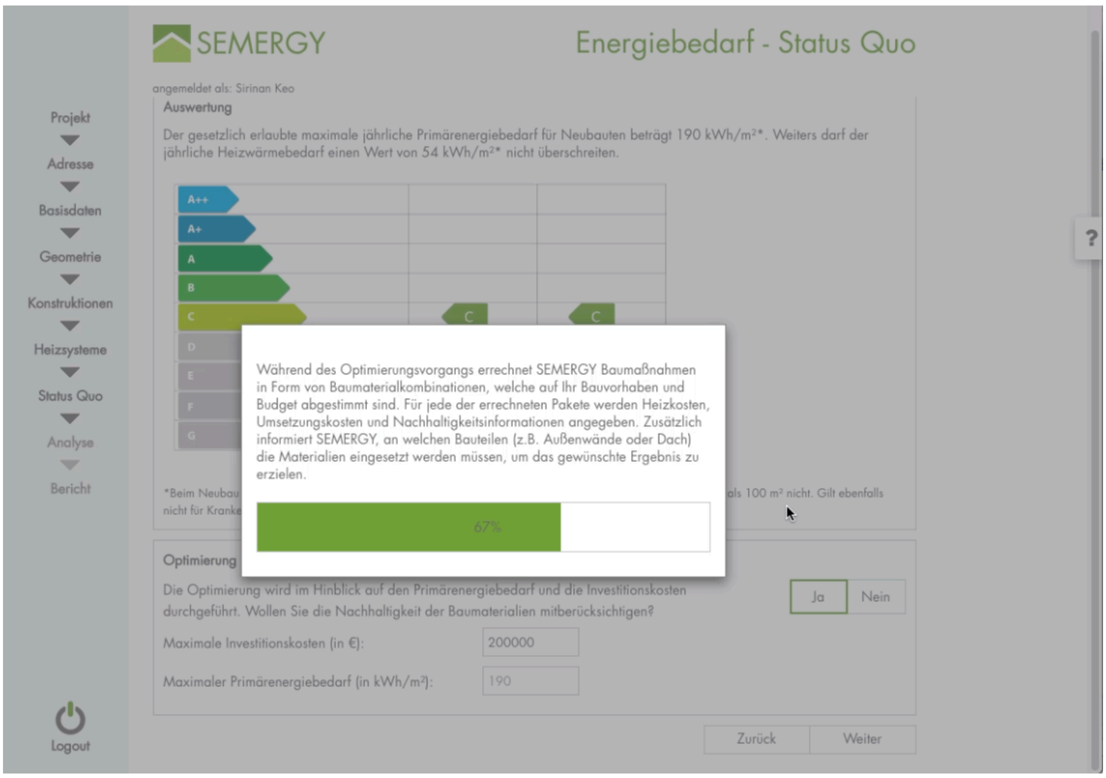

SEMERGY
Geometrie - Verschattung
angemeldet als: Sirinan Keo
Projekt
Adresse
Basisdaten
Geometrie
Konstruktionen
Heizsysteme
Status Quo
Analyse
Bericht
Logout
KG
EG
DG
SÜDAUSRICHTUNG
Abstand zum Ursprung: 0 m
Werkzeuge:
0 m
10 m
20 m
30 m
40 m
50 m
60 m

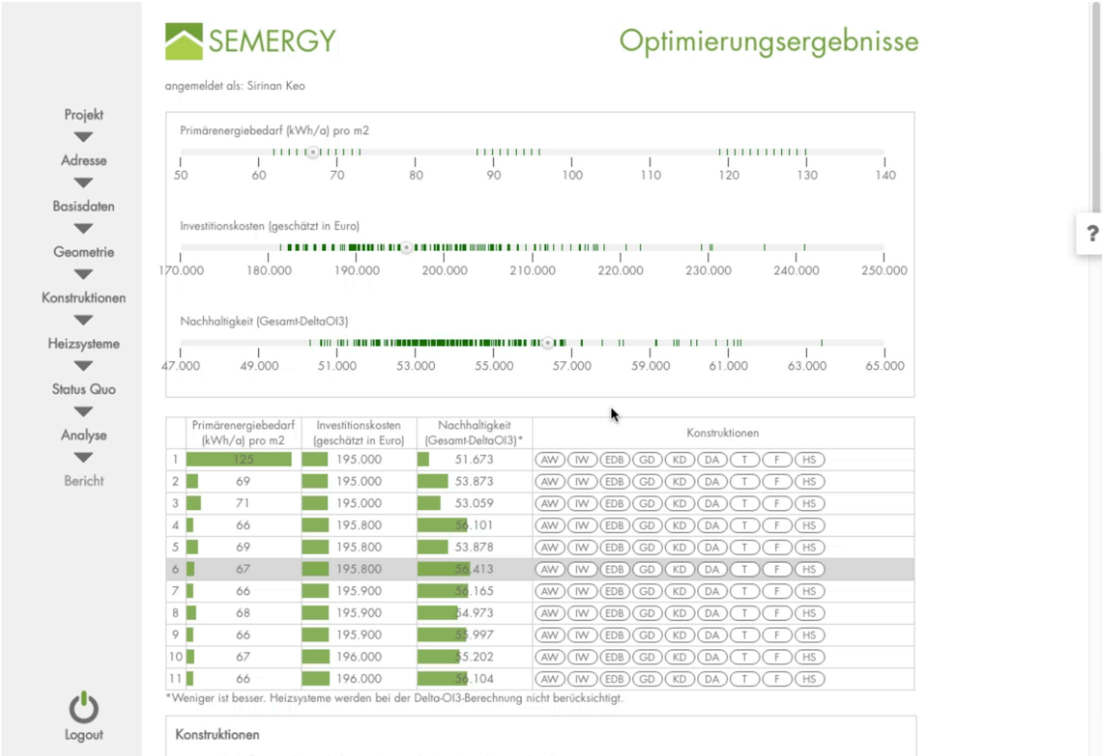

SEMERGY
Geometrie - Südausrichtung
angemeldet als: Sirinan Keo
Projekt
Adresse
Basisdaten
Geometrie
Konstruktionen
Heizsysteme
Status Quo
Analyse
Bericht
Logout
KG
EG
DG
SÜDAUSRICHTUNG
?
Zurück
Weiter

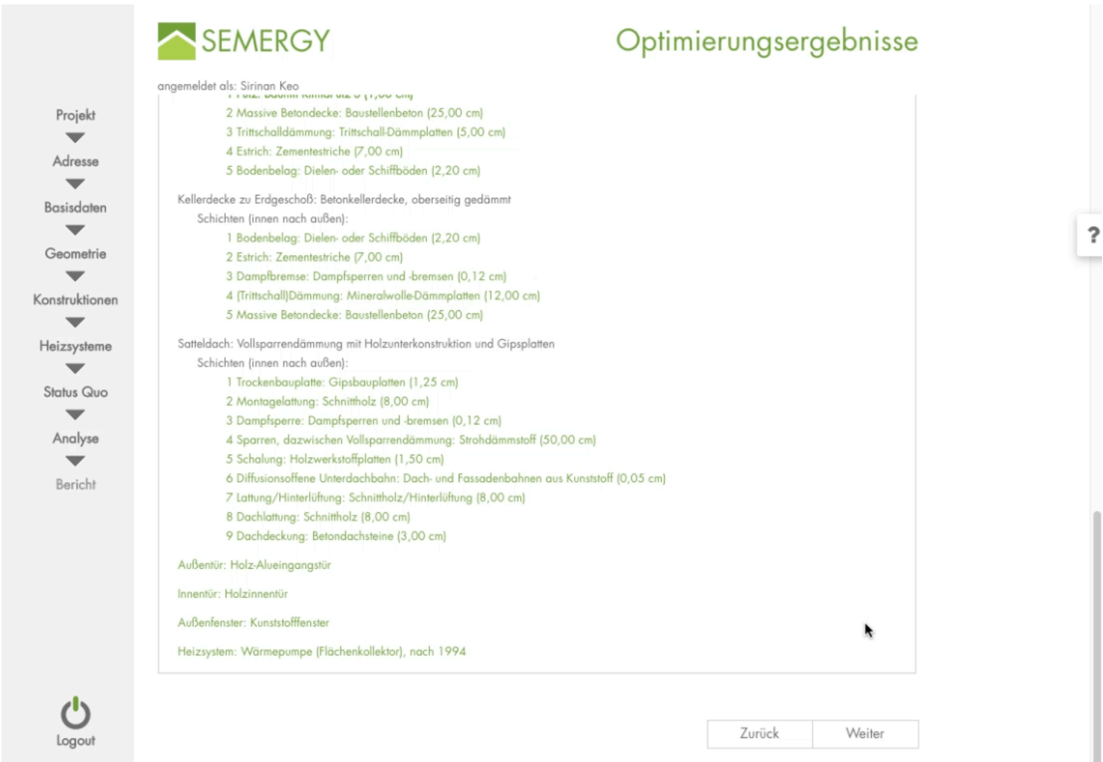

SEMERGY
Gebäudevisualisierung
angemeldet als: Sirinan Keo
Zoom
Projekt
Adresse
Basisdaten
Geometrie
Konstruktionen
Heizsysteme
Status Quo
Analyse
Bericht
Logout
Gebäudeelemente
Dach
Tragende Außenwand
Außenfenster
Tragende Innenwand
Innentür
Nichttragende Innenwand
Kellerdecke zu Erdgeschoß
Außentür
Erdberührter Boden (Keller oder Erdgeschoß)
Geschoßdecke
Kellerwand
Zurück
Weiter

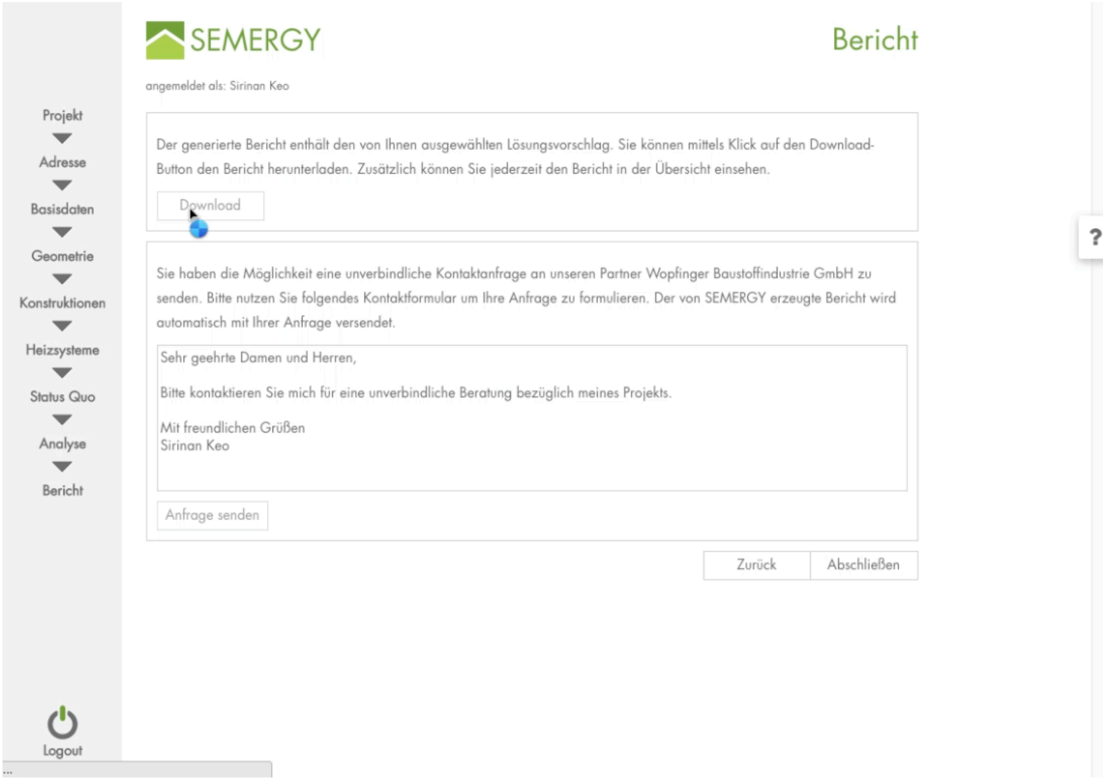

SEMERGY
Konstruktionen
angemeldet als: Sirinan Keo
Projekt
Adresse
Basisdaten
Geometrie
Konstruktionen
Heizsysteme
Status Quo
Analyse
Bericht
Logout
Zurück
Weiter
Tragende Außenwand
Einschaliges Mauerwerk mit Wärmedämmverbundsystem
Einschaliges Mauerwerk mit Wärmedämmverbundsystem
Einschaliges Mauerwerk gedämmt, mit hinterlüfteter Vorhangfassade
Zweischalige Außenwand mit verputzter Außenschale, hinterlüftet
Zweischalige Außenwand mit verputzter Außenschale
Zweischaliges Mauerwerk mit Luftschicht und Zusatzdämmung
Zweischaliges Mauerwerk ohne Luftschicht mit Kerndämmung
Massive Ortbetonwand mit Fassadenverkleidungen, Dämmung hinterlüftet
Massive Ortbetonwand mit äußerer Schale aus Ortbeton und Kerndämmung
Hochlochziegel-Scheidewand
1. Innenputz
2. Hochlochziegel porosiert
3. Innenputz
Tragende Innenwand
Hochlochziegel-Scheidewand
1. Innenputz
2. Hochlochziegel porosiert
3. Innenputz


SEMERGY
Energiebedarf - Status Quo
angemeldet als: Sirinan Keo
Projekt
Adresse
Basisdaten
Geometrie
Konstruktionen
Heizsysteme
Status Quo
Analyse
Bericht
Logout
Auswertung
Der gesetzlich erlaubte maximale jährliche Primärenergiebedarf für Neubauten beträgt 190 kWh/m²*. Weiters darf der jährliche Heizwärmebedarf einen Wert von 54 kWh/m²* nicht überschreiten.
A++
A+
A
B
C
D
E
F
G
Heizwärmebedarf: 54 kWh/m²a
Primärenergiebedarf: 190 kWh/m²a
*Beim Neubau gelten die Höchstwerte für Gebäude mit einer konditionierten Brutto-Grundfläche von nicht mehr als 100 m² nicht. Gilt ebenfalls nicht für Krankenhäuser, Pflegeheime und Hotels.
Optimierung
Die Optimierung wird im Hinblick auf den Primärenergiebedarf und die Investitionskosten durchgeführt. Wollen Sie die Nachhaltigkeit der Baumaterialien mitberücksichtigen?
Ja
Nein
Maximale Investitionskosten (in €):
200000
Maximaler Primärenergiebedarf (in kWh/m²):
190
?


SEMERGY
Energiebedarf - Status Quo
angemeldet als: Sirinan Keo
Während des Optimierungsvorgangs errechnet SEMERGY Baumaßnahmen in Form von Baumaterialkombinationen, welche auf Ihr Bauvorhaben und Budget abgestimmt sind. Für jede der errechneten Pakete werden Heizkosten, Umsetzungskosten und Nachhaltigkeitsinformationen angegeben. Zusätzlich informiert SEMERGY, an welchen Bauteilen (z.B. Außenwände oder Dach) die Materialien eingesetzt werden müssen, um das gewünschte Ergebnis zu erzielen.
67%
Optimierung
Die Optimierung wird im Hinblick auf den Primärenergiebedarf und die Investitionskosten durchgeführt. Wollen Sie die Nachhaltigkeit der Baumaterialien mitberücksichtigen?
Ja
Nein
Maximale Investitionskosten (in €):
200000
Maximaler Primärenergiebedarf (in kWh/m²):
190
Zurück
Weiter
Logout


SEMERGY
Optimierungsergebnisse
angemeldet als: Sirinan Keo
Projekt
Adresse
Basisdaten
Geometrie
Konstruktionen
Heizsysteme
Status Quo
Analyse
Bericht
Logout
Primärenergiebedarf (kWh/a) pro m2
50 60 70 80 90 100 110 120 130 140
Investitionskosten (geschätzt in Euro)
170.000 180.000 190.000 200.000 210.000 220.000 230.000 240.000 250.000
Nachhaltigkeit (Gesamt-DeltaOI3)
47.000 49.000 51.000 53.000 55.000 57.000 59.000 61.000 63.000 65.000
Primärenergiebedarf (kWh/a) pro m2
Investitionskosten (geschätzt in Euro)
Nachhaltigkeit (Gesamt-DeltaOI3)*
Konstruktionen
1 125 195.000 51.673 AW IW EDB GD KD DA T F HS
2 69 195.000 53.873 AW IW EDB GD KD DA T F HS
3 71 195.000 53.059 AW IW EDB GD KD DA T F HS
4 66 195.800 56.101 AW IW EDB GD KD DA T F HS
5 69 195.800 53.878 AW IW EDB GD KD DA T F HS
6 67 195.800 56.413 AW IW EDB GD KD DA T F HS
7 66 195.900 56.165 AW IW EDB GD KD DA T F HS
8 68 195.900 54.973 AW IW EDB GD KD DA T F HS
9 66 195.900 55.997 AW IW EDB GD KD DA T F HS
10 67 196.000 55.202 AW IW EDB GD KD DA T F HS
11 66 196.000 56.104 AW IW EDB GD KD DA T F HS
*Weniger ist besser. Heizsysteme werden bei der Delta-OI3-Berechnung nicht berücksichtigt.
Konstruktionen
?


SEMERGY
Optimierungsergebnisse
angemeldet als: Sirinan Keo
Projekt
Adresse
Basisdaten
Geometrie
Konstruktionen
Heizsysteme
Status Quo
Analyse
Bericht
Logout
2 Massive Betondecke: Baustellenbeton (25,00 cm)
3 Trittschalldämmung: Trittschall-Dämmplatten (5,00 cm)
4 Estrich: Zementestriche (7,00 cm)
5 Bodenbelag: Dielen- oder Schiffböden (2,20 cm)
Kellerdecke zu Erdgeschoß: Betonkellerdecke, oberseitig gedämmt
Schichten (innen nach außen):
1 Bodenbelag: Dielen- oder Schiffböden (2,20 cm)
2 Estrich: Zementestriche (7,00 cm)
3 Dampfbremse: Dampfsperren und -bremsen (0,12 cm)
4 (Trittschall)Dämmung: Mineralwolle-Dämmplatten (12,00 cm)
5 Massive Betondecke: Baustellenbeton (25,00 cm)
Satteldach: Vollsparrendämmung mit Holzunterkonstruktion und Gipsplatten
Schichten (innen nach außen):
1 Trockenbauplatte: Gipsbauplatten (1,25 cm)
2 Montagelattung: Schnittholz (8,00 cm)
3 Dampfsperre: Dampfsperren und -bremsen (0,12 cm)
4 Sparren, dazwischen Vollsparrendämmung: Strohdämmstoff (50,00 cm)
5 Schalung: Holzwerkstoffplatten (1,50 cm)
6 Diffusionsoffene Unterdachbahn: Dach- und Fassadenbahnen aus Kunststoff (0,05 cm)
7 Lattung/Hinterlüftung: Schnittholz/Hinterlüftung (8,00 cm)
8 Dachlattung: Schnittholz (8,00 cm)
9 Dachdeckung: Betondachsteine (3,00 cm)
Außentür: Holz-Alueingangstür
Innentür: Holzinnentür
Außenfenster: Kunststofffenster
Heizsystem: Wärmepumpe (Flächenkollektor), nach 1994
Zurück
Weiter
?


SEMERGY
Bericht
angemeldet als: Sirinan Keo
Projekt
Adresse
Basisdaten
Geometrie
Konstruktionen
Heizsysteme
Status Quo
Analyse
Bericht
Logout
Der generierte Bericht enthält den von Ihnen ausgewählten Lösungsvorschlag. Sie können mittels Klick auf den Download-Button den Bericht herunterladen. Zusätzlich können Sie jederzeit den Bericht in der Übersicht einsehen.
Download
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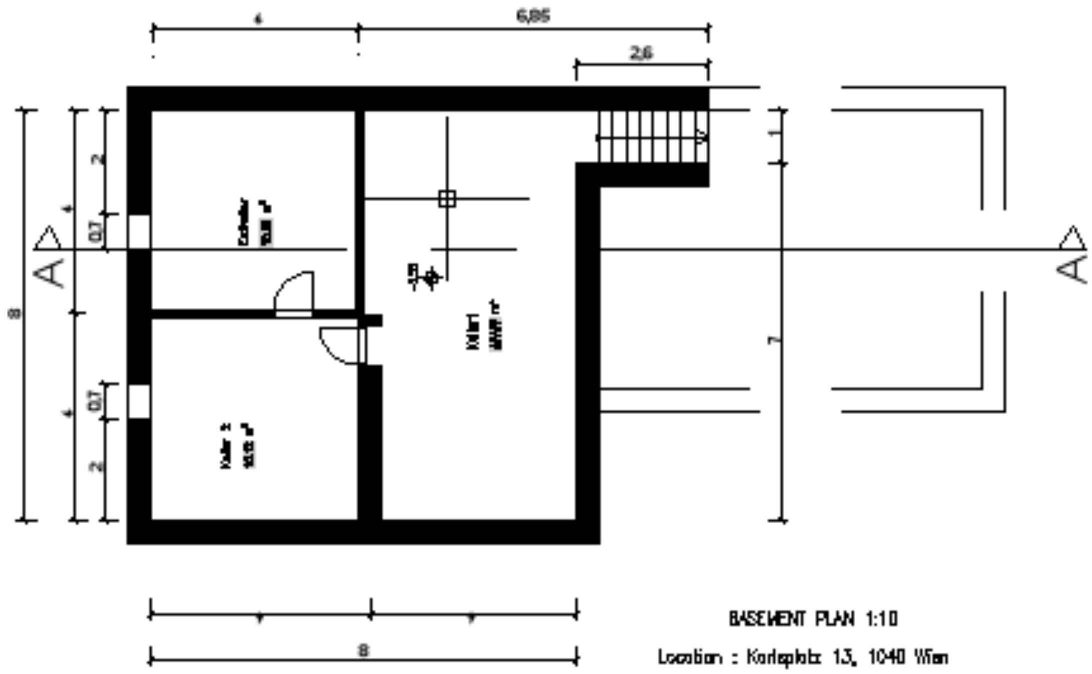
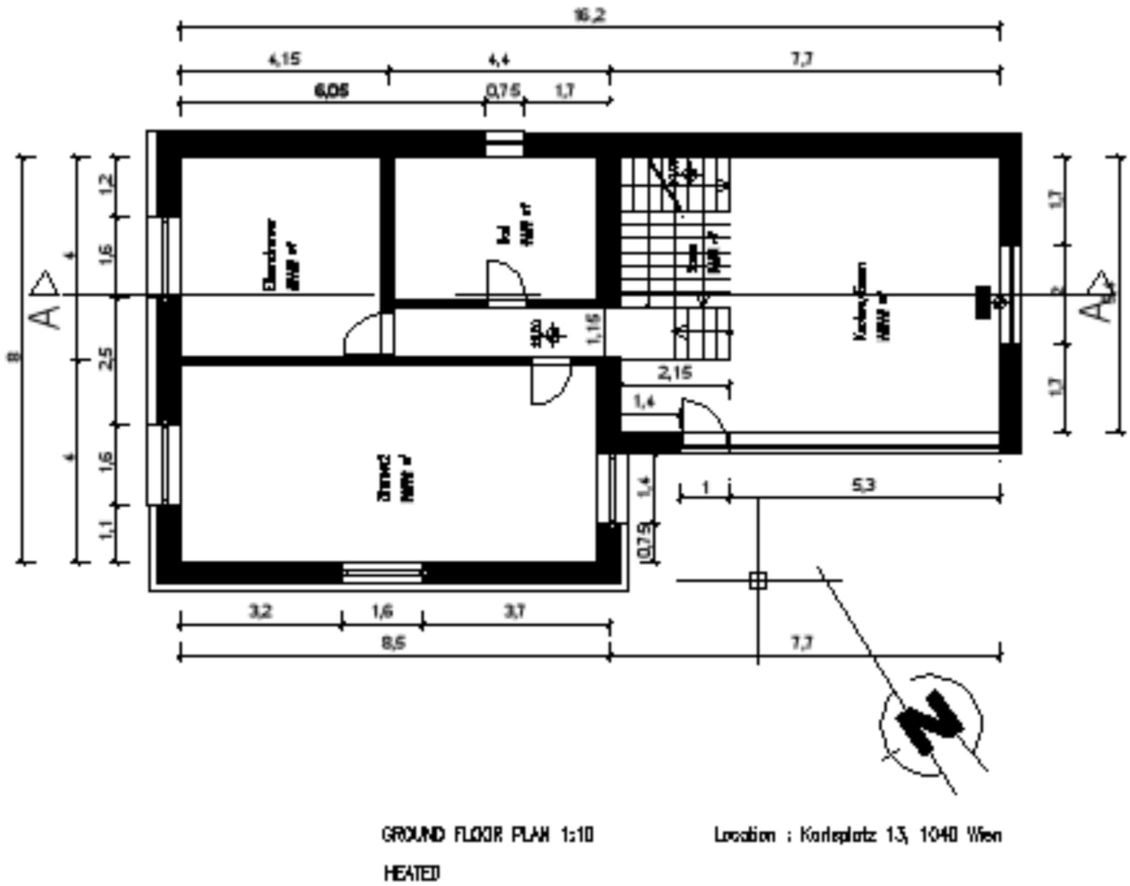
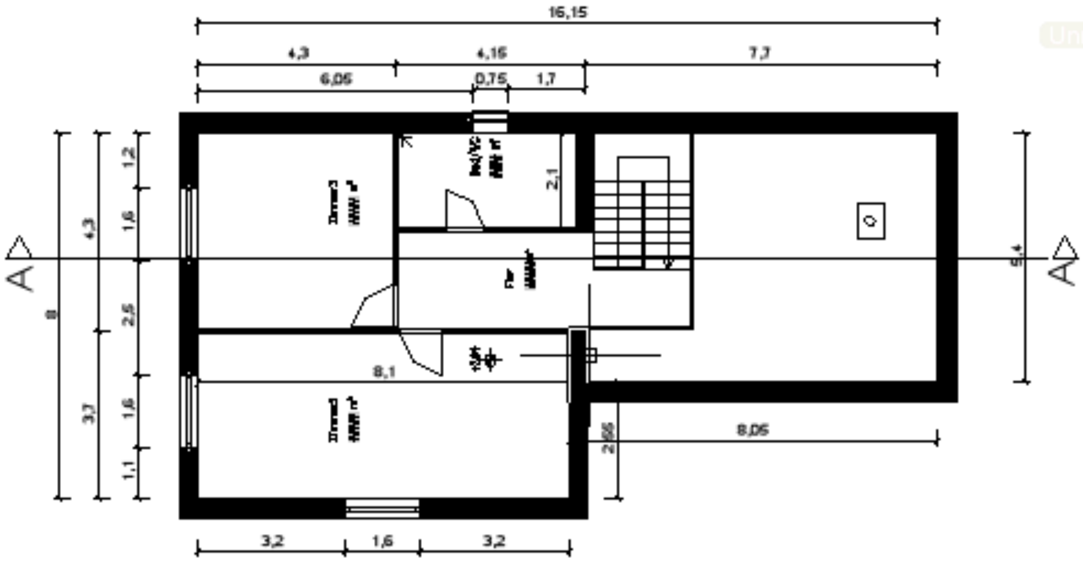
Sehr geehrte Damen und Herren,
Bitte kontaktieren Sie mich für eine unverbindliche Beratung bezüglich meines Projekts.
Mit freundlichen Grüßen
Sirinan Keo
Anfrage senden
Zurück
Abschließen
?

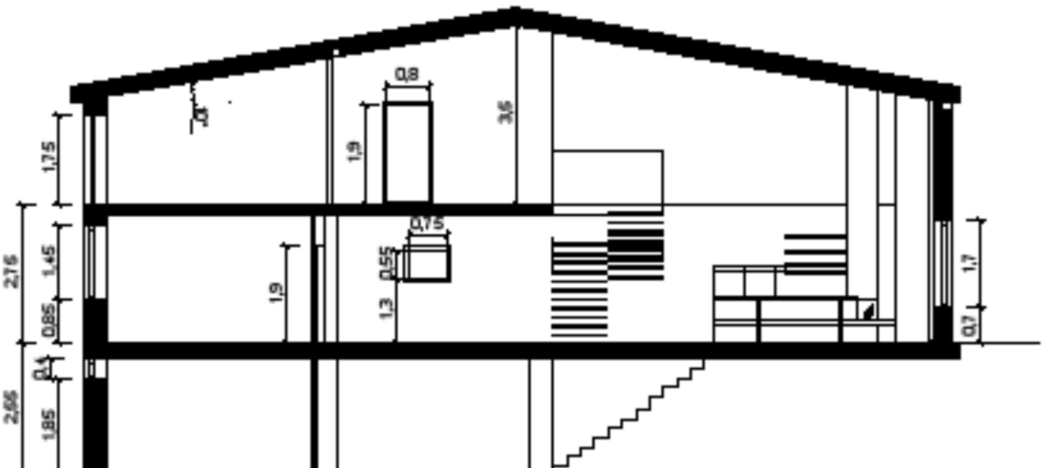
Appendix B: Test materials







1ST FLOOR PLAN 1:10
HEATED



Section A-A 1: 10