DISSERTATION

A comprehensive approach to web-enabled, optimization-based decision support in building design and retrofit

conducted for the purpose of obtaining the academic degree of

“Doktor der technischen Wissenschaften”

supervised by

Univ. Prof. DI. Dr. Ardeshir Mahdavi

E 259-3 Department Building Physics and Building Ecology
Institute of Architectural Sciences

submitted at the University of Technology Vienna
Faculty of Architecture & Regional Planning

by

DI Ulrich Pont
Student ID 9925967
Paradisgasse 62/2/6,
A-1190 Vienna, Austria

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Our concern is political too – to change the world... Architecture is my work, and I've spent my whole life at a drawing board, but life is more important than architecture. What matters is to improve human beings.

Oscar Niemayer

Jede Wissenschaft ist, unter anderem, ein Ordnen, ein Vereinfachen, ein Verdaulichmachen des Unverständlichen für den Geist.

Hermann Hesse

Drei Dinge sind an einem Gebäude zu beachten: dass es am rechten Fleck stehe, dass es wohlgegründet, dass es vollkommen ausgeführt sei.

Johann Wolfgang von Goethe

God is in the details.

Ludwig Mies van der Rohe

Too bright too even see the sun,

more and more sand in my eyes.

GusGus. “Arabian Horse”

Expert textpert choking smokers,

Don't you thing the joker laughs at you?

See how they smile like pigs in a sty,

See how they snied.

I'm crying.

The Beatles. “I am the walrus”
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0.4. Abbreviations used in this work

AEC… Architecture, Engineering, Construction
AP… Acidification Potential
BIM… Building Information Modelling
BPI… Department of Building Physics and Building Ecology, Vienna University of Technology
BPO… Building Product Ontologies
BPST… Building Performance Simulation Tools
CAAD… Computer Aided Architectural Design
CAD… Computer Aided Design
CEN… Comité Européen de Normalisation; European Committee for Standardization
CMU… Carnegie Mellon University
D-A-CH… Germany (D) – Austria (A) – Switzerland (CH)
DoE… United States Department of Energy,
DSS… Decision Support Systems
DWG… drawing (data format for Autocad drawings)
ERP… Enterprise Resource Planning
ES… Expert System
gbXML… Green Building extended Markup Language, green building XML
GC… General Cost
GIS… Geographical Information System
GUI… Graphical User Interface
GWP… Global Warming Potential
HVAC… Heating, Ventilation, Air-Conditioning
IFC… Industry Foundation Classes
IFS… Information & Software Engineering Group, Vienna University of Technology
ISO… International Organization for Standardization
KPI… Key Performance Indicator
LENI… Lighting Energy Numeric Indicator
LOD… Linked Open Data
LC… Labour Cost.
K… Kelvin
MC… Material Cost
MOO… Multi-Objective Optimization
OENORM… Austrian Institute of Standardization (Österreichisches Normungsinstitut)
p.a. per anno
PEC… Primary Energy Content (of non-renewable sources)
RDF… Resource Description Framework
SBM… SEMERGY Building Model
SOM… Shared Object Model
SPARQL… Simple Protocol and RDF Query Language
STF… import/export format of the DIALUX Lighting Simulation
UGR… Unified Glare Rate
UML… Unified Modelling Language
URL… Uniform Resource Locator
VTU… Vienna University of Technology
XML… Extended Markup Language
W3C… World Wide Web Consortium
www… World Wide Web
0.5. **Summary in English language**

This dissertation discusses the development of a web-enabled, optimization-based decision support environment for building design and retrofit. This development, which was carried out in the framework of a third party funded research project running from 2011 to 2015, was named SEMERGY. This term is generated from the merging of the concept of semantic web and energy considerations, and illustrates the fundamental idea of the SEMERGY-project: Utilization of semantic web technologies for energy-centered building design evaluation and improvement. The origin of this research incentive was the fact that current building planning and retrofit require a substantial amount of information, the lack of which hampers the integration of performance considerations in building design. While the World Wide Web provides the majority of the necessary data, its utilization is hampered by the current unstructured and disorderly data representation and provision trends. Semantic web technologies enable systematic retrieval and reorganization of data from multiple sources, therefore these technologies could facilitate the fulfillment of informational requirements of performance-based building design.

The SEMERGY project was conducted as a collaborative research effort by computer and building scientists of the Vienna University of Technology. A major intention of the SEMERGY project was to generate an environment that offers decision support for different user groups. These include clients with little knowledge in the building construction domain that demand support for investment decisions in energy-efficient building design and retrofit and AEC-professionals looking for a fast-responding and easy to use design support tool to identify energy-efficient building planning and retrofit options. A fundamental design decision in the development of the environment was that existing resources of data and evaluation tools should be coupled with SEMERGY, rather than being engineer own developments.

To realize this environment several research and implementation activities were conducted. These included a major background research on existing web-based tools, building performance assessment environments and requirements of potential users, the design of the general architecture of the SEMERGY environment, the generation of an adequate building data representation for data administration with regard to existing building data models, the utilization of semantic technologies for structured acquisition of relevant data for building performance assessment, the integration of and coupling with existing calculation and simulation engines, the generation of building component templates and alternatives building constructions, the integration of mathematical optimization techniques, the generation of data exchange routines with CAD/BIM-tools, and the design of a graphical user interface. These activities pertain to different fields of research, for instance building physics, building performance modeling, building construction, software engineering and evolutionary optimization research. The present contribution describes the research and implementation efforts that resulted in the release of a prototypical beta release of the SEMERGY environment (available in the World Wide Web via www.semergy.net).
0.6. Zusammenfassung in deutscher Sprache


0.7. Acknowledgements

First and foremost, I would like to thank my advisor, Univ.Prof. Dr. Ardeshir Mahdavi for his support and guidance during years of collaboration. The patience, energy, intellectual power and loyal support spent generously by him, allowed me to pursue my own scientific development in the past few years.

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Above all I am indebted to my parents, as well as all other persons, who helped to contribute during my scientific and personal life in the past years.

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1. **INTRODUCTION**

1.1. **Objective of this work**

This doctoral thesis will document a comprehensive approach to web-enabled, optimization-based decision support for building design and retrofit. Its findings are based on the conduction of a third-party-funded research project, conducted at the Vienna University of Technology from 2011 to 2015. The project is named SEMERGY. This acronym is a coinage from “semantic” and “energy”, and should illustrate the efforts to couple modern web-concepts such as the “web of data” with building performance evaluation, for instance the determination of a building’s heating demand.

This work

- intends to document the developed SEMERGY-environment in general.

- focuses in particular on the author’s specific contributions to the different fields in the development, which include the exact problem definition, the general architecture of the SEMERGY environment, the building representation developed for the environment, the generation of templates and alternative finding of building components and products, the implementation of normative calculation methods, simulation methods and evaluation tools, the design of the data ontologies, and the development of a graphical user interface and import routines from CAD/BIM-environments.

- describes the background, specific tasks, challenges, issues and solutions in each of the above-mentioned fields of development.

Furthermore, as SEMERGY is an environment under continuous development, the outline of future developments will be illustrated.
1.2. Motivation

The principal goal of the mentioned project was to proof that the combination of modern web-based technologies, optimization and building performance evaluation (i) can be realized successfully, (ii) is able to offer substantial support in energy-efficient building design and retrofit for different stakeholders, and (iii) therefore is able to contribute to the ambitious goals of reducing building related energy demand and emissions. Buildings are known to be major emitters of greenhouse gases and are responsible for a large share of energy use (EPBD 2002, 2010). Although a lot of incentives and subsidy programs toward reducing building’s energy consumption were initialized in the past few years (for instance “Sanierungsscheck”, Umweltfoerderung 2014), clients, and even AEC-professionals, often struggle to identify fitting solutions for their building projects. In practice, a lack of information concerning building product information, building technologies, performance indicators, legal constraints and subsidies can be identified as being the major obstacle towards realization of energy-efficient designs and retrofits (Strommagazin 2006). Thus, an additional target of the SEMERGY project was to bridge this information gap via the structured representation of necessary information.
1.3. Structure

This doctoral thesis describes efforts towards development of the SEMERGY environment. This environment was planned as a web-based, semantically-enriched decision support and optimization environment for energy- and environmentally-friendly building planning and refurbishment. As these efforts, due to the vast extent of the approach, neither show a linear nor a strict parallel progress, but are partly independent of each other, partly strongly related to each other, this work is structured in several chapters. While the chapters Objective of the project & Problem statement and Background & related work should act as a comprehensive overview and introduction into the discussed subject, all other chapters are describing different aspects of the SEMERGY environment. To illustrate the particular state of the art, background and challenge these chapters are arranged in subsections. The chapters described in this thesis are:

Problem Statement & Principele Outline: This shortly describes the problems addressed and targets pursued by the development of SEMERGY. Additionally an overview of the different fields of development is given, as well as a general description of the different challenges faced during the development work.

Background & related Work does describe the general background in view of state of the art, literature, related work and comparable efforts.

Subsequently, the following chapters then describe different fields of development

General Architecture of Semergy illustrates the overall structure of the SEMERGY Environment.

Building Data Representation describes the examination of existing building models toward their suitability for the purposes of a web-based optimization tool, and the efforts toward development of a flexible and agile building representation model to serve as a central data management core (SEMERGY Building Model).

Templates & Alternative generation focuses on the simplification efforts both for users and purposes of optimization. Generally this sections describes the process of building construction templates generation.

Semantic Web & Ontologies deals with the utilization of semantic web technologies for populating the SEMERGY environment with data provided via the World Wide Web. Furthermore, the structure of the data ontologies, which are used to manage this data, is described.

Calculation & Simulation Modules offers an overview about the integration of performance-related evaluation routines realized within the framework of SEMERGY.

Optimization illustrates the optimization approach realized in the SEMERGY environment
In *Graphical User Interface & Data Exchange*, the efforts toward generation of a user-friendly Graphical User Interface (GUI) are described. Furthermore, the usability considerations of the GUI are discussed. Moreover, routines for data-interchange with other applications such as CAD/BIM-Tools, and specific building-physics-related tools are discussed.

Finally, *Future Development* points out, which further developments, are currently under development for integration within the SEMERGY environment.
2. PROBLEM STATEMENT & PRINCIPAL OUTLINE

This section outlines the general problems addressed by the SEMERGY environment. First, a short summary about building-related environmental issues and incentives for energy demand and CO₂-emission reduction is given. Subsequently, a number of hampering factors for reduction of building-related environmental harm and potential solutions are described. Next, aspects of performance-assessment-guided design are discussed. The section concludes with a sketched principal outline of the proposed system based on the problems discussed in the previous parts.
2.1. Building related emissions and energy demand and building certification

Buildings can be identified as major emitters of greenhouse gases and are responsible for a large share of the global energy use. Figure 1, for instance, identifies nearly 40% of the overall energy demand in Germany as related to the building sector. If the operation of industrial buildings is included, the major share of the overall energy demand can be considered as building related.

![Figure 1: Distribution of energy demand in Germany, 2010 (modified, source: DENA 2013).](image)

The European Performance of Buildings Directive 2002 (EPBD 2002) stated:

*The residential and tertiary sector, the major part of which is buildings, accounts for more than 40% of final energy consumption in the Community and is expanding, a trend which is bound to increase its energy consumption and hence also its carbon dioxide emissions.*

As anthropogenic influence on the ongoing climate change cannot be denied (Rahmstorf 2008), and CO₂ levels have a strong influence on long term temperature development on the planet (Figure 2), mankind faces the challenge to reduce CO₂-emissions and energy-demand in all sectors. Buildings, as a major contributor, therefore need to rigorously increase their efficiency.
Figure 2. Climate history of the past 350,000 years, showing the connection between temperature and atmospheric CO₂-levels. (source: Rahmstorf 2008).
2.2. Incentives for reduction of building-related energy consumption and emissions

During the past 20 years many incentives toward reduction of emissions - in general and specifically targeting the building domain - have been started. The European Union, for instance, released the so-called 20-20-20 goals: By 2020, European countries should have completed 20% introduction of renewable energy, 20% reduction of CO₂ emissions (compared to the levels of 1999) and have 20% reduction of overall energy consumption. To reach such ambitious goals, it is inevitable that buildings contribute to these plans. Therefore, the EPBDs 2002 and 2010 demand certain requirements for buildings to be fulfilled: These include minimum standards of the overall energy performance of new buildings and major renovation of existing buildings as well as the obligation that the majority of buildings need to be equipped with energy certificates. In Austria these directives lead to the EAVG-law (Energieausweisvorlagegesetz, EAVG 2006, 2012), which states that new buildings, building retrofits and buildings and flats offered on the real estate market need to be equipped with an Energy Certificate. Figure 3 illustrates the scale used for covers of energy certificates in Austria.

In Austria, building related matters are legally determined by the provinces (B-VG 1920). Thus, the harmonization of minimum requirements toward energetic behavior of buildings was a long-lasting process involving many stakeholders. In the end, the Austrian Institute of Building Technology (Österreichisches Institut für Bautechnik, OIB) issued a directive and a guideline (OIB 2011a, OIB 2011b), determining minimum requirements on both the thermal quality of building’s envelopes (U-values) and overall energy consumption (heating demand, primary energy demand, calculated based on the energy certificate method). Planers and their clients need for legal reasons to stick to these minimum requirements. However, these values are far from typical values of low-energy or passive buildings. The Austrian government issued a nationwide energy strategy paper in 2010 (Energiestrategie 2010), which reckons – as one of the crucial parts of a sustainable energy concept – that the standard of thermal envelopes of buildings should be – on the long run – improved to near-
zero-energy-buildings. This does not only pertain to new buildings, but also to the existing building stock.
2.3. Obstacles toward the reduction of building-related energy demand

This section discusses obstacles that hamper the reduction of building-related energy demand, including the low refurbishment rate, the relative small share of new buildings compared to the total building stock and the reluctance of (private) building owners toward thermal retrofit.
2.3.1. Low refurbishment rate

Due to low rates of new buildings construction and retrofit, the overall energy consumption related to buildings is not decreasing as fast as it should. The Austrian action plan towards energy efficiency (BMWA 2007) states that the refurbishment rate was circa 1.4 % per anno between 1991 and 2001, while the rate for thermal retrofit was only 0.8% in this time. This means that less than 60% of the refurbishment efforts included measures for improving the thermal envelope in this time. The action plan – issued in times prior to the worldwide economic depression of 2008 – envisaged an increased retrofit rate of about 3% (for the period 2008 – 2012) and 5% per anno (on the long run). This can be considered as failed, as the retrofit rate in 2010 was still only about 1% (Baumgartner et al. 2010). Other sources (Umwelttechnik 2012) state an average retrofit rate of 1.2 % p.a. between 2001 and 2010 (Figure 4). The refurbishment rate within the European Union is considered to be at around 1.5% (Innospirit 2013)

![Figure 4. Development of retrofit rate in Austria (source: Umwelttechnik 2012, modified)]
2.3.2. Small share of new constructions

While the previous section discussed the low refurbishment rates, this section shortly describes the current building rate of new buildings (new buildings and buildings erected as replacement for demolished buildings).

ZOE (2008) states that per 1000 capita 5-6 new flats are erected per year in Austria. The central and eastern European countries show significantly lower rates of flat erection. Figures 5 illustrates the flat building rate expressed in flats per 1000 persons for the EU, Austria and a couple of central and eastern European countries.

![Diagram](image)

**Figure 5.** Flat erection per 1000 persons in EU, Austria and some central and eastern European countries (source: ZOE 2008, translated).

However, expressed as portion of the existing building stock, the rate for new building construction is considered to be between 1 and 2 % p.a. in Austria (Umwelttechnik 2012). A complete renewal of the building stock therefore would need between 50 and 100 years. However, the rate is expected to drop due to demographic development and long-term effects of the financial crisis of current years (Innospirit 2013).
2.3.3. Reluctance of (private) building owners toward retrofit

Two thirds of all buildings in Austria are single-family homes in (mostly) private ownership (Statistik Austria 2013). Furthermore, two thirds of the overall building net area used for residential purposes are located within buildings erected prior to 1980. A majority of these buildings can be considered as in need of thermal retrofit (Baumgartner et al. 2010). 2,2 million residential units could be potentially thermally retrofitted in Austria (Energie-Bau 2012). Studies show that private owners are reluctant towards thermal retrofit due to different reasons. Bleyhl (Modernisierungs-Magazin 2012) identifies the intransparent structure of different subsidy programs as a potential reason. In contrast, an article of the newspaper DerStandard (Der Standard 2012) confirms the overwhelming success of an Austrian subsidy program toward thermal retrofit (“Sanierungsscheck”) in the past, but states that due to lack of governmental funds and political willingness, the access to subsidies was later tightened via intransparent and complicated granting clauses. Another issue is that many building owners do not consider the inefficiency of outdated technical building systems as a trigger for replacement of these systems. Rather, 40% of the participants of an inquiry about renewal of building systems stated that they would exchange their heating systems only after the collapse of the old system (Bauratgeber n.d.).

According to DENA (2013), Building owners experience a set of hampering factors in view of renovation of their buildings:

- Severe lack of market transparency.
- Severe lack of information for clients.
- Thermal retrofits are high in complexity, and the results are sometimes disappointing.
- Low confidence in involved stakeholders.
- Lack of qualification of stakeholders for energy-efficient retrofit.
- Lack of sufficient funds/financing opportunities for thermal retrofit.

Mahdavi et al. (2004), Häusler (2003) and Kernstock (2003) examined the acquisition and elaboration of building product information of two important stakeholder groups in the building and retrofit process – architects and clients. Their findings confirm the severe lack of market transparency and lack of information for clients. Both clients and professionals showed a highly unorganized, often just-in-time information acquisition process that did not explore all possibilities within the market. At this point a typical issue of the majority of planning processes has to mentioned: The concept of planning fallacy, as described by Kahnemann (2012). This is the general trend in modern times to not timely and cost efficiently arrive at planed targets, due to underestimation of cost and / or effort for certain tasks within planning processes. Potentially, the highly unorganized data handling by clients and planers can be seen as an influencing aspect within planning fallacy.
2.3.4. Addressing the obstacles

The mentioned obstacles in general can be considered as a major barrier for reduction of building-related energy demand and emissions. Although they might not be completely dissolvable, there is potential to reduce their impact. Uncertainties of clients and other stakeholders toward decisions in building design could be addressed with incentives to provide structured and reliable information on building products and materials, legal requirements, subsidy and tax incentives and others. Such information campaigns could also positively influence the retrofit and building rates. However, for successful design of such information incentives, the behavior of clients and professional toward data acquisition and data handling needs to be known, as well as the typical AEC-domain related questions that will appear in building design and retrofit. Alongside to information, supportive tools for clients that intend to invest in thermal retrofit can be considered as supportive as well.
2.3.4.1. Data acquisition and handling by clients and professionals

The aforementioned studies of Mahdavi et al. (2004), Häusler (2003) and Kernstock (2003) identified electronic media (CDs and World Wide Web) as the preferable information source for building product information. However, at the time of publication, the potential of electronic media for decision making support in the AEC field seemed not to be fully exploited. From today’s viewpoint this can especially considered true for the World Wide Web, which back in 2004 did not offer as many possibilities as it does now. Clients and Planners, although both searching for building product information, seem to be interested in different aspects: While clients focus on qualitative product features, price and service information, architects desire additionally technical specifications, details, and applicable standards. Both groups try to postpone the final decision on applicable building products to a very late stage of planning. Furthermore, both groups show a very unorganized, often just-in-time information acquisition process, which at least in the case of planners seems to be surprising. As a conclusion, computational support for building product selection is supposed to be an auspicious part of an improved building planning and delivery process of the near future.

In business science, the data acquisition about required goods and services is described as acquisition market surveying (Kummer et al. 2013). Even for large companies this acquisition market surveying is considered as a complex matter, but crucial for business success. Robinson et al. (1967) developed a scheme (“Buygrid Framework”) that can be considered as a simplified generic conceptual model for buying processes within companies and organizations. The Buygrid Framework consists of a matrix of buyclasses and buyphases. This scheme is illustrated in Figure 6, buyphases are represented in lines, while buyclasses are represented in columns.

If these scheme is transferred to the AEC-context for clients and planers (and even craftsmen involved in the building process), it has to be stated that

- Clients will find themselves in the new task buyclass, as they do not buy building services or building materials on a regular basis. This means, they will regularly experience the buyphases need recognition, need definition and solution specification.

- Architects and planners will find themselves regularly in the new task or modified rebuy buyclasses. Each of their planed objects usually is a unique design and therefore demands different products and services. Therefore a certain change from acquisition process to acquisition process can be assumed, keeping architectural production from the straight rebuy buyclass.
Kummer et al. (2013) state that in case of new tasks (denoted as acquisition innovation) a great demand for structured information can be regularly recognized.
2.3.4.2. Typical uncertainties of clients pertaining to building related energy efficiency

Decisions pertaining to the investment of money into erection of buildings or building retrofit typically confront clients, especially those having little knowledge in the building context, with a set of critical questions. Such questions could be:

- What is the most cost-efficient and sustainable way to reach certain energy performance goals for specific buildings?

- What is the cost of the refurbishment project and how long does it take until the refurbishment is amortized?

- What is the impact of certain design decisions on cost, thermal or environmental performance of a building?

- Does a certain retrofit project or building design meet all legal regulations, for instance the minimum requirements for U-Values?

- Is it possible to receive subsidies for a certain refurbishment projects? How can the requirements for receiving subsidies be reached? Which extra cost does the achievement of subsidies-conform values cause, and does it pay off?

These questions are not trivial to answer, given the multitude of design options regarding materials, constructive systems and subsidy and tax incentives. Even experienced professionals would need to examine the situation of each building individually, as answers depend on location, building properties and proposed budget for a certain building project. The examination of individual cases, however, is connected with routine research work toward the mentioned aspects, such as performing normative calculations, calculation of the amortization time and searching for building product alternatives.
2.4. Aspects of Performance-guided building design & building performance assessment tools

Since the earliest availability of Information and Communication technologies (ICT), the AEC-branch adopted computers and software technologies for different building related purposes. Different products were developed to facilitate the processes of building planning and realization. These follow different purposes and feature different levels of detail, dependent on the targeted goals. However, while certain developments were instantly adopted by the design community (for instance CAD-drawing tools), other per-se useful applications were not fully accepted and integrated into building-related processes until today. The following sections discuss different aspects of the integration of building performance assessment tools in design and planning processes.
2.4.1. The role of building performance assessment tools in current architectural practice

While tools for computer aided drawing became a *conditio sine qua non* in architectural design soon after their development, the use of computational technical analysis tools until now was not widely adopted by architects. Rather, the use of computational tools for building performance assessment was ceded to the engineering branch of the AEC-community. Figure 7 illustrates the number of developed building performance simulation tools for engineers and architects between 1997 and 2010. The majority of tools were developed for engineers, while only few tools were specifically designed for architects.

![Figure 7. Building Performance Assessment tool developments for architects and engineers between 1997 and 2010 (from Attia 2011).](image)

Feurer (2003) researched about the application of computer aided (architectural) design (CAD, CAAD) and building performance assessment tools in Austria. One method in her work was the interviewing of a large number of AEC-professionals in Austria. While some of the results of her study could be somewhat outdated today (for instance the fact that by 2003 a couple of planning offices still denied the use of CAD-tools), some other facts still appear to be true: Architectural offices often deny building performance assessment tools due to a severe lack of knowledge of their partners and employees. Furthermore, many professionals reckoned that they were afraid of the time effort necessary for the application of building performance assessment tools. The conclusion of her work identified a set of crucial necessities to increase the use of building performance assessment tools. These included raising the awareness level toward building performance modelling and simulation in the design community, increased development efforts toward usability of such tools, and increased implementation of building performance assessment in the education of architects and building scientists.
Building performance assessment tools range from simple normative procedures to highly complex dynamic simulation software. While the sooner are regularly intended for easy-to-use certification and performance comparison of buildings, the latter target a relatively accurate estimation of a building's behavior before its construction and operation.

Many governments around the world – following interests for efficient and safe building design – have made normative assessment of the building’s performance mandatory for building projects. Energy certification got very common due to national and international incentives (EPBD 2002, 2010; EAVG 2006, 2012), as discussed in section 2.2.

However, it appears that available tools are more or less reduced on the assessment of finished building designs for certification labelling. Their large potential to support and optimize the generation of design alternatives is only rudimentary exploited (Mahdavi et al. 2003, Punjabi and Miranda 2005, Hensen et al. 2012, De Wilde 2004).

Moreover, despite an increasing number of developed and available tools, most architects and designer rarely consider the use of such software. Punjabi and Miranda (2005) report that the architectural community judges most tools as too complex and difficult to use, or simply as incompatible with their established working routines. Particularly, the argument of difficulty can be explained with the fact, that many tools are developed by domain-specific experts within research institutions and do address other domain experts. The development of such tools often does not consider usability aspects that are especially important for novice users or generalists such as architects.

Attia (2011) examined the most important expectations of architects toward building performance assessment tools. Architects name intelligence, usability, interoperability and accuracy as the most important criteria within building performance simulation tools (Figure 8). The most important selection criterion is the embedded intelligence which provides the opportunity to make informed decisions and offers insight on the impact of particular design decisions in view of performance and cost. In other words: Architects desire tools that analyze results of their performed evaluations and provide them with clear design guidelines.
In recent years, leading architectural offices, however, started to recognize the potential of building performance simulation for their design practice. For instance, the practices of Foster + Partners (“Specialist Modeling Group”), Skidmore, Owings and Merill (“Performative Design Studio”) and Adrian Smith + Gordon Gill Architecture (“Sustainable Design Team”) opened branches for environmental engineering and detailed building performance simulation for their projects (Detail Green 2014).

Figure 8: Architects’ priorities for selection of building performance simulation tools. (based on Attia 2011).
2.4.2. Early design support and optimization

It is a matter of fact, that early design stages offer the largest degree of freedom for crucial decision making in building design. Decisions taken during the conceptual phases have a large impact on the final building performance (Domeshek et al. 1994) in comparison to their time and effort. Bogenstätter (2000) estimates that 20% of the early design decisions have a major impact on 80% of the decisions in later stages of the planning. This means that errors in early design stages cannot easily be corrected. Moreover, the cost of implementation of changes in the building design is low during early design stages and increases with the progress of a project (McGraw-Hill 2007). This is illustrated in Figure 9.

![Figure 9: Changes in design are cheaper and more simple to integrate if performed in early design stages (right) than in later ones (left). (taken from McGraw-Hill 2007).](image)

Given these facts, it is obvious that the use of building performance assessment tools in early design stages can be of great advantage for the later building performance. However, due to time-pressure it is a common fact that performance evaluation and optimization are regularly performed in the final stages of architectural design.

In general, only few tools offer automated optimization efforts to explore optimal solutions within user-defined margins. Manual, trial-and-error based testing of different design variations is time-consuming and error-prone. Therefore, the development of optimization platforms that implement automatic routines for change of input parameters and simulation settings is highly demanded within the AEC-context (Coffey 2008).
2.4.3. Usability, Input data provision and expenditure of time

Next to “intelligence”, the study conducted by Attia (2011) identified usability as an important criterion for the selection of building performance assessment tools by architects. Usability hereby not only refers to the operability of the graphical user interface of a tool, but more generally to the tool as such. High-resolution simulation tools regularly require large amounts of detailed information on the building, its context and its (proposed) operation. Such information includes, for instance, the geometry of the building, detailed technical properties about building components and used materials, user behavior, weather data, and technical descriptions of the building systems and services implemented in the building. Conventional manual collection of this data can be cumbersome, time-consuming and error-prone (Ghiassi et al. 2012, Maile et al. 2007). Figure 10 illustrates the scope of data required to run a whole building performance simulation. Usability can also refer to the way data is communicated within a tool and to the user. As discussed before, users from architectural background would prefer clear and definite key performance indicators (KPIs) over large spreadsheets of result data that still need to be interpreted.

![Figure 10: Scope of data required for detailed whole building performance simulation (from Maile et al. 2007).](image)

Not only the amount and structure of input data can be problematic, often the pure acquisition of data in a satisfactory format and resolution can cause serious problems. Input data that is not provided in the correct resolution for a certain building performance assessment tool might crash the simulation procedure or cause untrustworthy results. Manual typing of large amounts of input data from sources that cannot simply be pasted into the corresponding input dialogues is both time-consuming and error-prone. However, the majority of data that is necessary for detailed building performance assessment tasks is available via the World Wide Web (e.g. building product information). Unfortunately this data is regularly offered in formats that cannot automatically be imported in specific simulation tools and therefore needs manual transfer to the tool. Therefore, the web-based potential remains mostly unexploited, as its extraction is hindered by lack of sufficient structure in the encapsulation and presentation of the information.
As previously discussed, architects fear the large effort and time necessary for the performance of detailed building performance simulation. It can be considered as a matter of fact that the current architectural practice is exposed to high levels of time and cost pressure. Mahdavi and El-Bellahy (2005) found that the largest portion of time-expenditure is regularly related to the preparation of input data and the generation of the building data model. Figure 11 illustrates the time needed for different tasks in running an energy simulation. Therefore, if these steps could be (semi-)automated via exploitation of existing web-based data repositories, a major part of time investment could be saved.

Figure 11. Time-expenditure on different tasks in running an energy simulation (from Mahdavi and El-Bellahy 2005).
2.5. **Principle Outline of the SEMERGY environment**

The previous discussions can be summarized as follows:

- Calculation or simulation of Key Performance Indicators for building performance assessment requires a large amount of input data and domain knowledge from various sources, making it difficult for clients and professionals to identify feasible solutions for their building or retrofit design.

- There are different calculation and simulation methods for building performance assessment. They can differ in their level of detail and their evaluated domain (for instance energy, light, or room acoustics).

- There are building performance assessment tools that are utilized for the legally required building certification, for instance the Austrian energy certificate.

- The required input data is not always available or easy to retrieve. Large amount of input data is available via the World Wide Web. However, it is difficult to automatically retrieve for use in building performance simulation. Input data needs to be provided in correct resolution for most tools to work properly.

- Existing calculation and simulation tools are designed regularly designed for domain experts and do not allow people with little domain knowledge to conduct calculations.

- Existing programs do not regularly feature the option for iterative optimization attempts. Optimization, if done at all, is often conducted manually, which is time-consuming and error-prone.

The SEMERGY approach addresses these issues: It is projected as a unique and web-based decision support system for identifying optimal building refurbishment strategies.

Therefore, it should include - at least - the following features:

- Semi-automated retrieval of semantic data (including building product information and properties, subsidy and tax incentives, weather data, etc.) from the World Wide Web and structured representation of this data for the use in building performance assessment applications.

- Optimization based on mathematical routines for identification of optimal building design options.

- Early-design stage decision support for professionals and novices with little to none domain knowledge.

- Implementation of tools for certification and simulation of different building performance domains. These tools should be provided with their required input information via the semi-automated retrieved data from the World Wide Web

The results obtained from the environment should offer realistic retrofit and building design strategies tailored for a given individual building configuration. These strategies should consider consequences of specific design options for investment cost, energy consumption and sustainability of the building.
3. BACKGROUND & RELATED WORK

This section describes important background information that inspired the development of the SEMERGY environment. It includes the illustration of the SEMERGY approach's positioning in view of different trends and the theory of building performance simulation, the definition of different systems for automated reasoning support (Expert Systems, Decision Support Systems) in view of SEMERGY, and a discussion about online tools and comparable efforts. Furthermore, uncertainties in building performance assessment are shortly described.
3.1. SEMERGY in view of different trends in building simulation
3.1.1. The role of the World Wide Web

With the progress of ICT (development of high-performance computers, continuing development of the World Wide Web, development of object-oriented programming) new possibilities for building performance assessment emerge. Augenbroe (2004a) points out different past and current developments and trends in building performance simulation. Figure 12 illustrates these developments and trends. The potential of the World Wide Web does strongly influence the two most recent trends (web-enabled tools, pervasive tools). Augenbroe envisions that with the utilization of the World Wide Web simulation will be available “anytime and anywhere”, up to even “unnoticed” run in the background of building control routines. Moreover, the web enables a new breed of simulation services that is offered at an increasing pace, mostly in conjunction with other project team services (Augenbroe 2004a).

![Figure 12. Developments and Trends concerning building performance simulation (Augenbroe 2004a).](image)

An important step towards web-enabled / web-hosted building simulation services is seen in the technical transformation of simulation tools to be “internet-ready”. Grilo et al. (2004) point out that the AEC industry in general embraces the web as a platform for services and data-interchange, however, not as fast as the automotive, aeronautic or retailing sectors do. The idea of a future World Wide Web as a web of things and a web of data as envisioned by Tim Berners-Lee (Berners-Lee et al. 2001, 2006) seems tempting for the AEC-industry, as it could facilitate many processes around the building planning and delivery process. Especially, this is true for the iterative reuse of web-based data sources for application within different tools. Shayeganfar (2008) developed a prototypical environment that illustrated the potential of integration of contemporary web-technologies in the building planning and delivery process: Based on the example of architectural skylights the role of semantic web technologies and data management was examined. This project was named SkyDreamer and can be seen as a development obstetrician for the SEMERGY environment.
3.1.2. Designer-friendly and design-integrated tools

Augenbroe (2004a) illustrated the trend toward tools for non-specialists, but reckoned that the transfer of complex simulation tasks in simplified form to non-specialists, named as “designer-friendly tools”, should be seen critical. Rather, he recommends utilizing the world wide web and contemporary technologies for collaborative and integrated design of buildings. This means that instead of reducing expert tools to simplified designer-friendly tools with limited explanatory power, he suggests the development of so called design-integrated collaboratively-useable tools. The basic distinction between the concepts of designer-friendly and design-integrated tools is the reduction and encapsulation of domain knowledge versus enrichment and externalization in the latter. Figure 13 compares the concepts of designer-friendly tools with design-integrated tools. In this figure, variants of integrating domain expertise into the design process is depicted in four variants (A – D). Variants A and B couple expert domain knowledge via interfaces to the design process, while C integrates domain experts into the design team. Variant D focuses on functional and behavioral interoperability across different performance characteristics. In contrast to the designer-friendly tools, this variant utilizes a transparent and modular data representation of the relevant building data for coupling with expert tools. The SEMPER environment could be counted as a prototypical variant D implementation with deep software integration.

![Figure 13. Concept of Designer-friendly tools (left), Concept of different design-integrated collaborative tools, including different coupling of domain expert knowledge to the design team (right). (Augenbroe 2004a).](image)

While SEMERGY targets user-groups of different knowledge background, the capabilities of its building performance assessment are intended to follow the design-integrated approach, rather than the designer-friendly one. However, the data interaction should be based on principles (graphical user interface, import functionalities) that facilitate the data input for users with limited domain knowledge as well as for professionals.
3.2. Systems for automated reasoning support

Computer systems that support users with knowledge in reasoning and decision processes can be considered in development since the 1950ies. General terms that are used often for definition of such systems are “Expert Systems” (ER) and “Decision Support Systems” (DSS). Based on the definitions described in the following sections, the SEMERGY concept is analyzed toward its belonging to one of these terms.
3.2.1. Expert systems (ES)

Luconi et al. (1984) define Expert Systems as follows:

*Expert Systems can be used to increase a human’s ability to exploit available knowledge that is in limited supply. They do this by building on the captured and encoded relevant experience of an expert in the field. This experience is then available as a resource to the less expert.*

Hemmer’s Definition (2006) of Expert Systems is similar:

*Expert systems are computer programs that aid an expert in making decisions about a certain problem. An expert system typically operates with rules that are evaluated to predict a result for a certain input. For the generation of rules a prior knowledge about the correlation between query and output data is necessary.*

The proposed SEMERGY environment is meant to exploit available knowledge for users with little to no domain knowledge (among others). Following these definitions, expert systems target other experts, which want to use specific and unique expertise in certain fields. SEMERGY is intended to be an environment capable of supporting users of different levels of knowledge in the AEC-branch. Therefore, even if SEMERGY’s intentions partly comply with the given definitions, the term expert system does not fully fit for the SEMERGY environment.
3.2.2. Decision support systems (DSS)

Kendall and Kendall (2001) define decision support systems as a class of information systems that emphasize the process of decision making and influence users’ decisions through their interaction with the system. Furthermore, decision support systems are well suited for addressing semi-structured problems where human judgment is still desired or required. Keen (1980) defined decision support systems as a concept of the role of computers within the decision making process, but remarked that the term is not well-defined. Generally, useful DSS need to be planned in detail to fulfill their purpose in an appropriate way. Simon (1977) identifies intelligence, design, and choice as the three main stages of decision making processes. Following Bohanec (2001), the major characteristics of DSS are:

- **DSS incorporate both data and models.**
- **DSS are designed to assist managers / decision makers in semi-structured or unstructured decision-making processes.** Note: There is no distinct definition of structured, semi-structured or unstructured decision processes, however, Kendall and Kendall (2001) define structured decisions as those for which all or nearly all the variables are known and can be totally programmed, while semi structured decisions are those that are partially automatable but still need human judgment.
- **DSS support, rather than replace, (managerial) judgment.**
- **DSS are aimed at improving the effectiveness- rather than efficiency – of decisions.**

Furthermore, according to Bohanec (2001) classification of DSS can be done with respect to:

- Decision type: **structured / semi structured / unstructured**
- Organizational level: **operational / tactical / strategic** (Note: This refers to the time-horizon and impact of a decision: Strategic is understood as long-term impact and major organizational impact, while operation is understood as short-term and minor organizational impact.
- Decision maker(s): **individuals / group / organizations**
- Prevailing DS-element: **data / models / knowledge / communication**
- Method: **reporting / visualization / modeling (qualitative or quantitative) / simulation, optimization.**

Concerning the workflow of Decision Making processes, Bohanec (2001) identifies the following steps:

(i) Assessing the problem.
(ii) Collecting and verifying information.
(iii) Identifying alternatives.
(iv) Anticipating consequences of decisions.
(v) Making the choice using sound and logical judgment based on available information.
(vi) Informing others of decision and rationale.
(vii) Evaluating decisions.

Given these definitions, characteristics and classifications of DSS, the following can be stated about the SEMERGY approach:

- SEMERGY incorporates both data (building product information, legal constraints, subsidies, etc) and models (for instance the building representation scheme as abstraction of a real building).
- The major intention of SEMERGY is the decision support for improving building designs and retrofits towards their sustainability. This process requires a large amount of information from various sources. The distribution of this data is scattered, and often is considered as a barrier for planners and clients. Decision-Making in this area can be considered as semi-structured, if not unstructured. As the SEMERGY-approach bridges this gap with offering the majority of required information in a (re)structured way, the second characteristic of DSS as stated above applies to the SEMERGY environment.
- Decisions in the AEC-field are often unique and very complex. While SEMERGY – in its current state – offers a rather convenient support for questions of energy- and cost-efficiency in building design processes, it is not – and was never intended to be – a replacement for the domain-knowledge and experience of AEC professionals. Therefore, SEMERGY offers decision support rather than decision making.
- SEMERGY addresses both the efficiency and effectiveness of decisions. Efficiency is increased, as manual search for information is reduced to a minimum, while effectiveness – as understood as the capability of producing a desired result – is also targeted, as SEMERGY at least suggests solutions that are meeting all basic requirements.

In view of the classification criteria,

- SEMERGY deals with semi-structured and unstructured decision problems.
- SEMERGY aims at a tactical to strategic organizational level. The effects of the decisions have long-term impacts and are not taken on the operational level (if “operational” is understood as ad hoc decisions at the building site).
- SEMERGY addresses different decision makers, which can be organized as individuals (architects, clients), groups (e.g. owners of an apartment building) or organizations (e.g. municipalities).
- SEMERGY uses data, models and knowledge as input parameters for decision making.
- SEMERGY uses different methods (Simulation / calculation, optimization and reporting and visualization) for decision support.

Summarizing these aspects, SEMERGY can be considered to be a DSS.
3.3. **Online Tools and Building Assessment Implementation in CAD and BIM Tools**
3.3.1. Online Tools

Since the general availability of the World Wide Web, many attempts to relocate building-related services to the web have been undertaken. These attempts also include online building assessment tools. Many of such services are offered by research institutions, environmental awareness promoters or financial institutions which offer special funds and loans to building owners. The majority of these tools are available to the public and address users with little or no background knowledge in the AEC-domain. To be useful for people with little experience in the field, such tools regularly demand only a minimum of user-defined input. To still be able to offer design or decision support such tools therefore often implement very rough and simple models of the reality. For instance, many tools simplify the geometry to templates and use default values for the thermal quality of building parts based on the year of construction. However, the goal of such tools is in general not to calculate very accurate results, but rather to offer a rough estimation of the building’s performance.

Cetin (2010) and Cetin and Mahdavi (2010) explored the availability and usability of web-based building performance simulation tools. After an extensive examination (including over 100 web-based tools in general, and a detailed, specific usability study dealing with the most promising tools) they identified potential, hampering factors, advantages and risks of such tools: The quantity of different tools, the cheap or free-of-charge use and the availability in the World Wide Web offer easy access to evaluation tools for a vast user group, which per se is a tempting concept. However, many tools are limited in applicability, opportunities for data interchange and data reuse, and significance of the results. Few providers offer an open-source or at least well documented environment, but supply just black-box-tools. This – one the one hand – hampers further development of such tools in comparison to collaborative incentives, and – one the other hand – bears the risk of misinterpretation of and distrust towards the results due to the lack of sufficient information about used algorithms, calculation schemes and models. However, the increased application of such tools is highly desirable. The SEMERGY approach does per se not target to replace existing tools, but rather to include existing tools and data-resources to offer a convenient environment for building performance simulation.

It seems not feasible to offer a broad overview about all available tools within this work. This is partly due to their often short life-cycles and continuous development: Many of the tools Cetin and Mahdavi (2010) examined are either not available any more by 2014 or changed their appearance following further development. Nonetheless some of the online tools that were examined in the course of the SEMERGY development should shortly be described in the following sections to visualize the broad scope of different applications offered in the World Wide Web. After a short narrative description, the type, the necessary input data and the derivable output data is mentioned for each of the tools.
3.3.1.1. **EnergyGlobe** *(Energyglobe 2014)*

The website energyglobe.com offers a set of tools for evaluation of new and existing buildings, as well as for determination of the energy demand of domestic appliances.

The “Energie-Check” is a tool for existing houses, capable of calculation of a “virtual energy certificate” based on a set of user-defined parameters. However, user preferences are limited to predefined values and templates for most parameters. For instance, an accurate entry of the exact perimeter form of the building is not possible. Based on the basic input a value for the Heating Demand is derived. Users can then determine different ways of thermal retrofit to improve their building, and the effect of measures is expressed in percent of the basic indicator derived earlier. The tool can be considered as a supportive tool for people intending to get a first impression of retrofit measures. However, it does not explore the scope of different approaches toward retrofit in terms of building material and product combinations.

Figures 14 and 15 illustrate the Graphical User Interface of the energy globe tool.

![Figure 14. Interface of the energy globe tool, comparison of status quo and retrofit potential (Energyglobe 2014).](image)
Figure 15. Interface of the energy globe tool, before and after states of energy demand (Energyglobe 2014).

**Type:** free to use tool for suggestion of retrofit options.

**Input Data:** Postal Code, Mean of heating system, Heating Demand from Energy Certificate / Real estate advertisement, and rudimentary geometry.

**Output Data:** Estimation of the cost and feasibility of a limited number of retrofit measures.
3.3.1.2. **Energieausweis-Vergleich** *(Energieausweis-Vergleich 2014)*

This tool – offered by A-Null Bauphysik GmbH, the company that develops the building-physics-related software package Archiphysik *(Archiphysik 2014)* – is capable of comparing up to three objects based on the information provided by real estate advertisements. Required input information includes the postal code, the heating demand as stated for a certain flat or building in an real estate advertisement, the net floor area and the mean of heating (electricity | gas | oil | district heating | wood | pellets | black coal | brown coal | heat pump). The tool itself is not intended to calculate an energy certificate or any performance indicators on its own, but estimates based on the stated heating demands the expectable heating cost. Figure 16 shows the website / Graphical User Interface of the tool.

![Figure 16. Interface of www.energieausweis-vergleich.at (Energieausweis-Vergleich 2014).](image)

Limitations of the tool – as stated by the developers in the guide of the tools – lie in the explanatory power of the input data. For instance, the user behavior and climate data are estimated values based on the energy certification method, but might not necessarily correspond to the reality (see section 8.2.). Another issue is that the heating demand, as stated in real estate advertisements, can be incorrect. Moreover, regularly no information is stated about the age of the energy certificate, and therefore the applied calculation method (annual or monthly) is not clearly determined. Concerning this matter the studies conducted by Kaiser (2009) and Pont et al. (2009) have to be cited. The sooner found that the majority of issued energy certificates in Austria have serious issues concerning the correctness of the derived heating demand, while the latter examined the effect of uncertainties in input data on the result of energy certificate calculations.

**Type:** free of charge web-based comparison tool for energy certificates.

**Input Data:** Postal Code, Mean of heating system, Heating Demand from Energy Certificate / Real estate advertisement.

**Output Data:** Ranking of up to three flats/buildings based on estimated heating cost.
3.3.1.3. Express-Pass (Express-pass 2014)

This tool offers automated derivation of heating and electricity demand for residential and nonresidential buildings, based on German guidelines and standards. Residential buildings can be evaluated based on their energy consumption of past years or via demand calculation comparable to the Austrian energy certificates. Users are requested to enter building related data into the graphical user interface of the tool. Based on this data the key performance indicators are calculated and a pdf-report can be bought for a certain amount of money. Figure 17 illustrates the graphical user interface of express-pass.

![Figure 17. Interface of www.energieausweis-vergleich.at (Express-pass 2014).](image)

However, it is not clear, if the derived energy certificates are validated by a human expert, or if the issued (and bought) energy certificate is just performed via automated calculation routines based on the user-defined data. If the latter is the case, the practice is strongly questionable, as no validation by
a domain expert ensures the correctness of the issued certificate. Errors – if included intentionally or not – could barely be found, and it renders the concept of energy certificates dubious.

Type: Online-energy certification tools (German normative procedures). Energy certification (as pdf or hardcopy) are subject to a fee.

Input Data: Postal Code, Mean of heating system, consumed energy based on energy bills, geometry, construction age, information about insulation efforts on the existing structure (no specific numeric properties).

Output Data: Energy certification for residential and nonresidential buildings based on German standards.
3.3.1.4. Energiesparhaus (Energiesparhaus 2014)

This platform offers a set of estimation tools, intended for interested clients with little knowledge in the AEC domain. These include U-Value calculation for retrofit and new building constructions and heating demand of residential buildings. However, the heating demand hereby is solely based on values of used combustibles in the heating systems (for instance, kilograms of pellets). Such a calculation is based on very simple equations that translate the used fuel into an energy performance indicator. Indirectly, the results consider – in contrast to normative procedures for energy certification – thereby the user behavior. Figure 18 illustrates the graphical user interface of the Energiesparhaus-website.

![Figure 18. Interface of the energiesparhaus-website (Energiesparhaus 2014).](image)

**Type:** Simple client support tools addressing U-value and consumption-based heating demand. Free of charge.

**Input Data:** For the U-Value calculation: selection of materials from exhaustive lists and their thickness; For the heating demand calculation: Fuel consumption, gross area and number of residents.

**Output Data:** U-Values, Consumption based heating demand.
3.3.1.5. U-Wert.net (U-value.net 2014)

This website offers (June 2014) a couple of stand-alone services:

- Calculator for building components towards their U-Value, condensation behaviour and overheating influence, including a set of template building parts.
- Ventilation losses.
- Electricity through photovoltaic panels.
- Heating demand calculator.

All these services are based on German / European / international standards. Each of the services demands a number of numeric input data values. However, the different calculators are neither linked to each other, nor offer a data transfer from one calculation to the other, making multiple calculations time-consuming and error-prone. Therefore, it can be stated that the platform offers convenient one-time calculation support in a specific domain, but does not offer a general approach to a complete building evaluation including a building representation. Figure 19 illustrates the U-value evaluation of this service.

*Type:* Supportive calculation services in specific small-scale domains based on standards for steady state building performance assessment and one-dimensional building component evaluation. Free of charge.

*Input Data:* Building product properties (λ, μ, thickness), rudimentary geometry of the building, including orientation and roof slope angle (for electricity production via photovoltaics).

*Output Data:* Normative Evaluations of building components and buildings.
Figure 19. U-Value-Calculation of U-Wert-Net (u-value.net 2014).
3.3.1.6. **ThermalCalc** (Thermalcalconline 2014)

This tool offers U-Value and thermal resistance calculation, as well as calculations of heat load and heating and hot water demand. The calculations are based on international standards, and offered in English language. Moreover, the tool offers calculation capabilities for the Psi-value, which is a thermal bridge-related key performance indicator. An underlying database offers an exhaustive list of building components that can be used in the calculations. Alternatively the properties of existing building components can be changed. However, results are just offered as values indicated on the website. An option to save or to recycle calculation results in other partial calculations of the same website is not integrated. The tool seems to be intended for easy use through laymen or for educational use. Figure 20 illustrates the graphical user interface of this environment.

![U value and R value calculator](image)

Figure 20. Interface of the thermalcalconline (Thermalcalconline 2014).

**Type:** Different free-of-charge calculation tools for U-Values, heating and cooling loads and rudimentary thermal bridge evaluation.

**Input Data:** Building product properties (λ, μ, thickness), rudimentary geometry of the building, including orientation.

**Output Data:** U-Values and rudimentary building performance indicators.
3.3.2. Building Assessment Implementation in CAD and BIM Tools

As mentioned in one the previous sections, design-integrated tools in a collaborative design process with integration of different domain specialists seem a preferable development in the current efforts toward energy-efficient architectural planning. The idea of integrated performance assessment in design tools seems, however, even more tempting, even with the thread of losing explanatory power through non-specialist users. Developers of BIM and CAD-tools therefore started efforts to couple building performance evaluation tools with their products. Moreover, efforts toward adding building performance assessment tools to their own product portfolios could be watched in the past years. However, few successful approaches toward integration of building performance evaluation within their main products, in other words as integrated feature within their products, are known. Summarizing, integrative building performance assessment uses regularly one of the following approaches (Figure 21):

(i) CAD/BIM and Building assessment tools of different producers can transfer data via specific file formats / building data representations. The interoperability efforts of the global design community, namely ifc (BuildingSmart 2014) and gbXML (gbxml 2014), are examples of such file formats.

(ii) CAD/BIM and Building assessment tools of different producers can import/export data to each other via plugins. An example for this approach is the provision of plugins by the producer of Archiphysik (Archiphysik 2014) for common drawing and modeling tools, such as SketchUp (SketchUp 2014).

(iii) CAD/BIM and Building assessment tools of identical producers can transfer data via specific, company defined file formats. An example for this approach is the data exchange between ArchiCAD (Graphisoft 2014) and ArchiPhysik via the ArchiPhysik-specific file format .aps.

(iv) Total integration of a building performance evaluation tool within a BIM/CAD environment by one producer. An example for this approach is the EcoDesigner tool that offers detailed thermal performance simulation in ArchiCad (from version 17 on).

Figure 21. Different approaches to CAD/BIM-integrated building performance assessment.
It is quite obvious that approach (iii) and (iv) offer the most “seamless” interaction, while (i) and (ii) potentially show compatibility issues that need manually be solved by a user. Also, the level of shared data is larger than in approach (i) and (ii): For instance, it is possible to define insulation materials within the CAD-drawing resulting in the correct hatch in a plan printout that are automatically understood as insulation layers within the integrated building performance simulation. Batueva (2014) examined the mentioned EcoDesigner tool in ArchiCad 17. She found that the integration of the simulation tool in the BIM software offers quick and preliminary simulation-driven design support. However, the simulation tool is neither standard-compliant nor validated in its current state, and suffers from small, but substantial hampering factors, such as missing comparison options of different variants and strange geometry misinterpretations. Nonetheless, this BIM/CAD-integrated approach to building performance assessment is a promising approach for future simulation-powered design.
The SEMPER project (Mahdavi 1995, 1996) was a research project started in the 1990ies at Carnegie Mellon University, Pittsburgh, USA. It can be considered as a novel approach toward integration of building performance simulation capabilities (energy lighting, and acoustics) via an active multi-aspect computational tool into computational design systems. Its main objectives were (i) consistent and coherent modeling of the fundamental physical processes (relevant to the building’s performance) throughout the entire building design phases, (ii) seamless and dynamic communication between various simulation models and a shared object-based building representation, and (iii) design refinement using active (mainly preference-based) design support involving the derivation of the design implications of the desired changes in performance attributes. A major goal of the SEMPER project was to offer high-end simulation techniques for all stages of the planning process, but with a special attention to the early design process. The common argument that advanced simulation tools are difficult to operate even in early design stages due to lack of comprehensive input data should be addressed with the appropriate integration of simulation tools with the over building design environment. The mentioned dynamic communication inside the SEMPER environment could be understood in the way that the change of a design parameter would automatically be adopted for the corresponding input data for simulation and calculation tools. Therefore, such an environment can be considered as offering fundamental time-saving potential and increased exploration of the options within a design space. One of the key features of the SEMPER environment was the integration of a building data representation scheme that acted as the sole communication node between different applications. This building representation scheme was object-oriented and space-based and thus met the requirements of most simulation tools regarding input data. Data from CAD-Tools, which per se regularly does not incorporate a representation of spaces but rather only the boundary surfaces cannot be directly used for building performance simulation, therefore all communication between different applications was performed via this building representation named SOM (SEMPER Object Model). As the SOM was designed based on the requirements for simulation tools, it was considered as an important reference in the research and design of SEMERGY’s building data representation.
3.5. Uncertainties in building performance assessment

Discussing environments and tools for building performance analysis cannot be done without consideration of uncertainties. Uncertainties need to be critically evaluated, and they are especially relevant, when decisions are made on the basis of results of calculations or simulations, where uncertainties cannot be excluded totally (de Wit 2004). Macdonald et al. (1999) identify four categories of uncertainty in building simulation (Figure 22):

(i) Abstraction. This refers to the fact that representations of the reality need to accept certain simplifications in comparison to reality. For instance, if occupancy profiles are modeled on hourly base, an occupancy of 31 minutes potentially is considered as an occupied hour.

(ii) Databases. This refers to the databases of materials, products, internal loads. Such template might show differences to real elements. For instance, the most tools feature a generic material named reinforced concrete. The attributes of this template for concrete might show significant differences to the concrete that is used at the building site.

(iii) Modelled Phenomena. The level of detail how certain physical phenomena can be modeled can have impact on the representation of such phenomena in the simulation software. An example for this is the modelling of heat flow, that can be modelled one-dimensional (as for instance premised in U-Value calculations), two-dimensional or three-dimensional (as for instance in detailed thermal bridges evaluation)

(iv) Solution methods. The simulation of certain physical phenomena used mathematical approximation to provide results after an acceptable time. This category of uncertainty is usually outwith the control of the user.

Figure 22. Different categories of uncertainty in building simulation (from Macdonald et al. 1999).
To address uncertainty issues, sensitivity analysis techniques can offer support. To assess the implications of uncertainties within a modeling and simulation environment, Macdonald et al. (1999) suggest to examine a couple of aspects of the simulation:

- Model realism, referring to the resolution realism of a simulation model.

- Input parameters, referring to the defaulting of not measured or unknown input parameters.

- Stochastic processes, referring to assumptions of difficult-to-predict aspects such as future weather data, individuals occupancy profiles and user behavior.

- Tool capabilities, referring to the uncertainties associated with the chosen algorithms within a tool.

- Impact of design variation, referring to the elasticity of the model behavior influenced by the change of certain input parameters.

SEMERGY incorporates building performance simulation tools and therefore might be subject to the mentioned uncertainties such as many other tools and environments are. However, the impact of database-related uncertainties can be considered as reduced within the SEMERGY approach: The retrieval of data via semantic web technologies, for instance about building product data, is exactly addressing this uncertainty. Even if not all necessary data for building simulation might be available via the World Wide Web, it can be assumed that a substantial part of the required information can be retrieved in a sufficient resolution and therefore helps reducing uncertainties caused by default values.
4. GENERAL ARCHITECTURE OF SEMERGY

This chapter describes the overall system architecture of the SEMERGY environment. Note that the text of this section includes references to and excerpts from previously published conference papers (Mahdavi et al. 2012, Pont et al. 2013).

SEMERGY was designed to be a web-based building analysis and evaluation environment for different user groups. To accomplish this ambitious goal, a well-developed and clearly-defined overall system architecture was required. Therefore, the following steps were taken in the development of the system architecture:

- Study of a previous developed, prototypically realized system (SEMPER) in view of its architecture.
- Definition of targeted user groups addressed by SEMERGY
- Development of Use-case based Sketches of the typical workflow in SEMERGY.

Based on these steps, in this chapter the overall system architecture of SEMERGY is described.
4.1. The architecture of the SEMPER project.

An early incentive toward a computational, multi-aspect design support tool was developed in the 1990ies at Carnegie Mellon University, Pittsburgh, USA. The SEMPER project aimed at the generation of a building performance modeling environment capable of offering support services through the entire building design and engineering process. Although being developed in pre-web-2.0 times and before the BIM-concept was generally established, it already incorporates many concepts that now can be seen as today’s standard of integral building data handling, such as the objected-oriented representation of buildings and constituting parts of buildings.

SEMPERs general architecture is illustrated in Figure 23. Its core components are a graphical user interface (GUI), a database, and model representations. The GUI performs all interaction with the systems user concerning data input and result output delivery. The database encapsulates data on building components, materials, layers, and units. The model representations include the unique shared object model and a number of domain object models. While the sooner is the building’s general representation and administrates the general building-related data such as the geometry, the latter are domain specific representations of the building or parts of the building tailored for usage within a certain performance or simulation domain. Examples for domain specific representations could be representations pertaining to energy, air flow, HVAC, Thermal Comfort, Lighting, Acoustics or Life-Cycle evaluations. Attached to the Shared Object Model is a topology Kernel, and attached to the domain specific representations is a corresponding domain kernel. These two calculation kernels ensure that input data for different simulation kernels is provided in the correct resolution and format and that the system operates dynamically together (changes to parameters of the building representation are automatically mapped to the specific domain models).

![Figure 23. General architecture of SEMPER (from Mahdavi 1996).](image)
A general schematic representation of the object-oriented structure of SEMPER is illustrated in Figure 24.

Figure 24. Object-oriented structure of SEMPER (from Mahdavi et al. 1996).
4.2. User-Groups

To identify potential targeted user groups for the SEMERGY environment, the stakeholders of building and retrofit processes were analyzed. As SEMERGY should offer support in the area of energy-efficient planning, it addresses those directly involved in principal decision making concerning energy-related matters. Therefore, SEMERGY targets three different potential user groups:

- Novice Users, who regularly have little or no knowledge of the building sector (building products, laws, applicable subsidies, etc.). This user group incorporates, for instance, private owners of single family homes that are thinking about a thermal refurbishment. This user group regularly requires a convenient and comprehensive guidance through the whole retrofit process, as they are not able to quickly gather the necessary domain knowledge for planning of new buildings or retrofits.

- Architects, Engineers and building designers, who demand a highly flexible and rapidly adaptable environment for impact estimation of design variations in their planning. The SEMERGY environment could serve them as a platform for quick evaluation of the early stages of their design. Furthermore, SEMERGY could serve as a communication platform between clients and planers: Client-relevant information can be easily derived from the environment and be summed up via standardized reports.

- Municipalities, developers and other authorities as well belong to the target group. These organizations often need to manage large portfolios of buildings, and therefore could be interested in a toolbox for fast evaluation of buildings at a larger scale (neighborhood, town).
4.3. Typical Use-Case

The typical use case in this field of building planning involves the evaluation of alternative building design and retrofit options for a basic initial design. Users provide information regarding the intended building activity (erection of a new building, addition or modifications of an existing structure, etc.). This initial data contains information about the building itself (location, geometry, principal construction method) as well as additional background information (budget, intended performance objectives). The level of detail provided by the user depends on their grade of experience (novice users versus expert users). The SEMERGY environment generates, based on user-specific constraints toward different performance criteria (for instance energy efficiency, sustainability or cost), a number of semantic (non-geometric) permutations of the initial design. These permutations fulfill the requirements and constraints of both the user and applicable laws, standards and guidelines. Thereby, material, element, and component alternatives are considered. For instance, different compilations of windows, external wall systems, and roof constructions are combined in multiple ways to generate a larger set of possible design alternatives. Figure 25 illustrates this principle use case.

![Figure 25: 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.](image-url)
4.4. Strategic Approach within SEMERGY and SEMERGY’s architecture.

To fulfill the described task of the typical use case, the SEMERGY environment deploys two main strategies:

(i) Data acquisition: Information regarding building materials, elements, and components are obtained from the World Wide Web using semantic web technologies. Likewise, further relevant and required information is retrieved from the web. This includes product prices, microclimatic boundary conditions, applicable legal and administrative constraints, and available subsidies and tax incentives. The user-specified input of initial data allows for filtering the data obtained from the web, based on their appropriateness. Thus, the corpus of possible permutations of the initial design in the optimization step could be efficiently reduced to a computationally reasonable size.

(ii) Comprehensive evaluation process: After the ordered set of feasible alternatives is established following the data acquisition process, it is made subject to a comprehensive evaluation process. Thereby, the SEMERGY environment is tailored for implementation of both simplified calculation routines (for instance tools for energy certification or life cycle analysis) and numeric simulation tools (e.g. sophisticated thermal and lighting performance simulation applications). These tools are used for alternative evaluation, and their results are used for a criteria based ranking of alternatives. Such criteria could be based on (locally applicable) benchmarking systems (e.g. energy certificate results) or on user preferences. To facilitate this step and to keep this step feasible from a view of algorithmic cost and elaboration time, methods of multi-objective optimization are implemented.

The general layout of the SEMERGY tool, as illustrated in Figure 26, is based on the requirements of the typical use case and considers the different user groups, available resources and tools that can be coupled with SEMERGY.

The SEMERGY kernel acts as linchpin, interaction coordinator and consolidation device of different data streams. It is linked to the applications utilized in the evaluation process via the reasoning interfaces and to the sources of information (data acquisition) via the semantic data interface. Furthermore, the Kernel manages the interaction with the users of the environment via a Graphical User Interface. The SEMERGY kernel can be understood as a converted-to-software implementation of the different developments within the SEMERGY project. This includes, for instance, the SEMERGY Building Model (SBM), the routines of templates and alternative generation, the utilization of web-of-data approaches such as the Resource Description Framework (RDF) for making AEC-related data semantically readable for machines or ontologies for the provision of structured information about building products and materials for the evaluation modules, and the integration of optimization routines within the SEMERGY framework. These different developments are described in subsequent sections of this dissertation.
The User Interface supports the acquisition of data from the user and enables user interaction. The format of this interface and the interaction method is tailored to the specific needs and expertise of the aforementioned target groups. According to the use case, the data required for computation is to be provided by the user through a web-based Graphical User Interface, extracted automatically from an advanced building design software (CAD, BIM), or derived from GIS data.

The key feature of the SEMERGY environment is the incorporation of semantic web technology toward efficient search for and compilation of input information required for comprehensive analysis and evaluation of candidate design options supported by multi-objective decision support methods. This is the key task of the Semantic Interface.

The reasoning interface involves the assessment methods and calculation procedures that the model is to undergo. Given that different design scenarios are to be rated based on their functional, ecological, and economical performance, the reasoning interface needs to accommodate cost estimation, life cycle analysis, and other performance assessment procedures. SEMERGY involves both simple (e.g. normative) performance calculation procedures and advanced numeric analysis and simulation applications on the background, and is coupled with an elaborate optimization engine to identify, evaluate, and rank different design options.
The workflow within the SEMERGY environment can be summed up as follows (illustration in Figure 27):

The initial design intention is conveyed by the user through the User Interface, either through direct geometry input (web based graphical user interface for novice users) or data import (via BIM or GIS). This data is structured in the form of a building data model. Based on the preferences of the user (e.g., available budget, desired performance level, and construction system), alternative design options regarding construction materials of various building components are identified by the semantic and the reasoning interfaces. The building model subsequently inherits the semantic information pertaining to various alternatives from the semantic interface and undergoes evaluations. These iterations continue until the optimal solution(s) have been detected in view of cost, performance, and environmental impact.

Figure 27. Structure of SEMERGY as workflow schema.
This chapter describes the SEMERGY Building model (SBM) and its development. Note that the text of this section includes references to and excerpts from previously published conference papers (Ghiassi et al. 2013). Furthermore, the development was the subject of a master’s thesis conducted in the framework of the SEMERGY project at the department of Building Physics and Building Ecology of Vienna University of Technology (Ghiassi 2013).

SEMERGY is intended as an optimization environment for building designs and retrofits. This environment should be able to serve as an interoperable platform between semantic data sources (for instance building product information, climate data, GIS data, legal constraints, available subsidies), the building design, as provided by the user via a web-based GUI, CAD/BIM-drawings or via GIS-data, and reasoning tools. Reasoning tools hereby are defined as tools for calculation, simulation and optimization processes. For instance, reasoning tools could include normative heating demand calculation methods and procedures, calculation of environmental footprint, cost estimation and different building performance simulation engines. To enable the transfer of data between the different components of the SEMERGY environment, building related data is structured and stored in form of a building data model. Many existing web-based tools do not utilize comprehensive building data models, as these tools are regularly just intended for specific, small-scale inquiries (e.g. for calculation of U-values such as u-value.net, 2014), or for very general evaluations (e.g. rudimentary energy demand calculations such as energyglobe, 2014). The SEMERGY environment, in contrast, needs such a generic building data representation to be able to perform seamless data exchange for a multitude of tasks between different data sources and applications. Augenbroe (2004b) defines a building model as an object-oriented data model describing a building as a set of conceptual entities with attributes and relationships. Additionally he points out that two fundamental structural approaches for building data representations exist: First, a general data representation scheme that as it is fits to all data sources and applications (Figure 28), Second, a building model that incorporates different subschemes that are tailored to fit to the requirements of specific applications (Figure 29).

Figure 28. General data representation fitting to all applications (Augenbroe 2004b).
Two major questions in the starting phase of the SEMERGY project dealt with this building data representation:

(i) How should the requirement profile of a building data model suitable for the SEMERGY environment look like? This question is answered in the requirement analysis section.

(ii) Do existing building data models fulfill the requirements, or is there need for a proprietary development? This question is discussed in the section Evaluation of existing building data representations.

The outcome of the research and the current state of the SBM is documented in the section The development of the SEMERGY Building Model (SBM). Subsequently, the future development of the SBM is described in the Outlook section.
5.1. Requirement Analysis

To answer the first question an extensive requirement analysis was performed, including the following efforts:

- A set of selected computational engines were analyzed toward identification of essential input information. This data was considered as a benchmark for data that should be represented in the building data model. The computational engines examined include tools based on annual and monthly normative procedures for derivation of energy certificates, as well as a detailed thermal simulation engine. The annual calculation procedure (Demacek 1999) served as calculation scheme for energy certificates in Austria from 1999 till 2007. Originally being published as an Excel-Tool, the analysis of input data could be performed rather rapid. The method was later implemented in the SEMERGY environment as a basic heating demand calculator, due to its simplicity and robustness. The monthly normative procedure serves as the calculation scheme for energy certificates in Austria since 2007, though being under constant development since its first implementation. The method is based on a number of Austrian and European Standards (detailed references are described in the section Calculation & Simulation Modules, Subsection: Current Energy Certificate Method), hence the analysis of the input data was more complex in comparison to the annual method. Therefore, the identification of input data structures was performed via examination of commercial energy-certificate-tools (Archiphysik 2014, GEQ 2014) incorporating all related standards within comfortable GUIs. The dynamic thermal simulation tool analyzed toward its required input information was Energy Plus (DoE 2014a), developed by the U.S. Department of Energy. In comparison to the normative procedures, this tool features a much higher level of complexity, and demands very fine-grained input information. Furthermore, Energy Plus does not provide an embedded graphical user interface. Interaction with EnergyPlus is performed via command line and text based manual input. For the analysis of this tool's input data requirements the documentation of Energy Plus was used. Additionally, two well-established third-party tools with graphical user interfaces for EnergyPlus as underlying simulation engine were examined: OpenStudio (OpenStudio 2014) and DesignBuilder (DesignBuilder 2014).

As an outcome of the requirement analysis, the following crucial aspects of the required building model were identified:

- **Extensibility**: Since the building model should serve as a central data exchange module in the SEMERGY environment, its extensibility and flexibility towards integration of data necessary for intended calculation and evaluation methods should be guaranteed. An object-oriented structure enables integration of new information with minor effort and minimal readjustments.

- **Space-based structure**: A key functionality of the SEMERGY environment is building performance assessment. Many building performance assessment tools require a space-based view of buildings, in which building components are represented not solely as material entities but additionally by their relationship to various spaces. Building performance simulation tools for energy, light and sound evaluation require space descriptions containing geometric, topologic and semantic information about enclosure components, as well as overall building and site context and
adjacency relationships to other spaces (Mahdavi et al. 2002). Within space-based building representations building components are regarded as enclosure elements of a certain space, and therefore as borders between this space and surroundings, other spaces. The relational information between spaces and components is crucial for the implementation of heat transfer and airflow calculations. The principle of space-based thermal modeling applies to the majority of assessment tools, regardless of their input data granularity. In such a space-based data structure, a building is subdivided in a number of rooms or spaces. Such rooms / spaces should be defined as entities enclosed by physical elements like walls, ceilings and floors. In view of certain energy performance considerations, the additional concept of “zone” (analytical space) should also be adopted in the building data model. A zone is a virtual redefinition of spaces, not necessarily being margined by physical entities but by similarities and differences in properties. For instance a “thermal zone” could be set according to heat distribution schemes, solar orientation or functionality of various parts of a building. A zone, therefore, could combine a set of rooms/spaces, could correspond to one room/pace or just to a part of one or more rooms/spaces.

- **Simplification of enclosures to two dimensional entities:** While enclosing building components in reality are three-dimensional entities described by coordinates or dimensions, many performance-assessment tools define enclosures as two-dimensional planes. A building representation scheme needs therefore to be capable of representing such elements as two-dimensional elements. It is important to be aware of the consequences of the two-dimensional representation: This simplification causes variations in the resulting enclosure areas or space volumes in comparison to reality. By convention, in thermal building performance simulation, this simplification is performed via two simple rules: The net volume of the building is maintained by adopting the inner planes of the outmost elements of the building as envelope boundaries. To avoid gaps between the zones of a building, a different rule for inner elements is necessary. Inner elements regularly are represented by a virtual plane half-way between the two facets of a physical element. Figure 30 illustrates these rules and shows the difference between architectural walls and space boundaries. However, although the simplification of enclosures to two dimensional entities is utilized in a large number of simulation tools, normative procedures partly show other conventions. In Austria, for instance, generally all building related calculations should be done using the external perimeter of the building’s envelope gross area and volume following OENORM B 1800 (OENORM 2013), unless stated differently.

![Figure 30. Difference between architectural walls and space boundaries (Ghiassi 2013).](image-url)
5.2. Evaluation of existing building data representations

To answer the second question with regard to compatibility of existing building data representations with the requirements of the SEMERGY environment three building representations were examined towards their suitability for the proposed SEMERGY environment: Industry Foundation classes (IFC 2014), Green Building Extented Markup Language (gbXML 2014) and the Shared Object Model (SOM), developed in the SEMPER research project at Carnegie Mellon University (Mahdavi 2000).
5.2.1. IFC data model

The **IFC data model** is generally seen as the defacto interoperability standard in the AEC-industry. It is an object-based data model initiated by the former International Alliance for Interoperability (IAI) in 1995. The current deployments of IFC are promoted by the Building Smart alliance (Building Smart 2014). The main idea is that the data model should be versatile enough to serve the majority of different stakeholders throughout the entire life cycle of the building (for instance architects, structural engineers, HVAC-planners, facility management). The IFC model is open-source and freely available, and it's schema can be extended with additional classes and properties. Many software tools of the AEC-industry allow data-transfer via IFC. Building Performance Assessment Tools, however, do commonly not consider the IFC-structure as a building data representation, but rather as a data format for importing from and exporting to. This might be caused by the fact that IFC does not fully accommodate fully to the needs of building performance assessment. The IFC approach is not a space-based attempt to represent buildings and building components. Rather, the IFC building data representation consists of architectural objects (walls, ceilings, roofs, floors) and their properties. These entities constitute a building. Figure 31 illustrates the principle representation of building components, spaces and space boundaries in IFC.

![Figure 31: Schematic representation of building components, space and space boundaries in IFC (Ghiassi 2013).](image)
While well-suited for the purpose of building construction or structural analysis of a building, this representation lacks the structural requirements of building performance assessment. IFC can identify spaces, but lacks the clear topological relationships between spaces. Space boundaries are attached to the properties of architectural objects and therefore dependant on how they were generated within a BIM-software. Regularly, space boundaries are aligned along a reference line of the separating architectural object. There are no clear guidelines, how a reference line of an architectural object is situated toward spaces, thus space boundaries can be positioned on the inside, the outside or halfway between two facets of an architectural object. These boundary definitions are not consistent in most IFC-building models. Often, the dilution of inside, outside and arbitrary reference lines is simply a result of the drawing order of the architectural objects. As a result, in view of space-boundaries, IFC-files can contain irregularities in form of overlaps or gaps. Such models can only be used for building performance assessment with cumbersome conversion routines in form of geometry analysis and transformation algorithms (Bazjanac 2008, 2010). Ghiassi (2013) mentions further issues with geometrical and semantic properties within IFC-building representations that might not be problematic for building engineering or structural engineer, but are problematic in thermal building performance modeling. For instance, the building representation should offer the possibility to reference one space boundary to several building components: A separation wall adjacent to more than two spaces or zones needs to be subdivided following its different adjacencies. While in principle possible, transforming the current IFC model into one that correctly represents semantic data pertaining to various space enclosures requires extensive computational effort. An automated recognition can be realized within the IFC-model only with a complex further analysis to identify which section of a space boundary lies within the limits of which physical building component. Figure 32 illustrates the problem.

Figure 32: Left: Real Situation; Middle: IFC-representation losing the semantic information about the tow different building components in boundary 9 and 13. Right: Re-construction of a performance compliant space boundary representation from the IFC model (based on Ghiassi 2013).

Concluding, it can be said that the IFC-building representation at its current state could only serve the SEMERGY environment with a set of obstacles to overcome. Even if pre- and post-processing steps would solve the mentioned issues, they render the use of IFC as a data model in view of numerous optimization steps and the web-character of SEMERGY infeasible. IFC is seen as industry standard.
and there are different research efforts targeting these issues (Hietanen 2000, BLIS-project 2011, Bazjanac 2008, 2010, Granlund 2013). Within the SEMERGY project it thus remains a valid possibility for data import from CAD-applications, once a robust and reliable data transformation is developed by the research community, but it does not qualify as an efficient, dynamic model for building performance evaluation.
5.2.2. gbXML data model

GBXML – the green building extended markup language – is a development initiated around the millennium to enable and facilitate data exchange between BIM applications and analysis tools (gbXML 2014). Currently, a wide array of software adopted the format to enable interoperability and therefore gbXML can be considered as a defacto standard. In contrast to the IFC building representation, gbXML follows the space-based concept. Therefore, it is widely compatible to the necessities of building performance assessment. A building is defined and composed as a combination of spaces. Spaces are represented by their corresponding space boundaries as well as by associated operational classes and attributes. Space boundaries are represented by their planar geometry. Additionally, the information about adjacency and semantic information regarding their composition and construction materials is stored. The attribute “oppositeldRef” determines the adjacency, while the attribute “surfaceldReference” references the space boundary to an architectural element containing the semantic data about construction. Figure 33 and 34 illustrate the representations of building, space and space boundaries as implemented in the gbXML scheme.

![Figure 33. Building and space representations in the gbXML schema (gbXML 2014).](image-url)
So far, gbXML can be considered suited for a prototypical implementation into the SEMERGY environment. Unfortunately, gbXML is not extensible (while XML itself is). The gbXML-file has a rigid, inextensible structure. In case of modifications/extension of this structure, various applications may seize to recognize the resulting XML file as a valid file format. If additional information beyond the designated information is stored in the gbXML-file (which as XML tags per se is possible), it will at best be ignored. More likely, however, is that even the valid information in the file won’t be imported.

SEMERGY is envisioned as an environment open to extension with different calculation and simulation tools. Therefore, the gbXML building model, although suitable from viewpoint of thermal building performance simulation, is considered inadequate due to its inability to be extended. Nevertheless, gbXML is considered valuable for the SEMERGY environment. Due to its establishment in numerous CAD-, BIM- and building performance software tools it offers remarkable options for data exchange with such applications. Thus, the development of mapping routines from gbXML to SEMERGY is foreseen within the SEMERGY project.
5.2.3. Shared Object Model (SOM) from SEMPER

The SOM is a development in the framework of the SEMPER project that was conducted in the 1990s at Carnegie Mellon University (CMU). SEMPER was designed to be a prototypical computational environment for integrated building performance modeling in the building design-process. Inspired from the concept of object-oriented programming, SOM is a hierarchically structured, template of space-based building data. SOM was not intended to be a “universal application independent building model”, adequate for all various AEC-related inquiries or application independent. Rather, it is a bottom-up approach to develop a building data model that is tailored for feeding a number of technical analysis applications with required data in the required resolution (Mahdavi et al. 2002). Following Augenbroe’s definition (Augenbroe 2004b), the SOM is therefore a building representation with subschemes to serve different applications. Figure 35 illustrates the Structure of the Shared Object Model. SOM itself does not contain all required building information. Rather, it contains a tightly structure denotation of constitutive building elements. Pointers link to the specific detailed information about such elements in a persistent data repository.

Figure 35: Structure of the SOM from SEMPER (Mahdavi et al. 2002).

The SOM retrieves the necessary data about building geometry, material, and contextual information for the technical analysis applications. However, for the domain-specific building performance simulation application to function, the SEMPER environment generates a domain specific object
model. This model filtrates and modifies the information from the SOM according to the specific view on the building from that domain. Next to the inherited information from the shared model, domain specific entities might have to be added.

The SOM-scheme shares the space-based structure with gbXML, and is extensible. Furthermore it is clearly structured and was developed based on a performance-oriented view of a building. Therefore it was considered to be a good foundation for the development of a SEMERGY – specific building model.
### 5.2.4. Comparison of IFC, gbXML and SOM

Table 1 summarizes and compares the fundamental aspects of the three examined building data representations.

#### Table 1. Comparison of IFC, gbXML and SOM in terms of crucial aspects for utilization within the SEMERGY environment.

<table>
<thead>
<tr>
<th></th>
<th>IFC</th>
<th>gbXML</th>
<th>SOM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>First appearance</strong></td>
<td>1995</td>
<td>Around 2000</td>
<td>1995</td>
</tr>
<tr>
<td><strong>Basic Approach</strong></td>
<td>Generation of a general data model to be used throughout the whole life-cycle of a building by different stakeholders.</td>
<td>Facilitated data exchange between drawing and analysis tools</td>
<td>Bottom-Up approach of a building data representation tailored to the requirements of a number of technical analysis applications.</td>
</tr>
<tr>
<td><strong>Subschemes</strong></td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td><strong>Object-orientated</strong></td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td><strong>Extensibility</strong></td>
<td>yes</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td><strong>Space-based structure</strong></td>
<td>Partial (conversion and postprocessing efforts necessary)</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td><strong>Enclosure simplification to 2D-entities</strong></td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>
5.3. Development of the SEMERGY Building Model (SBM)

As mentioned before, the development of the SBM was based on the SOM of the SEMPER project. SOM was extended according to the requirements of the SEMERGY environments calculation and simulation methods with additional classes and attributes. The methods taken into account included two normative calculation methods (annual and monthly heating demand routines as determined in Austrian Standards) and the dynamic thermal simulation tool Energy Plus (Doe 2014a). The additional data includes detailed material and construction properties, modalities for the definition of operative data and case-appropriate calculation parameters. To reduce the calculation load in assessment and optimization efforts, certain parameters were already incorporated in aggregated form. The extension and aggregation efforts resulted in the development of an object-based extensible, space-oriented data model referred to as SEMERGY Building Model (SBM). Figure 36 (next page) offers an overview about the hierarchical structure of the SEMERGY building model. A detailed UML (Unified Modeling Language)-representation of the whole schema (including all classes, hierarchical relationships and corresponding attributes can be found in the annex.

The data represented in the SBM can generally be structured in 4 categories of classes:

- Calculation parameters: The calculation parameter objects need to be understood as links to external repositories of calculation and weather data templates. Influenced by the user-provided physical data such as location and construction system, relevant parameters and values are extracted from these external repositories, stored, and supplied to the corresponding assessment tools. While currently these repositories were generated manually to serve in the general proof of the SEMERGY concept, this is intended to be changed in terms of the general architecture of SEMERGY: Data is retrieved via the semantic interface, stored and administrated in the SEMERGY kernel and provided to the reasoning interface.

- Operational data: The operational data includes all settings regarding internal conditions of zones. It includes HVAC data and settings such as schedules and set points for temperature, relative humidity, ventilation and infiltration, internal gains through lighting, occupancy and equipment use, and information about the zone’s equipment and furniture. For novice users and simplified calculation engines pre-defined templates are provided to populate the corresponding classes in the SBM baed on case-specifications. Furthermore, a property to space was added in the structure named “Function” that serves as shortcut to predefined templates of operational data following the space’s function. For instance, if “function” is set to residential, default internal gains of 3.75 W.m\(^{-2}\) and a ventilation rate of 0.4 h\(^{-1}\) are assumed.

- Physical Data regarding Geometry: The SBM’s geometry data classes can be populated by user input via the graphical user interface or via data import from CAD/BIM-tools (see Section Graphical User Interface & data exchange). If the Graphical User Interface is used, the data is generated based on the drawing done by the user and additional stated information (for instance the room height). The use case of evaluation of building groups, for instance by municipalities and real
estate property owners, will in future utilize GIS-Systems for basic geometry retrieval. This is currently under exploration and implementation in the SEMERGY environment. However, the detailed geometry data is unlikely to be offered by even detailed GIS-systems. Therefore it is expected that geometry data from GIS-data is not directly used but rather used as a foundation for reconstruction of building geometry within the SEMERGY environment based on perimeters.

- Physical Data regarding Semantics. This category summarizes all classes with semantic information about building constructions, layers and material necessary for calculation and simulation purposes. To populate this kinds of information, the SEMERGY environment utilizes a comprehensive ontology of building products, supported by semantic web technologies and structured in a SBM-compatible way. For novice users – comparable with the operational data – default options are integrated. For instance, if a user does not know about the constructive details of his existing building, SEMERGY assumes default data about constructions from the specific construction years. Similar, simplifications concerning classes such as shading, screens and blinds are implemented in the SEMERGY environment.

The detailed design conventions of the classes and their corresponding attributes of the SEMERGY Building Model are described in Ghiassi (2013). Figures showing the details of attributes and links between classes can be found in the annex. An informative overview about different classes within the four categories is provided in tables 2, 3, 4 and 5.

Table 2: Classes of the SBM pertaining to Calculation Parameters.

<table>
<thead>
<tr>
<th>Class Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Weather Data</td>
<td>Class representing annual climate data (necessary for annual calculation method), retrieved from external repositories via semantic interface</td>
</tr>
<tr>
<td>Monthly Weather Data</td>
<td>Class representing monthly climate data (necessary for monthly calculation method), retrieved from external repositories via semantic interface</td>
</tr>
<tr>
<td>Simulation Weather Data</td>
<td>Class representing climate data in resolution for dynamic thermal simulation, retrieved from external repositories via semantic interface</td>
</tr>
<tr>
<td>Weather Data</td>
<td>Climate data superclass</td>
</tr>
<tr>
<td>Annual Method Calculation Settings</td>
<td>Representation of the calculation settings for the annual calculation method.</td>
</tr>
<tr>
<td>Monthly Method Calculation Settings</td>
<td>Representation of the calculation settings for the monthly calculation method.</td>
</tr>
<tr>
<td>Simulation Method Calculation Settings</td>
<td>Representation of the calculation settings for the dynamic thermal simulation.</td>
</tr>
<tr>
<td>Calculation Settings</td>
<td>Calculation settings superclass</td>
</tr>
</tbody>
</table>

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Table 3. Classes of the SBM pertaining to Physical Data – Geometry.

<table>
<thead>
<tr>
<th>Class Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site (Root Object)</td>
<td>Top-level physical entity</td>
</tr>
<tr>
<td>Features</td>
<td>Natural or anthropogenic elements on site which cast shadows</td>
</tr>
<tr>
<td>Location</td>
<td>Data about the location, currently featuring longitude, latitude, postal code, country and region as attributes</td>
</tr>
<tr>
<td>Building</td>
<td>Is a logical unit, part of “site” and decomposed into “sections”. Buildings are associated with one or more HVAC-systems. Attributes stored in the building class include the year of construction, construction type and usage. These attributes help reducing the number of construction alternatives and determine calculation settings. Additionally the building class features attributes to store the gross area of the building envelope, the gross floor area and the gross volume of the building. These values are pre-calculated based on the geometry input to reduce later calculation load.</td>
</tr>
<tr>
<td>Section</td>
<td>Is a group of spaces, usually sharing some properties, but being different in others. Each section is decomposed into one or multiple spaces. Note that section is used for the simplified normative procedures to represent all zones of one floor (sharing the same ceiling height property).</td>
</tr>
<tr>
<td>Zone</td>
<td>Zone is an additional grouping scheme for spaces. It accounts for user-defined thermal zoning (for professional users). In the current deployment of SEMERGY the zone feature is by now not used. Currently each space is considered as a thermal zone.</td>
</tr>
<tr>
<td>Space</td>
<td>Spaces are the constituting elements of a building and of the building representation following the idea of space-based structure. A space is a volume margined by a collection of enclosures forming a polyhedron. Spaces generated in the web-based SEMERGY GUI in its current state, such a space as a minimum consists of 6 enclosures (cuboid). Imported geometry, however, does not stick to this rule necessarily. Similar to the building class, spaces store area and volume values, as well as function. Function thereby is a keyword (kitchen, bedroom, office, unheated attic, etc.) linking to default templates for different calculation and simulation properties of the spaces (for instance, internal gains). Spaces can have operational datasets such as furniture, occupant, equipment, lighting and required internal condition.</td>
</tr>
<tr>
<td>Partition</td>
<td>Spaces can feature partitions. While these in reality would separate a space into a number of smaller spaces, in the SBM they are not considered as dividers, part as room elements. Their representation is important due to their influence on thermal storage capacity in view of thermal simulation.</td>
</tr>
<tr>
<td>Enclosure</td>
<td>Enclosures are the physical boundaries of a space. Currently three types of enclosures are defined in SBM: walls, roof/ceiling and floor. Instances of enclosures incorporate information about its vertex coordinates and its adjacency status (outside, ground, adiabatic, surface). The latter is of crucial importance for the majority of thermal building performance assessment tools. The adjacency status “surface” is representing a boundary to another space of the same building. While being just one architectural element, each involved space needs an enclosure for its representation. As these enclosures share their vertex coordinates, the direction of its surface normal is stored for distinction. The surface normal of enclosures points to the center of its parent space. Enclosures consist of a construction and feature attributes like “area” and “U-Value”.</td>
</tr>
<tr>
<td>Aperture</td>
<td>Apertures are understood as openings in enclosures, and therefore represent for instance doors, windows and skylights. Currently for opaque doors “door” and for transparent elements “windoworglazeddoor” are implemented. The aperture class – similar to the enclosure class – stores general properties such as area. They inherit their “adjacencystatus”, “surface resistance” and “temperature correction factor” from their parent enclosures.</td>
</tr>
<tr>
<td>Roof or Ceiling</td>
<td>Representation of all Roof and Ceiling elements within the building</td>
</tr>
<tr>
<td>Wall</td>
<td>Representation of all Wall elements within the building</td>
</tr>
<tr>
<td>Floor</td>
<td>Representation of all Floor elements within the building</td>
</tr>
<tr>
<td>Door</td>
<td>Representation of all Door elements within the building</td>
</tr>
<tr>
<td>Window or Glazed Door</td>
<td>Representation of all Window and Glazed Door elements within the building</td>
</tr>
<tr>
<td>Adjustable Shading</td>
<td>Adjustable shading elements such as curtains, blinds and rolls are represented in this class. They can be mounted on windows and glazed doors, inside, outside and between the panes. For their control, schedules and automated controlling schemes can be used.</td>
</tr>
<tr>
<td>Simple Shading</td>
<td>This class represents shading elements in simple normative calculation procedures. The properties of the shading elements are reduced to few values within this class.</td>
</tr>
<tr>
<td>Attached Shading</td>
<td>Shadings on the outside of the buildings, e.g. overhangs and shading fins. They are defined by their coordinates and are referenced to an enclosure.</td>
</tr>
</tbody>
</table>
Table 4. Classes of the SBM pertaining to Operational Data.

<table>
<thead>
<tr>
<th>Class Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schedule</td>
<td>This class represents various kind of schedules, understood as time-dependent variation of input data (e.g., ventilation schedule, occupancy in buildings of different usage)</td>
</tr>
<tr>
<td>Ventilation</td>
<td>Representation of the intended flow of air from the outdoor environment to the inside for fresh air-supply and hygienic purposes.</td>
</tr>
<tr>
<td>Infiltration</td>
<td>Representation of the unintended flow of air from the outdoor environment to the inside.</td>
</tr>
<tr>
<td>Humidistat</td>
<td>Representation of the humidity threshold values for humidifying and dehumidifying operations within a space.</td>
</tr>
<tr>
<td>Equipment</td>
<td>Representation of equipment. The class contains information about the contribution to internal gains by equipment.</td>
</tr>
<tr>
<td>Occitant</td>
<td>Representation of living agents. The class contains information about the contribution to internal gains by occupancy.</td>
</tr>
<tr>
<td>Lighting</td>
<td>Representation of artificial lighting devices. The class contains information about the contribution to internal gains by electrical light.</td>
</tr>
<tr>
<td>Required Internal Condition</td>
<td>This is the simplified representation of the different influences on internal conditions (ventilation, infiltration, thermostat and humidistat) prepared for use within the calculation and simulation procedures.</td>
</tr>
<tr>
<td>Furniture</td>
<td>This class describes the furniture within a space. Currently, this is used for the description of thermal storage mass of the furniture</td>
</tr>
<tr>
<td>HVAC</td>
<td>This represents one or more HVAC-systems within the building.</td>
</tr>
</tbody>
</table>

Table 5. Classes of the SBM pertaining to Physical Data – Semantics.

<table>
<thead>
<tr>
<th>Class Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction</td>
<td>Layered composition of materials that form an enclosure or aperture. This class can incorporate different types of constructions, represented in the classes door construction, enclosure construction, window construction. Construction further utilizes results of calculations performed on lower levels of the class hierarchy concerning building components (layers, materials) as attributes or to constitute attributes.</td>
</tr>
<tr>
<td>Door Construction</td>
<td>In the current state of SEMERGY, this class represents doors and might only consist of homogeneous layers.</td>
</tr>
<tr>
<td>Enclosure Construction</td>
<td>Enclosure constructions consist of one or multiple enclosure layers. Next to the direction of heat flow, specified via the outmost enclosure layer position, information about integrated heating systems (underfloor heating, radiant heaters) and surface resistance values are stored in this class.</td>
</tr>
<tr>
<td>Window Construction</td>
<td>Window construction are constituted by Window Glazing and Frame.</td>
</tr>
<tr>
<td>Homogeneous Opaque Layer</td>
<td>Homogeneous layers are composed of a single opaque material.</td>
</tr>
<tr>
<td>Inhomogeneous Opaque Layer</td>
<td>Inhomogeneous layers are composed of two or more opaque materials. Shares of the different materials are expressed in percentage values.</td>
</tr>
<tr>
<td>Unventilated Cavity</td>
<td>This class represents non-ventilated cavities within the construction.</td>
</tr>
<tr>
<td>Opacite Material</td>
<td>This class represents opaque materials including their physical properties</td>
</tr>
<tr>
<td>Enclosure Layer</td>
<td>Enclosure Layers can be either homogeneous, inhomogeneous or unventilated cavities.</td>
</tr>
<tr>
<td>Layer</td>
<td>Layers are semantic entities composed of materials with a specific thickness values. Currently the SBM features two different types of layer: Enclosure layers and glazing layers. An attribute named thermal relevance states, if a certain layer should be taken into consideration for U-Value calculations.</td>
</tr>
<tr>
<td>Glazing Layer</td>
<td>Glazing Layers are composed of a glazing material</td>
</tr>
<tr>
<td>Frame</td>
<td>This class represents the frame of window constructions with its attributes.</td>
</tr>
<tr>
<td>Glazing Material</td>
<td>Glazing materials incorporate all valid materials for the composition of window glazing layers. In regular window construction, only Gas and Glas are used. Advanced constructions can include visual and thermal shading elements as Screens, Shades and Blinds can be considered.</td>
</tr>
<tr>
<td>Gas</td>
<td>Representation of gas layers within glazing systems (dried air, Argon, Xenon, Kryptron) and their properties.</td>
</tr>
<tr>
<td>Glas</td>
<td>Representation of glas Layers within the glazing systems.</td>
</tr>
<tr>
<td>Screen</td>
<td>Representation of screens within the glazing systems. Screens are hereby understood as shading devices made of wire meshes. Their solar and visible transmittance varies with the angle of incidence of solar radiation. The only allowed position for screens is only on the outside of window constructions.</td>
</tr>
<tr>
<td>Shade</td>
<td>Representation of shades within the glazing systems. Shades are understood as shading devices with shading and diffusing capabilities independent of the solar angel.</td>
</tr>
<tr>
<td>Blind</td>
<td>Representation of blinds within the glazing systems. Blinds are understood as slat-type shading devices, that are strongly dependent on the sun angle in terms of transmission, absorption and reflectance.</td>
</tr>
</tbody>
</table>
Figure 36: SEMERGY Buidling Model Scheme (first published in: Ghiassi 2013).
5.4. Further Evolution of the SBM

The current state of the SEMERGY building model is serving its purposes to feed the implemented and proposed calculation modules with input data corresponding to their input requirements. The current calculation methods include the annual heating demand method, the OI3-evaluation regarding the ecological performance of the building materials, and an investment cost calculation. Moreover, the design and generation of the SBM in its current form was based on the current energy certification method in Austria and the thermal dynamic simulation tool Energy Plus (Doe 2014a). These tools are intended to be coupled with the SEMERGY environment in the efforts of the ongoing SEMERGY project. The PHPP-method (PHPP 2014) requires a similar data resolution as the monthly method for energy certificates. However, the SBM needs to be extended with the specific efforts of this tool.

On the long run, the SEMERGY environment should be extended in its analytic capabilities, pertaining to other building performance related inquiries such as daylight and artificial lighting analysis or acoustical performance. The current SEMERGY building model does not feature all necessary input information for tools capable of performing such analysis. However, the space-based structure as of the current state of the SBM should offer a solid foundation for extension possibilities (classes, variables and attributes) serving these fields of building performance evaluation. The mentioned areas, however, consider buildings or spaces as examination subjects. Analysis on level of building components, for instance on two- and three dimensional thermal bridges analysis or computational fluid dynamics would demand for a major revision and extension of the building representation. Figure 37 illustrates that the current state of representation of the building components joints would not allow for a detailed thermal bridges calculation.

![Figure 37. Attica detail of a flat roof (partially derived from Aalen 2014, modified): Left shows the detail as architectural drawing, in the middle the necessary level of detail for a thermal bridge evaluation tool, right the current representation in the SEMERGY environment.](image)

However, future development in the SEMERGY environment will include the integration of other performance assessment tools. Therefore, the extendibility of the SBM will be utilized for integration of required classes, attributes and object hierarchies. Figure 38 illustrates the future development.
Figure 38. Structure of the SBM for coupling with further calculation methods. For each calculation method a corresponding data subscheme is generated, providing required data in required resolution.
6. TEMPLATES & ALTERNATIVE GENERATION

This section describes the template and alternative generation within the SEMERGY environment.
6.1. General structure of the templates & alternative generation

As people with little or no domain knowledge about building construction would struggle to compose their building model in an appropriate way for further elaboration steps, SEMERGY offers a large set of templates of different building constructions. Furthermore, these templates are used as a basis for refurbishment options and optimization attempts. For the development of these templates, the following steps were carried out:

(i) Identification of typical constructions used for erection of historical and current buildings based on literature (Beinhauer 2005, Baubook 2014, Cheret 2010, Dataholz 2014), industry (Knauf 2014, Isover 2014) and the domain knowledge of the SEMERGY team. These constructions usually consist of an assembly of different building component layers. Such layered building components were identified for all constituting parts of the overall thermal envelope of buildings. Therefore, templates for the following opaque building components were generated: Exterior walls, internal walls, exterior walls adjacent to ground, Floors on the ground, flat roofs, sloped roofs, floor constructions to unheated attic spaces, intermediate floor constructions and floors above unheated basement spaces. The first rollout of SEMERGY included all together 109 different templates of constructions. Figure 39 and 40 show typical examples of building component information (exterior wall) as provided in the literature.

Figure 39. (left) Example of building detail information as provided in Beinhauer (2005).

Figure 40. (right) Example of building component information as provided in Cheret (2010).

For each construction the main construction method was declared (e.g. massive masonry, massive wood, wood frame, concrete or steel frame). This information is relevant to ensure compatibility of different building construction to each other. Thus, in this way it is guaranteed that a ceiling for massive masonry constructions is not paired with a non-compatible steel-frame wall. Furthermore, the
data source for the construction, the applicable line-types for plan-drawing in the graphical user interface, typical thickness prior to and after retrofits, minimal and maximal possible thickness and the time period of practical use of this building construction were defined. The identified building part compositions were then analyzed toward the constructive functions of their different layers. Hereby, specifications toward format, material, function and position in assembly were defined for each layer. This step is necessary for the later finding of suitable real products for each particular layer from the building product ontology. The templates themselves only offer generic place holders for each layer. As an example, many building components feature a layer named “thermal insulation”. For a human planer with at least basic AEC domain knowledge and experience, it might be obvious, which materials and products are suitable at a certain position, however, for the machine, this information is not meaningful. Therefore, machine-readable properties for each layer need to be defined, to answer question such as “Is it allowed to use any given insulation mat at this position, or is it required to use a load-bearing, water-proof and water-vapor-resistant insulation board?”. To make this possible, the templates define certain requirements for each layer, which are used for query in the product ontology later. The templates do not provide any physical properties of the constructions or their layers, except the aforementioned data. Physical properties of building materials like conductivity, specific heat or vapor diffusion resistance are attached to the building products stored in the ontology. The suitability of a building product / building material to a layer of a certain construction is determined by four parameters: Main construction method of the construction, Function of the layer, Position of the layer and Format of the layer. Table 6 lists all possible states of these parameters. Table 7 (layer-wise data) and 8 (general data) illustrate a template of an external wall (AW002). Figure 41 illustrates the identification of building materials / building product categories for layer two of the same external wall.

(ii) While constructions of new buildings can be clearly defined via the templates, the refurbishment case is more complicated. As in retrofit cases existing building components have to be taken into consideration, and often there is no detailed information about the layer structures and components of such constructions, SEMERGY uses a versatile approach: On the one hand, data from resources dealing with building stock and heritage protection were taken into consideration to identify typical constructions of different periods. Unfortunately these resources regularly do not offer specific information on the construction’s overall thermal performance or the thermal properties of different layers. Thus, on the other hand, default values for the thermal properties of constructions were generated based on the OIB Guideline for calculation of energy certificates (OIB 2011b). A set of templates for each period’s typical construction were generated following this two approaches.

(iii) For the refurbishment cases potential, typical retrofit options for each “historical” template were defined. This is quite complex and was done manually, as there are more than one retrofit option per construction, and certain building elements (e.g. load bearing masonry) would not be “replaced” in typical retrofit cases. Both the “historical” and “retrofit” layer compositions were stored as template, so that for each historical template simply the possible refurbishment template IDs could be used for refurbishment suggestions. Figure 42 shows an example of retrofit templates as realized in SEMERGY.
**Table 6. Exhaustive list of possible states for the parameters Main Construction Method, Function, Position and Format.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
</table>
| Main construction method (construction) | MMB…Massiv Mauerwerk oder Beton (Massive, Masonry or Concrete)  
SSB…Skelett Stahl oder Beton (Steel or Concrete Frame)  
MH…Massiv Holz (Massive Wood)  
SH…Skelett Holz (Wood Frame) |
| Function (layer) | Sem_Aussenabschluss | A (Finishing Outside)  
Sem_BARRIERE_DAMPF | BD (Water Vapour Barrier)  
Sem_Daemmmung_Normal | D (Insulation – standard)  
Sem_Daemmmung_Feuchteunempfindlich | DFU (Insulation – non susceptible to moisture)  
Sem_Daemmmung_Innen | DI (Insulation – internal)  
Sem_Daemmmung_Mischbauweise | DM (Insulation – in composite construction)  
Sem_Daemmmung_Spezial | DS (Insulation – special)  
Sem_Daemmmung_Schluettung | DU (Insulation – granulate)  
Sem_Fuellstoff | F (Filling)  
Sem_Fenster | FE (Window)  
Sem_Rahmen | FR (Frame)  
Sem_Verglasung | FV (Glazing)  
Sem_Gas | G (Gas)  
Sem_Hinterlueftung | H (Ventilation Space)  
Sem_Innenabschluss | I (Finishing Inside)  
Sem_Luftschicht_stehend | LS (Enclosed Air)  
Sem_Massiv | M (Massive)  
Sem_Massiv_Aussenabschluss | MA (Massive + finishing outside)  
Sem_nicht_benutzt | O (Not in Use)  
Sem_Tuer | T (Door)  
Sem_Vegetationsschicht | V (Humus)  
Sem_Verschatzung | VS (Shading) |
| Position (layer) | Sem_Aussenwand_Normal (external wall)  
Sem_Aussenwand_Erde (external wall adjacent to ground)  
Sem_Innenwand (interior wall)  
Sem_Wohnungstrennwand (partition wall)  
Sem_Geschossdecke_normal (floor slab)  
Sem_Geschossdecke_Decke (floor slab – ceiling part)  
Sem_Geschossdecke_Boden (floor slab – floor assembly)  
Sem_Geschossdecke_Aussen (slab as flat roof)  
Sem_Geschossdecke_Erde (floor slab to ground)  
Sem_Dacht (roof) |
| Format (layer) | Formstabil…non deformable  
Einblasstoff…injection material  
Schuettung…fill (stones, sand)  
Schaum…Foam |

**Table 7. Layer-wise data table of the building construction template AW002 - Single-shell masonry walls, plastered on both sides (porous large-format stone).**

<table>
<thead>
<tr>
<th>No</th>
<th>Layername</th>
<th>Schicht für Optimierung</th>
<th>Ursprungsschicht</th>
<th>Ursprünglicher Aufbau laut Quelle</th>
<th>Thematisch relevant</th>
<th>Position</th>
<th>Format</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sem_Innenabschluss</td>
<td>N</td>
<td>Interior</td>
<td>Plaster</td>
<td>J</td>
<td>Sem_Aussenwand_Normal</td>
<td>Sem_NA</td>
<td>Innenputze</td>
</tr>
<tr>
<td>2</td>
<td>Sem_Massiv</td>
<td>J</td>
<td>Solid Masonry</td>
<td>J</td>
<td>Sem_Aussenwand_Normal</td>
<td>Sem_Formstabil</td>
<td>Ziegelmauerwerk, Natursteinmauerwerk, Betonmauerwerk</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Sem_Außenabschluss</td>
<td>N</td>
<td>Exterior</td>
<td>Plaster</td>
<td>J</td>
<td>Sem_Aussenwand_Normal</td>
<td>Sem_NA</td>
<td>Außenputze</td>
</tr>
</tbody>
</table>
Table 8. General data table of the building construction template AW002 - Single-shell masonry walls, plastered on both sides (porous large-format stone).

<table>
<thead>
<tr>
<th>AW002</th>
<th>Einschaliges Mauerwerk, beidseitig verputzt (poroischer großformatiger Stein)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Name_en</strong></td>
<td>Single-shell masonry walls, plastered on both sides (porous large-format stone)</td>
</tr>
<tr>
<td><strong>Quellen</strong></td>
<td>Handbuch &amp; Planungshilfe Baukonstruktion, S.42 Abb 7.; S.43 Abb 10.</td>
</tr>
<tr>
<td><strong>Konstruktion</strong></td>
<td>MMB</td>
</tr>
<tr>
<td><strong>Linientypen</strong></td>
<td>EXTERNALLOADBEARINGWALL; EXTERNALADIABATICWALL; EXTERNALBRACINGWALL</td>
</tr>
<tr>
<td><strong>Geeignet für</strong></td>
<td>Sanierung, Denkmalschutz</td>
</tr>
<tr>
<td><strong>Typical thickness before retrofit</strong></td>
<td>0.4</td>
</tr>
<tr>
<td><strong>Typical thickness after retrofit</strong></td>
<td>0.51</td>
</tr>
<tr>
<td><strong>Min d</strong></td>
<td>0.25</td>
</tr>
<tr>
<td><strong>Max d</strong></td>
<td>1.20</td>
</tr>
<tr>
<td><strong>Kosten</strong></td>
<td>39.34</td>
</tr>
<tr>
<td><strong>Ursprungsjahr</strong></td>
<td>0001</td>
</tr>
<tr>
<td><strong>Finaljahr</strong></td>
<td>9999</td>
</tr>
</tbody>
</table>

Layer-wise data is illustrated in table DDD.

Figure 41. Extraction of a candidate list of materials / building product categories for the load-bearing part of template AW002 out of the building product ontology.
Figure 42. Example of the retrofit options for one construction (exterior wall AW002): Either the construction is not considered in a retrofit attempt (A), or one or more layers are replaced (B), or an adjustment of / addition to the layer structure (C) is considered.
6.2. Semi-automated Building Part generation based on formal modelling concepts

In its current state, the SEMERGY environment is equipped with an adequate number of templates for commonly accepted building components. However, an approach based on hard-coded templates has certain limits: Special constructions cannot be evaluated or need to be added to the template database. Each new template requires a proof of functionality toward products and material combinations. Therefore, the SEMERGY team started to search for alternative concepts of building component generation based on existing materials and products.

The utilization of basic concepts of formal modeling languages, as used in computer science, seems to be a promising approach. Hereby, the concepts of finite-state machines and sequential logic seem to be versatile enough to be adopted for building component generation. To examine the possibilities of utilization of these concepts, a master’s thesis is currently conducted in the framework of the SEMERGY project (Master thesis of C. Sustr).

The main idea is to formalize the knowledge necessary to generate building components. This knowledge regularly includes specific knowledge about layers but also about the order of layers and the functions each layer has. Based on this formalization, a set of rules could be determined that determine how building parts should look like. A simplified example is illustrated in the Figure 43.

---

**Possible Functions of Building Component Layers**

- (a) Finishing Outside
- (b) Thermal Insulation
- (c) Water-Vapour-Banner
- (d) Load-Bearing
- (e) Finishing Inside

A/L/1 Layer that combines Finishing Outside, Load-Bearing and Finishing Inside (e.g. old one-layered brick walls)

L/1 Layer that combines Finishing Outside and Load-Bearing

L/1 Layer that combines Finishing Inside and Load-Bearing

L/D Layer that combines Insulation and Load-Bearing (e.g. wood-frame-constructions)

Set of all possible Layer functions: \{ (a), (b), (c), (d), (e), (a), (b), (c), (d), (e) \}

---

**Rules of Building Component Generation:**

Number of Layers: maximum number of Layers = 5

Layer-No 1 2 3 4 5

exterior \{ (a), (b), (c), (d), (e) \} interior

Layer functions that are definitely required: A, L, I

Rules concerning order and number of layer functions:

- The layer adjacent to exterior needs to show a function \( \lambda \). Layer-Function \( \lambda \) is only allowed adjacent to exterior
- The layer adjacent to interior needs to show a function \( L \). Layer-Function \( L \) is only allowed adjacent to interior
- If layer function \( L \) shares the layer position with layer function \( \lambda \), or Layer Function \( \lambda \) is closer to the interior than \( L \) without another function \( L \) even closer to interior, a Layer Function \( L \) needs to be positioned even closer to the interior. \( L \) is only allowed in such settings.
- Maximal two layers with functions \( L \) and \( \lambda \) are allowed, maximal one layer with functions \( \lambda \) and \( L \) is allowed.

---

**Resulting valid combinations**

1-layered: \{ (A/L/1) \}

2-layered: \{ (A/L/1), (A/L/2) \}

3-layered: \{ (A/L/1), (A/L/2), (L/1) \} \{ (A/L/1), (L/2), (L/1) \} \{ (A/L/2), (L/1) \} \{ (A/L/2), (L/2), (L/1) \} \{ (A/L/2), (L/1) \}

4-layered: \{ (A/L/1), (A/L/2), (L/1), (L/2) \} \{ (A/L/1), (L/1), (L/2), (L/2) \} \{ (A/L/1), (L/1), (L/2), (L/2) \} \{ (A/L/1), (L/1), (L/2), (L/2) \}

5-layered: \{ (A/L/1), (A/L/2), (L/1), (L/2), (L/3) \} \{ (A/L/1), (L/1), (L/2), (L/3) \} \{ (A/L/1), (L/1), (L/2), (L/3) \} \{ (A/L/1), (L/1), (L/2), (L/3) \} \{ (A/L/1), (L/1), (L/2), (L/3) \}

---

Figure 43. Simplified example of the generation of possible external wall layer combinations from an exhaustive layer-function alphabet and a set of rules.
7. SEMANTIC WEB & ONTOLOGIES

One of the main pillars the SEMERGY environment is built on is the implementation of semantic web technologies. This section, therefore, illustrates the efforts toward the utilization of these technologies within the AEC-context of SEMERGY. Note that the text of this section includes references to and excerpts from previously published conference papers about the SEMERY project (Shayeganfar et al. 2013, Mahdavi et al. 2012).
7.1. Background & General Approach

The semantic web can be understood as an advancement of the established World Wide Web. It aims to amend the existing web with a web of data, where machines are able to comprehend data in order to facilitate logical inferences (Berners-Lee et al. 2006). Berners-Lee et al. (2001) state ‘that the goal of the semantic web is to develop enabling standards and technologies designed to help machines understand more information on the web so that they support richer discovery, data integration, navigation, and automation of tasks.’ It has to be said that the majority of useful data is already published in the World Wide Web. Unfortunately this information is published in a way that is optimized for human users (presentation and styling) rather than for machine processing. Moreover, the information is not offered in a structured and linked way, but is scattered in many different data sources. John Markoff (NYT 2006) describes a web featuring the advances of the web 2.0 (including social networking, media sharing and other achievements) and the concepts of the semantic web as the third generation of the World Wide Web or ‘web 3.0’. Actually, three developments are considered as major steps forward toward the semantic web: (i) extensible markup language (XML), (ii) Resource Description Framework (RDF), and (iii) ontologies. XML is a simple, but flexible text format (W3C 2014a), that allows users to create standardized, hierarchical structures for their documents. RDF is considered as a standard model for definition of metadata on the World Wide Web (W3C 2014b) that defines the meaning or grammar between the elements within a structured document. Ontologies are a concept for a network between different kinds of data, illustrating their relationship to each other (W3C 2014c). Currently, they are considered as standard to model relationships of the semantic web. Figure 44 illustrates the proposed development of the World Wide Web, as envisioned by Radarnetworks (Radarnetworks 2007) based on the semantic web ideas.
The AEC branch of economy is composed of multiple knowledge domains. Thus the amount of data and different data sources is very large but fortunately a majority of data is available online: For instance, the building product industry offers elaborate descriptions of their products via web-sites or downloadable catalogues. Local authorities offer information about legal constraints towards building design and information about grantable subsidies. Unfortunately, the majority of this data is either trapped in customized data structures or locked in domain-specific databases. A human user can still access this data, but the required inspection of different sources makes the data acquisition very time-consuming. For machines, such data structures hinder efficient data processing.

To bridge the gap between required and available AEC data sets in the SEMERGY context, the following two-stepped approach seemed to be promising:

(I) Generation of compact and versatile ontologies that serve as shared standard vocabulary of AEC concepts.

(II) Mapping of the scattered existing information of different web-resources to the freshly generated ontologies.

A prototypical implementation of these two steps can be found in Shayeganfar 2008. In this work, transparent and translucent skylight elements were chosen as sample domain, and the interoperability between different stakeholders seeking information about skylights and the overall design implementation within the interests of architectural design, facility management and structural engineering was conceptually facilitated via semantic web technologies (Figures 45).

![Figure 45. Interoperability requirements concerning skylight (from Skydreamer – project, Shayeganfar 2008).](image)

The required conceptualisation for such AEC-ontologies and mapping routines is defined in general by the later purpose of the data and the structure of the data models that should be supplied with data. In the AEC-context, the object-oriented data models that have been established in the recent years in the framework of the Building Information Modelling (BIM) seemed to be suited as design guideline. In SEMERGY an original building representation scheme (the SEMERGY building model SBM) was developed based on the requirements of building performance evaluation. The approaches toward
semantic web technology implementation were adapted to this building model. However, the SBM offers capability of mapping data to other building representations; therefore the data ontologies developed within the SEMERGY framework should be adaptable as well.

The scattered information available in the World Wide Web can – with the described strategy – form a global data graph that connects distributed resources and facilitates the discovery of new resources. This approach is commonly referred to as “Linked Data” or “Linked Open Data” (LOD) in case of freely accessible and reusable data of the World Wide Web (Linkeddata 2011). Berners-Lee (2009) defined a five star quality score of shared LOD illustrated in table 9.

Table 9. Star-Score-Sheet for Linked Open Data (Berners-Lee 2009).

<table>
<thead>
<tr>
<th>Score</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>Available on the web (whatever format) but with an open licence, to be Open Data</td>
</tr>
<tr>
<td>-</td>
<td>Available as machine-readable structured data (e.g. xls instead of image scan of a table)</td>
</tr>
<tr>
<td>-</td>
<td>Like ⭐⭐ but in non-proprietary format (e.g. csv instead of xls)</td>
</tr>
<tr>
<td>-</td>
<td>⭐⭐⭐⭐ plus: Use open standards from W3C (RDF and SPARQL) to identify things, so that people can point at your stuff</td>
</tr>
<tr>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐ plus: Link your data to other people’s data to provide context</td>
</tr>
</tbody>
</table>
7.2. Proof of Concepts & Current Implementation in the SEMERGY environment

To test the concept of semantic data acquisition in the framework of the SEMERGY project, the different kinds of data were examined toward their priority for the project’s success. As a major part of the SEMERGY environment focuses on building performance evaluation based on building material / building product properties, this part of the AEC-branch was chosen for a first implementation. However, the data acquisition of other important information in this context (e.g. a structured and hierarchical representation of different subsidy and tax incentives) is not of minor relevance and intended for future implementation. Another reason for the prioritisation of the building products data acquisition is that vast data repositories in this specific field are necessary for other parts of the project, e.g. the alternative generation via templates and the optimization efforts. For a first implementation, the different existing conventional data repositories of building product data in the World Wide Web were examined. These include


(ii) Websites of professional representatives of single branches of the building product industry. The examined included the representatives of the insulation (GDI 2014) and brick producers (Ziegel 2014).

(iii) Web portals offering general information around building processes and products. These include portals like baubook (Baubook 2014) and the MASEA database (Masea 2014)

The producers regularly offer information about their products in a vast and rather detailed extent on their websites. But these are clearly meant for human costumers. Generally, the product data is summed up in pdf-document, available for download. Technically, the extraction of data from not specially protected pdf-documents to ontologies could be performed without larger obstacles. Tools such as the pdf-parser (Stevens 2008) utilize methods such as key-word search for extraction of information. However, as different producers tend to arrange their information differently in terms of content, arrangement and resolution, it would be necessary to develop parsing routines manually for every producer. Figure 46 illustrates this problem with depicting the pdf-building product information offered by two producers of bricks for a rather similar product (50cm brick).
Figure 46. Different schemes of Building Product Information of a 50cm brick product as offered by the producers Wienerberger (left) and Eder Ziegel (right).

The websites of professional representatives of different product branches offer only general information about the producers (e.g. product capacities and production location). The latter information could be useful in the further development of a decision support system in the AEC-branch, as it could help, for instance, to minimize the transportation of products to sites. However, this information does not facilitate the evaluation of design alternatives.

Web-Portals, like BauBook and MASEA, offer very useful data about different products, product categories, and product properties in a standardized form. Therefore, these portals seem to be a good starting point for semantic data incentives in the AEC-branch. The BauBook is a web-based data repository focusing on sustainable building and features aside from constructive information about highly-insulated building components a comprehensive database of building materials including their major physical properties. Building product manufacturers can define their products, which will be evaluated and classified according to their physical attributes such as conductivity, specific heat, density, etc. The MASEA database (“Materialdatensammlung für die energetische Altbausanierung”) is an offspring of a research project from Fraunhofer Institute, and features building materials from historic buildings including their physical properties.

Baubook (Figure 47) was chosen as the main resource for building products and materials for the initial SEMERGY prototype. In order to semanticfy the data from Baubook, the building product
categorization was adopted and formatted to act as main building product data hierarchy within SEMERGY. Hereby, a customized RDFizer component (Klyne 2004) reads the BauBook categories and converts them to the RDF-hierarchy. Figure 48 illustrates a part of this converted class hierarchy.

Figure 47. The Baubook building products database (Baubook 2014).

Figure 48. Class hierarchy in the building product ontology of SEMERGY, based on the BauBook categories.
After adopting the structure, products that are stored in BauBook are extracted and converted to the RDF format via a dedicated page parser. Hereby, the products are enriched with additional properties. These properties are either manually added (if no other source is available), are added through the linking with other data sources, or are derived from existing properties. The latter is done to reduce the computational efforts in later calculation and optimization efforts. An example for such an derived value is the R value (thermal resistance) calculated as quotient of thickness and conductivity. This value is used in U-Value calculations (compare compliance checking routines of section 8). The relation between the data source (BauBook) and its representation in the ontology is kept via the the `owl:sameAs`-Axiom, which keeps the URL (Uniform Resource Locator) of the original element. Figure SEM illustrates the semantic building product description by means of an example (acoustic panel).

To enable SEMERGY’s alternative generation and optimization efforts to put the correct element in the correct position within a building component assembly, a number of attributes are added to each product. These attributes correspond with the parameters Main Construction Method, Function, Position and Format as described in the section about templates and alternative generation chapter. These attributes ensure that for instance a gypsum board is not used as external finishing of a construction. These properties establish a class hierarchy in the SEMERGY.

It is important to note, that the building product ontology utilizes concepts such as inheriting and multi-class-affiliation of building products. The incorporation of these concepts renders it a flexible and extendable structure, fitting to the requirements of the SEMERGY use-cases. Note, that each class determines one default product out of its instances, to facilitate the population of the SEMERGY building model for the initial design. The procedure of selection of a default product is described in the subsequent section.

To be able to query the building product ontology and to populate the required classes of the SEMERGY building model, the semantic interface is able to translate design constraints and requirements to SPARQL-queries (SPARQL 2013) and offers mapping routines to map the queried data to the SBM. The SPARQL queries are composed dynamically from stored query components. An example for such an SPARQL-query is shown in listing 01.

Listing 01. SPARQL query for building products.

```
SELECT ?name ?conductivity ?thickness
WHERE {
  ?product a semergy:WoodConcreteWallElement.
  FILTER (?thickness < 30) .
  FILTER (?conductivity < 0.5)
}
```
7.3. Ontology-based default Product Selection based on the categories of Materials

At the current state, SEMERGY uses one real product that represents instances of all products in the corresponding category as "default product". These categories were implemented within the building product ontologies, to store similar products and their properties in a structured way. For selection of this real product, the following approach was chosen:

(i) Evaluation of the distribution of the GWP (Global Warming Potential), AP (Acidification Potential), PEC (Primary Energy Content), λ (thermal conductivity) and MC (Material Cost) values of the whole dataset within one category. Elimination of outliers (Outliers hereby are defined as individual items lying above the 95% percentile or below the 5% percentile in one or more of the mentioned values)

(ii) Calculation of the average values for GWP, AP, PEI, Lambda, MC of each category (including all n individuals of a category except the outliers), as illustrated in equation 1.

\[
\begin{align*}
GWP_{avg} &= \frac{\sum_{i=1}^{n} GWP_i}{n}; AP_{avg} = \frac{\sum_{i=1}^{n} AP_i}{n}; PEC_{avg} = \frac{\sum_{i=1}^{n} PEC_i}{n}; \lambda_{avg} = \frac{\sum_{i=1}^{n} \lambda_i}{n}; MC_{avg} = \frac{\sum_{i=1}^{n} MC_i}{n}
\end{align*}
\]

\(GWP_{avg}\) …average Global Warming Potential [\(\text{[-]}\)]
\(GWP_i\) …Global Warming Potential of product \(i\) [\(\text{[-]}\)]
\(AP_{avg}\) …average Acidification Potential [\(\text{[-]}\)]
\(AP_i\) …Acidification of product \(i\) [\(\text{[-]}\)]
\(PEC_{avg}\) …average Primary Energy Content [\(\text{[-]}\)]
\(PEC_i\) …Primary Energy Content of product \(i\) [\(\text{[-]}\)]
\(\lambda_{avg}\) …average conductivity \([\text{W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}]\)
\(\lambda_i\) …conductivity of product \(i\) \([\text{W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}]\)
\(MC_{avg}\) …average Material Cost [\(\text{€}\)]
\(MC_i\) …Material Cost of product \(i\) [\(\text{€}\)]
\(n\) …number of elements in one category

(iii) Calculation of a relative deviation from the average for each individual \(j\). The resulting value, named \(\Delta_j\), is the weighted deviation from the average values of a category. The individual with the lowest value for Delta is chosen as the representative. The calculation is conducted based on equation 2

\[
\Delta_j = \frac{33.5 \frac{\lambda_{avg} - \lambda_i}{\lambda_{avg}} + 33.5 \frac{MC_{avg} - MC_i}{MC_{avg}} + 11 \frac{PEC_{avg} - PEC_i}{PEC_{avg}} + 11 \frac{AP_{avg} - AP_i}{AP_{avg}} + 11 \frac{GWP_{avg} - GWP_i}{GWP_{avg}}}{100}
\]

\(\Delta_j\) …relative deviation of element \(j\)
8. CALCULATION & SIMULATION MODULES
8.1. Introduction

The major idea of the SEMERGY environment was to offer decision support and optimization for energy-efficient and environment-friendly building design and retrofit. To facilitate this service, SEMERGY requires a toolbox of different methods and software for building performance evaluation. SEMERGY’s general structure was designed to be modular, and therefore is flexible enough to offer possibilities of implementing different performance assessment modules. In the design phase of SEMERGY, different computational methods were examined in view of three aspects of consequence in the SEMERGY environment:

(i) **Usefulness**: This refers to the possibility of deriving useful results from a certain tool. Specifically, results of evaluation engines should be useful in a building optimization process in the area of building performance. As an optimum, these methods should deliver results that can be expressed as single-value key performance indicators (KPIs). Such benchmark values quantify the performance of the building (or of one or multiple zones or components of the building). Such methods and their corresponding KPIs can be used in mathematical optimization approaches with ease.

(ii) **Required Input data**: This examination step is necessary to determine the data required for conducting different calculations and evaluations. This includes not only the nature of the input data, but also the format and resolution of the data. For instance, different thermal building performance tools require different resolutions in view of time steps of the climate data, the occupancy patterns or the internal conditions control settings necessary for conducting computations. While annual methods need averaged or summarized values for an entire year, the number of values increases by a factor of 12 for a monthly evaluation and a factor of 8760 for hourly evaluations.

(iii) **Technical and organizational Aspects**: Some methods – for instance the simple annual method for heating demand (published as spreadsheet and described in detail in different governmental documents) – are well documented and comprehensible, and more or less openly accessible. Such methods can be attached to the SEMERGY environment with ease. Unfortunately, concerning other methods and tools, an implementation is often hampered due to technical or organizational issues.

Technical issues, for instance, include the fact that many tools do not offer comprehensive data import/export functionalities, so that an input data/output data transfer from or to the SEMERGY environment is not seamlessly possible, or possible only to a very limited extent. Even if data exchange is possible in a sufficient and satisfying way, many tools regularly cannot be utilized for repetitive, semiautomatic simulation as required in an optimization process. Therefore, their utilization for optimization attempts is limited. Dynamic simulation tools, in particular, face another potential issue toward their implementation in optimization attempts: Due to the complexity of the underlying mathematical and physical models, simulations regularly take longer than simple
normative procedures. Despite the rapid development of the information and communication technologies, this fact still renders the utilization of simulation tools for a great number of iterative optimization runs in a web-based environment infeasible. Therefore, current technical developments in the areas of parallel computing and co-simulation need to be explored toward their capability of overcoming this obstacle.

Not only technical issues can hamper the utilization of methods in the SEMERGY environment: Concerning the actual implementation of energy certification in Austria it has to be stated that the numerous underlying national and international standards as well as governmental guidelines are constantly undergoing rapid and continuous development and modification. It is a challenging task to keep an overview of the current state and the future developments. This implies that the inclusion of the energy certificate method in the SEMERGY environment has to be carefully prepared.

It is important to state that the SEMERGY project as such was not aimed towards development of new computational engines or reengineering of existing tools for assessment of various aspects of building performance. Rather, the approach envisages the SEMERGY as a core component of a flexible and extensible environment, capable of utilizing different existing tools for evaluation of energy, environmental and financial performance of buildings. The current state of the SEMERGY environment implements three calculation methods that were (re)written as JAVA-programs as part of the SEMERGY environment to allow quick assessment: The annual heating demand calculation, the OI3-indicator calculation, and a cost-estimation method based on material cost (MC), labor cost (LC) and general cost (GC). Calculation and simulation methods in the architecture of the SEMERGY environment can be structured in three categories:

(i) **Third party tools (commercial or open source):** These can be coupled with the SEMERGY environment and could include energy certification tools (Archiphsik, GEQ, etc.) and dynamic thermal simulation applications (for instance DoE Energy Plus). Further applications in this area could include tools for assessment of active solar systems (proposed tool: Polysun, Velasolaris 2014), artificial and natural lighting (proposed tool: DIALUX) and thermal bridges evaluation (proposed tool: AnTherm).

(ii) **In-house programmed evaluation engines based on standard methods:** Such calculation and simulation methods are based on standards and/or general AEC-domain knowledge. The integration via in-house programming can have different reasons. These are illustrated by means of the three evaluation tools available in the current state of SEMERGY: The annual heating demand method was included in the SEMERGY environment as java-programmed calculation module, although a spreadsheet-based tool is available, due to performance reasons (computational speed). For the same reason, the calculation for the OI3-Value was engineered in Java, based on the documentation of this KPI (IBO 2006, IBO 2011, IBO 2013a). The cost accounting approach was as well implemented as an in-house program, as none of the commercial available products was appropriate for the purposes of SEMERGY.
(iii) **Compliance Check routines in the SEMERGY kernel:** Compliance check routines are implemented in the SEMERGY environment for two reasons: First, to ensure that suggested building components are compliant to legal requirements and general state of the art in building construction. Secondly, the elimination of non-compliant building components will reduce the solution space for the optimization attempts and therefore help keeping algorithmic cost on an acceptable level. The second reason also denotes that compliance checking routines are located in the SEMERGY kernel rather than as calculation modules. The current state of SEMERGY includes two compliance checking routines addressing building components regarding their U-Values and the avoidance of condensation.

Figure 49 shows the scopes of the three categories: While (i) and (ii) are coupled to the SEMERGY environment via the reasoning interface, (iii) is considered as part of the SEMERGY kernel. All of the described calculation and simulation methods require information retrievable by the Semantic Data Interface.

The following section briefly describes important general aspects of energy related KPIs and calculation schemes that need to be taken into consideration in view of integration in a decision support and optimization environment. Next, the calculation methods currently implemented in SEMERGY are described in detail. Subsequently, further methods and calculation schemes are described that are currently intended to be coupled with the SEMERGY environment. Proposed future evaluation tools examined for the implementation in the SEMERGY environment are described in the section Future Development of this Dissertation. Note that the descriptions of the calculation methods need to be seen in the context of the semantic web and ontologies, the SEMERGY building model and the optimization efforts addressed by the SEMERGY environment.
8.2. Aspects toward integration of energy related KPIs into the SEMERGY environment

SEMERGY should offer easy to use energy related building performance evaluation for users with little experience in the AEC-field. It should also integrate complex simulation tools for advanced examination of building and retrofit strategies. The latter is of interest to professionals in the building and planning sector. Users of SEMERGY are assumed to be interested in the derivation of values of Key Performance Indicators. Although users might have different technical backgrounds, the nature of their inquiries is the same. One Key Performance Indicator that is important in building design is the heating demand. This demand depicts the amount of (thermal) energy necessary to maintain comfortable indoor conditions inside a zone or building (in the cold season). There are different approaches for the assessment of heating demand of a proposed design. These approaches vary in underlying model assumptions and complexity, but are similar in that they simplify reality in terms of a calculation or simulation model. However, it should not be expected that different calculation methods lead to the same result. The author examined the results of heating demand calculations performed with two normative procedures and one dynamic thermal simulation in a previous study (Pont 2011). Despite use of the same initial assumptions (aside from adaptations in resolution of some input data such as the climate data), results showed significant deviations. The deviations have their origin potentially in the level of detail of the different interim results. For instance, the normative approaches do not consider the building materials heat storage capacity in detail, but just approximate it. This is an important fact, also with respect to the meaningfulness of the results of SEMERGY. The calculation procedure for heating demand implemented in the current state of SEMERGY is an annual calculation method, incorporating a number of major simplifications. For instance, ventilation and internal gains are considered constant for the whole year, representing the behavior of a virtual normative building user for the calculation.

Therefore, users of the SEMERGY environment with little to no experience in the field of building performance modeling need to be informed that the results of their building or retrofit design evaluations can be used for comparison of different design variations, but not necessarily depict their real heating demand. Housez et al. (2014) compared projected and actual energy performance of buildings after thermal retrofit measures. They found in a sample of seven thermal retrofit projects that the measured post-occupancy performance concerning energy demand for heating was in six out of the seven observed projects significantly larger than the projected energy demand targeted in the planning. To find an explanation, different monitoring and calculation attempts were conducted, and it turned out that effect of user behavior with regard to ventilation could provide a plausible explanation for the large gap between planned and measured energy demand.

The currently in SEMERGY implemented annual method does not comply with the International and European Standard 13790 (ISO 2008). The major reason for its implementation was to have a robust calculation engine for the SEMERGY proof of concept. Current efforts target the implementation of the current Austrian energy certificate method and, furthermore, the PHPP-method, developed by the Passivhaus Institut of Darmstadt, Germany (PHPP, 2014). Figure 50 illustrates the standing of the
different methods intended for implementation in SEMERGY in view of the mentioned European standard.

The implementation of the Austrian Energy Certificate calculation method is a process currently happening within the SEMERGY project. The idea behind is that users, after utilizing SEMERGY for their optimization purposes, can reuse both the generated building model and the conducted calculations for deriving an energy certificate. This is considered useful, as most building owners are required to issue energy certificates for their buildings both by the EPBD (2002, 2010) and the Austrian law concerning energy certificates (EAVG 2006, 2012). Energy certificates have to be issued for new constructions, building undergoing major retrofits, and buildings and flats offered for rent or sale on the real estate market. Note that the current Energy Certificate procedure does not only incorporate a heating demand calculation, but additional calculations addressing primary energy demand and CO2-emissions based on the building equipment and appliances.

Recent studies, however, illustrated that the results of energy certificates should be – even if only used for comparison of buildings – evaluated with caution: Pont et al. (2011) illustrated that unclear input assumptions can result in large deviations in the results of energy certificate calculations. This is especially meaningful, if calculations are performed in an early design phase, where certain decisions (such as “Will the basement rooms be heated or used as unheated food storage rooms?”) are not yet taken. Moreover, Kaiser (2009) proofed that from a sample of 20 energy certificates of Austrian buildings more than 50% showed errors in their provided input data. These errors resulted in
significant deviation of the resulting KPIs, up to 100% different from the results of an energy certificate of the same building, but calculated with correct input data.
8.3. Simple annual calculation method for heating demand

The heating demand – energy necessary to provide comfortable conditions in spaces in the cold season – is considered to be one of the Key Performance Indicators (KPI) for the energetic and thermal performance of buildings in regions with temperate climates, such as central Europe. To provide a fast and easy calculation engine for estimation of the value of this indicator, a simple annual heating demand calculation method (Demacek 1999) was implemented in SEMERGY. The method was originally published as a spreadsheet with embedded formulas. Figure 51 illustrates a typical result sheet out of this spreadsheet. This method was used in Austria for building energy certification between 1999 and 2007. Because of its incompatibility with international / European requirements for energy certification (EN 13790) and limitations in validity, it was later replaced by a monthly method. However, due to its robust and easy-to-understand structure, it was considered as a feasible first calculation module for the SEMERGY environment. Additionally, the structure of the necessary input data is widely compliant to the requirements of the current energy certification method in Austria. Therefore, an adaption toward implementation of the current state of energy certification routines does not require major changes in the SEMERGY environment.

The annual method is based on the general heat balance equation (equation 3). The heating demand \( Q_H \) is expressed as balance between heat losses (through transmission \( Q_T \) and ventilation \( Q_V \)) and heat gains (through insolation \( Q_S \) and use of building \( Q_i \)). Gains are reduced by a factor of safety \( \eta \). This factor is – in this calculation scheme – dependent on the weight of the building construction’s components. This is a simplified representation of the higher specific heat capacity of massive
materials and their capacity to store heat gains in the construction. Table 10 states different values for $\eta$.

$$Q_H = (Q_T + Q_V) - \eta \cdot (Q_i + Q_S)$$

\begin{align*}
Q_H & \text{... Heating Demand [kWh.a$^{-1}$]} \\
Q_T & \text{... Transmission Losses [kWh.a$^{-1}$]} \\
Q_V & \text{... Ventilation Losses [kWh.a$^{-1}$]} \\
Q_i & \text{... Internal Gains [kWh.a$^{-1}$]} \\
Q_S & \text{... Solar Gains [kWh.a$^{-1}$]} \\
\eta & \text{... factor of safety [-]}
\end{align*}

Table 10. Values for the factor of safety in the general heat balance (Demacek 1999).

<table>
<thead>
<tr>
<th>Construction</th>
<th>$\eta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy</td>
<td>1</td>
</tr>
<tr>
<td>Middle</td>
<td>0,98</td>
</tr>
<tr>
<td>Lightweight</td>
<td>0,9</td>
</tr>
</tbody>
</table>

In this calculation scheme the constituting parameters ($Q_T$, $Q_V$, $Q_S$, $Q_i$) are calculated based on simple equations. Equations 2 - 8 show the formulas for derivation of these parameters, as implemented in the annual heating demand calculation module of the SEMERGY environment. The Transmission losses (equation 4) take into consideration the heating degree days for consideration of the site’s climate, and the conductance of the different building components and due to linear and point thermal bridges (equation 5). While the conductance for building elements adjacent to outdoor air, to unheated spaces and to ground is the product of U-Value and Gross Area of the corresponding element and a temperature proportionality factor (equation 6). Table 11 offers an overview about the temperature proportionality factors. The thermal bridges are calculated via an approximation formula (equation 7).

$$Q_T = 0,024 \cdot L_T \cdot HGT$$

$$L_x = L_e + L_u + L_g + L_v + L_Z$$

$$L_e + L_u + L_g = \sum_{i=1}^{a} f_i \cdot U_i \cdot A_i$$

$$L_v + L_Z = 0,2 \left( 0,75 - \frac{L_e + L_u + L_g}{A_B} \right) \left( L_e + L_u + L_g \right)$$

\begin{align*}
Q_T & \text{... Transmission Losses [kWh.a$^{-1}$]} \\
L_x & \text{... Conductance of the zone envelope [W.K$^{-1}$]} \\
HGT & \text{... Heating Degree Days [K$\cdot$d]} \\
L_e & \text{... Conductance of elements adjacent to outdoor air [W.K$^{-1}$]} \\
L_u & \text{... Conductance of elements adjacent to unheated zones [W.K$^{-1}$]}
\end{align*}
\[ L_s \ldots \text{Conductance of elements adjacent to ground [W} \cdot \text{K}^{-1}] \]
\[ L_w \ldots \text{Conductance of linear thermal bridges [W} \cdot \text{K}^{-1}] \]
\[ L_z \ldots \text{Conductance of point-like thermal bridges [W} \cdot \text{K}^{-1}] \]
\[ f \ldots \text{Proportionality temperature factor} \]
\[ U_i \ldots \text{U-Value element } i \ [\text{W} \cdot \text{m}^{-2} \cdot \text{K}] \]
\[ A_i \ldots \text{Gross Area of element } i \ [\text{m}^2] \]

Table 11. Temperature proportionality factor (OENORM 2011b).

<table>
<thead>
<tr>
<th>Components adjacent to</th>
<th>( f )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outdoor air</td>
<td>1</td>
</tr>
<tr>
<td>Unheated spaces</td>
<td>0.5–0.9</td>
</tr>
<tr>
<td>ground</td>
<td>0.5–0.6</td>
</tr>
</tbody>
</table>

The Ventilation loss calculation takes into account the ventilated net zone volume, the air change rate, the Heating Degree days and density and specific heat of the air (equation 8).

\[ Q_v = 0.024 \cdot \rho_a \cdot c_a \cdot n \cdot V_n \cdot HGT \approx 0.024 \cdot 0.33 \cdot n \cdot V_n \cdot HGT \quad (8) \]

- \( Q_v \ldots \text{Ventilation Losses [kWh} \cdot \text{a}^{-1}] \)
- \( \rho_a \ldots \text{Density of Air [kg} \cdot \text{m}^{-3}] \)
- \( c_a \ldots \text{Specific heat capacity of Air [J} \cdot \text{kg}^{-1} \cdot \text{K}] \)
- \( n \ldots \text{air change rate [h}^{-1}] \)
- \( V_n \ldots \text{Ventilated net zone volume [m}^3\text{]} \)
- \( HGT \ldots \text{Heating Degree Days [K} \cdot \text{d}] \)

The solar gains calculation requires incident solar radiation sums of different orientations, the glazing area of the heated zones, and two factors to include the shading effect and the transmission property of the glazing and pollution of its surfaces. Note that in the original version of this calculation scheme as published in the original excel sheet only the cardinal orientations plus the horizontal orientation were considered. This means, that all transparent building components with solar gains needed to be collated to one of the major orientations (equation 9).

\[ Q_S = \sum_{j=\text{hor,N,S,W,E}} I_j \cdot A_{g,j} \cdot f_s,j \cdot g_{w,j} \quad (9) \]

- \( Q_S \ldots \text{Solar gains [kWh} \cdot \text{a}^{-1}] \)
- \( j \ldots \text{Orientation (horizontal, north, south, west, east)} \)
- \( I_j \ldots \text{incident solar radiation [kWh} \cdot \text{m}^{-2} \cdot \text{a}^{-1}] \)
- \( A_{g,j} \ldots \text{Area of glazing [m}^2\text{]} \)
- \( f_s,j \ldots \text{reduction factor for shading [-]} \)
- \( g_{w,j} \ldots \text{fraction of transmitted solar radiation [-]} \)

The internal gain calculation simply includes a heat emission rate and the gross area, as well as the heating days as information about the site’s climate (equation 10).
\[ Q_j = 0.024 \cdot q_j \cdot BGF_B \cdot HD \]  

\[ \begin{align*} 
Q_j & \quad \text{internal gains} \quad \text{[kWh.a}^{-1}] \\
q_j & \quad \text{heat emission rate} \quad \text{[W.m}^{-2}] \\
BGF_B & \quad \text{gross area of zone} \quad \text{[m}^2] \\
HD & \quad \text{Heating Days} \quad \text{[d]} 
\end{align*} \]

To utilize this calculation scheme for comparison of different building designs, the derived heating demand \( Q_H \) is normalized on to 1 m\(^2\). This normalized heating demand is used in the current state of optimization in the SEMERGY environment and is referred to as HWB (abbreviation for the german expression “Heizwärmebedarf” meaning heating demand). Equation 11 illustrates this calculation.

\[ HWB = \frac{Q_H}{BGF_B} \]  

\[ \begin{align*} 
HWB & \quad \text{normalized heating demand} \quad \text{[kWh.m}^2.a}^{-1}] \\
Q_H & \quad \text{heating demand} \quad \text{[kWh.a}^{-1}] \\
BGF_B & \quad \text{gross area of zone} \quad \text{[m}^2] 
\end{align*} \]

To illustrate the data origin of the information used in this calculation approach, Table 12 offers an overview of the data-related collaboration of the user interface/user input, the SEMERGY data model and the data ontology of building materials and products.
Table 12. Input data overview for simple annual heating demand calculation (SBM... SEMERGY Building Model, BPO... Building Product Ontology).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Name</th>
<th>Heat Transfer Type</th>
<th>Data storage</th>
<th>Data origin</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>U&lt;sub&gt;i&lt;/sub&gt;</td>
<td>U-Value of element i</td>
<td>Q&lt;sub&gt;T&lt;/sub&gt;</td>
<td>SBM/BPO</td>
<td>BPO</td>
<td>The U-Value of elements is calculated within the SEMERGY kernel based on the templates, interaction rules of components, and user preferences</td>
</tr>
<tr>
<td>A&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Gross Area of element i</td>
<td>Q&lt;sub&gt;T&lt;/sub&gt;</td>
<td>SBM</td>
<td>GUI/Import</td>
<td>The gross area values of the different building components are defined by the user via GUI or geometry data import. In the GUI Semergy automatically derives all areas from the user’s drawing.</td>
</tr>
<tr>
<td>f&lt;sub&gt;i&lt;/sub&gt;</td>
<td>temperature proportionality factor for element i</td>
<td>Q&lt;sub&gt;T&lt;/sub&gt;</td>
<td>SBM</td>
<td>GUI/Import/Reasoning Interface/Calculation Method</td>
<td>Based on the user’s drawing, SEMERGY automatically detects the adjacency relations of the different zones and sets the f-values for the calculation. The catalogue of different f-values is defined by the calculation method’s documentation (therefore coming from the reasoning interface)</td>
</tr>
<tr>
<td>HGT</td>
<td>Heating Degree Days</td>
<td>Q&lt;sub&gt;i&lt;/sub&gt;, Q&lt;sub&gt;v&lt;/sub&gt;, Q&lt;sub&gt;v&lt;/sub&gt;</td>
<td>SBM</td>
<td>User defined location/Semantic Interface</td>
<td>The user specifies the location – in this calculation method via postal code. From the semantic interface the climate data is retrieved and formatted in the required solution.</td>
</tr>
<tr>
<td>n</td>
<td>Air change rate</td>
<td>Q&lt;sub&gt;v&lt;/sub&gt;</td>
<td>SBM</td>
<td>GUI/Reasoning Interface/Calculation Method</td>
<td>The air change rate is automatically set based on the user’s data input concerning the usage of the different zones.</td>
</tr>
<tr>
<td>V&lt;sub&gt;n&lt;/sub&gt;</td>
<td>Net volume of Zone</td>
<td>Q&lt;sub&gt;v&lt;/sub&gt;</td>
<td>SBM</td>
<td>GUI/Import</td>
<td>The net volume is determined by the user’s input</td>
</tr>
<tr>
<td>j</td>
<td>Orientation of (transparent) building elements</td>
<td>Q&lt;sub&gt;S&lt;/sub&gt;</td>
<td>SBM</td>
<td>GUI/Import</td>
<td>The orientations of all building elements is automatically determined from the user’s input via GUI or import.</td>
</tr>
<tr>
<td>A&lt;sub&gt;gj&lt;/sub&gt;</td>
<td>Area of transparent elements to orientation j</td>
<td>Q&lt;sub&gt;S&lt;/sub&gt;</td>
<td>SBM</td>
<td>GUI/Import</td>
<td>The gross area values of the different transparent elements are defined by the user via GUI or geometry data import.</td>
</tr>
<tr>
<td>f&lt;sub&gt;s&lt;/sub&gt;</td>
<td>Reduction factor for shading</td>
<td>Q&lt;sub&gt;S&lt;/sub&gt;</td>
<td>SBM/BPO</td>
<td>User specification/GUI/Import</td>
<td>The classification if a transparent element is penetrated by direct sun or experiences partly or full shading needs to be determined by the user, unless SEMERGY is provided with additional site information.</td>
</tr>
<tr>
<td>g&lt;sub&gt;wa&lt;/sub&gt;</td>
<td>Fraction of transmitted solar radiation</td>
<td>Q&lt;sub&gt;S&lt;/sub&gt;</td>
<td>SBM/BPO</td>
<td>BPO</td>
<td>This variable is determined by the properties of window/glazing products from the SBM.</td>
</tr>
<tr>
<td>q&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Heat emission rate</td>
<td>Q&lt;sub&gt;i&lt;/sub&gt;</td>
<td>SBM</td>
<td>User specification/Reasoning Interface/Calculation Method</td>
<td>The heat emission rate is a function of a zone’s usage in this approach, therefore its indirectly specified by the user via the zone’s usage.</td>
</tr>
<tr>
<td>BGF&lt;sub&gt;s&lt;/sub&gt;</td>
<td>Gross area of zone</td>
<td>Q&lt;sub&gt;v&lt;/sub&gt;, HWB</td>
<td>SBM</td>
<td>GUI/Import</td>
<td>The gross area is determined by the user’s input</td>
</tr>
<tr>
<td>HD</td>
<td>Heating Days</td>
<td>Q&lt;sub&gt;i&lt;/sub&gt;</td>
<td>SBM</td>
<td>User defined location/Semantic Interface</td>
<td>The user specifies the location – in this calculation method via postal code. From the semantic interface the climate data is retrieved and formatted in the required solution.</td>
</tr>
</tbody>
</table>
The climate data set for this calculation method includes heating degree days (HGT), heating days (HD) and incident solar radiation for the cardinal orientations. The selection of the building site climate is done via the postal code. Table 13 shows a sample of the climate data as delivered with the original excel sheet tool. However, the SBM offers place holders for weather data in different resolutions (annual, monthly and hourly). Therefore, the climate data could – following the initial idea of SEMERGY – be obtained from the World Wide Web and – if necessary – converted to the right format. Pont (2011) discusses the corresponding algorithms.

Table 13. Excerpt of the original climate data catalogue for the annual heating demand calculation (Demacek 1999).

<table>
<thead>
<tr>
<th>Postal Code</th>
<th>Locations Name</th>
<th>HGT$_{12/20}$</th>
<th>HD$_{12}$</th>
<th>$I_S$</th>
<th>$I_{OW}$</th>
<th>$I_N$</th>
<th>$I_{Hor}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>[K.d.a$^{-1}$]</td>
<td>[d]</td>
<td>[kWh.m$^{-2}$.a$^{-1}$]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1010</td>
<td>Wien – innere Stadt</td>
<td>3319</td>
<td>204</td>
<td>351</td>
<td>211</td>
<td>144</td>
<td>357</td>
</tr>
</tbody>
</table>
8.4. Calculation of environmental indicators for buildings based on the OI3-Indicator

In the current state of SEMERGY, alongside the heating demand and cost evaluation, the environmental impact of proposed building materials and products is assessed and used as an objective function in optimization efforts. For this purpose, the calculation scheme of a simple, but well-established indicator was used: The OI3-Indicator (IBO 2006, IBO 2011, IBO 2013a). This indicator considers the Global Warming Potential (GWP), the Acidification Potential (AP) and the Primary Energy Content of nonrenewable sources (PEC) of used building materials and products. All of these parameters are expressed in point scales (the lower the better) based on linear functions. For GWP the corresponding linear function takes into consideration the emission of Green House gases in CO₂ equivalents in kg.m⁻² caused by the material’s production (OI_GWP), for AP the linear function takes into consideration the emission of SO₂ equivalents in kg.m⁻² (OI_AP), for PEC the linear function considers the overall consumption of energy resources required to manufacture a product in MJ.m⁻² (OI_PECnr). These linear functions are illustrated in Figure 52.

Figure 52. Linear functions for derivation of OI_PECnr, OI_GWP, and OI_AP (based on IBO 2011).
Actually, the OI3-method offers two base indicators:

- Environmental indicator $OI_{3_{Kon}}$ for one square meter of a structure or building material. This indicator is calculated via equation 12.

$$OI_{3_{Kon}} = \frac{1}{3} \cdot OI_{PECnr} + \frac{1}{3} \cdot OI_{GWP} + \frac{1}{3} \cdot OI_{AP}$$

Equation 13, 14 and 15 illustrate the linear functions used for derivation of the different parameters.

$$OI_{PECnr} = \frac{1}{10} \cdot (x - 500)$$

$$OI_{GWP} = \frac{1}{2} \cdot (x + 50)$$

$$OI_{AP} = \frac{100}{0,25} \cdot (x - 0,21)$$

- Environmental indicator $\Delta OI3$ for one layer of building material, as illustrated in equation 16.

$$\Delta OI3_{BS} = \frac{1}{3} \cdot \left[ \frac{1}{10} \cdot (PECnr)_{BS} + \frac{1}{2} \cdot (GWP)_{BS} + \frac{100}{0,25} \cdot (AP)_{BS} \right]$$

Equation 13, 14 and 15 illustrate the linear functions used for derivation of the different parameters.
The Calculation engine for environmental indicators within the SEMERGY environment does use both of the two base indicators. The OI3$_{\text{KON}}$ is used in the use case of new buildings as a base for calculation of an environmental indicator for the whole thermal envelope, while the $\Delta$OI3 Concept is used for the refurbishment case, as it provides a scale for the environmental impact of small scale measures, e.g. addition of an insulation panel to an existing construction. The general concept of the Environmental Indicator Calculation as realized in SEMERGY is illustrated in Figure 53. For determination of the basic data of GWP, AP, and PECnr the methods suggested in the IBO-Guideline (IBO 2011) and in the European Standard (CEN 2013) need to be used. However, there is no legal requirement for the manufacturers of building materials to investigate the GWP, AP and PECnr-values of their products. Actually, many products on the building product market do not offer certificates for their environmental performance. To bridge this gap, the IBO published a catalogue with default values for different building material categories (IBO 2013b). Due to the lack of accurate data for many building products, the OI3-indicators calculated with default data need to be used cautiously and with attention to their limited explanatory power. Nonetheless, the OI3-indicator calculation still offers meaningful results about the environmental impact of building constructions.

Figure 53. Environmental Indicator Calculation as realized in the SEMERGY environment.
8.5. Cost Calculation / Erection & Refurbishment Cost Model

Cost calculation in building construction is still a very challenging task for architects and planners. Many – even small scale - projects suffer from cost overrun for erection cost. Cost calculation is usually done manually in planning practice and existing tools are based on data accumulated on former projects. Construction companies, as well as planners do not share their cost models, as they consider it a as an advantage over their competitors. Therefore, a comprehensive, overall procedure for cost calculation (comparable to the methods used for OI3 and Heating Demand Calculation) could not be identified. The cost model implemented in SEMERGY was designed following the typical cost structures of building constructions and works as follows: SEMERGY evaluates the erection (investment) cost for optimization purposes. A module for operational costs is planned to be designed for the SEMERGY environment, but not implemented yet. In the SEMERGY approach, cost of a building construction or retrofit project is composed of Material Cost (MC) for building construction materials, Labor Cost (LC) for application of the building construction materials, and General Cost (GC) which is a sum of all indirect cost (for instance, building a scaffold in front of the façade, transportation of demolition waste, security measures for protection of passing-by pedestrians). Sources for the different cost categories are different. While MC are taken from current web sources (e.g. catalogues of building supplies stores), LC and GC were derived from domain literature (BKI 2014, Buhse et al. 2014a, 2014b). Figure 54 illustrates data for the cost of an insulation panel made of EPS for flat roofs, as depicted in Buhse et al. 2014a.

![Figure 54. Example of Cost (Labour cost and material cost) for a flat roof. (from Buhse et al. 2014a).](image)

An automated approach toward cost calculation is rather prone to errors, for instance due to neglected site specific cost (such special constructions, for instance insulated trusses for balconies). It was thus decided to use the corresponding maximum value from the reference cost examples. Furthermore, the labor cost can vary in different regions of the world, of Europe and even in Austria, and is strongly dependent on the general economic situation in a country. Therefore this “cautious” approach needs to be considered as an approximation of the expected construction cost, but not as a definite price. It can be understood as an indication of the resulting cost of different building measures. Furthermore, the investment cost for both retrofit and new construction in SEMERGY is limited to the building
components represented in the SEMERGY building model. This includes the thermal envelope of the building and additional elements such as intermediate floors and internal walls. This is due to the fact that the parts of the building currently not represented in the SEMERGY building model (for instance foundation) can be realized – depending on the specific building object and its circumstances – in innumerable ways. An overall approximation of the entire construction costs was thus not targeted in the current SEMERGY tool. Figure 55 illustrates the cost-calculation currently implemented in the SEMERGY environment. Note that GC is based on rules implemented in the SEMERGY Kernel, while LC and MC are stored in the Ontology. The Cost Calculation, in general, combines different cost information available in the system with the user-defined input (geometry etc.) of the examined building.

![Cost Calculation Diagram](image)

Figure 55. Current Cost Calculation as implemented in the SEMERGY environment.
8.6. Compliance Checking routines in the SEMERGY kernel

As discussed earlier, the SEMERY Kernel features two compliance checking routines. These compliance checks fulfill two functions: One the one hand layer combinations that do not meet U-Value requirements or are prone to condensation are omitted from the pool of valid combinations. This can be understood as a quality assurance measure within the SEMERGY environment. On the other hand – as a side effect – the reduction of the alternative space improves the performance of the optimization process in terms of computation time and intensity. The principle process of compliance checking is illustrated in Figure 56: In a first step, solutions that do not comply with the U-Value regulations are omitted from the solution space. In a second step the remaining solutions are examined toward their condensation behavior. Solutions prone to condensation are omitted from the solution space as well.

Figure 56. Illustration of the integration of the compliance-checking regarding maximum U-Value and condensation risk in the layer combinations within the SEMERGY environment. Invalid combinations are omitted from the solution space.
8.6.1. U-Value-Compliance Checking

The U-value compliance checking is based on the calculation method described in the international Standard 6946 (ISO 2007). Furthermore, the semantic interface retrieves the minimum standards concerning U-Values from the World Wide Web for utilization in the compliance checking. The current state of minimum requirements towards U-Values in Austria is determined by a national guideline (OIB 2011). Table 14 (next page) illustrates these requirements (maximum limits for U-Values). However, following the semantic web approach incorporated in SEMERGY, it is possible to retrieve other countries’ regulations concerning U-Values (for instance the German EnEV, EnEV 2014). The compliance checking is performed construction-wise for each product combination of building materials. In the current state of SEMERGY, the compliance check is performed via the ISO’s calculation scheme for homogenous building components. Inhomogeneous layers, e.g. for the building components in wood frame constructions, are currently reduced to homogeneous approximations (this simplification affects also ontologies and templates). However, the ISO’s calculation scheme for inhomogeneous building components is currently under implementation in the SEMERGY kernel. Equations 17 and 18 show the derivation of the U-Values for homogenous building components following the ISO-Standard. The standard’s guideline for \( R_{si} \) and \( R_{se} \) are illustrated in Table 15. The derived U-Value is compared with the maximum permitted U-Value of the corresponding building component. If the U-Value is not compliant with the legal requirements, the corresponding combination of products is omitted from the set of alternatives, which form the solution space for further calculations and evaluations.

\[
U = \frac{1}{R_T} \tag{17}
\]

\[
R_T = R_{si} + \sum_{i=1}^{n} \frac{d_i}{\lambda_i} + R_{se} \tag{18}
\]

- \( U \): U-Value
- \( R_T \): total thermal resistance of the multi – layered building element
- \( R_{si} \): surface resistance on the inside
- \( R_{se} \): surface resistance on the outside
- \( d_i \): thickness of element \( i \)
- \( \lambda_i \): thermal conductivity of element \( i \)

Note that the quotient of \( d / \lambda \) for each layer, at the current state of SEMERGY, is already a building material property in the building product ontologies. This means that the compliance check based on equation a and b requires very little computational effort. However, benchmark tests to test the impact of this shortcut on system performance, for instance with the JMeter-environment (JMeter 2014), were not performed yet but are planned for the further development of SEMERGY.
Table 14. Values for the factor of safety in the general heat balance (OIB 2011a).

<table>
<thead>
<tr>
<th>Building Component</th>
<th>U-Value Maximum (W.m(^{-2}).K(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>External Wall</td>
<td>0.35</td>
</tr>
<tr>
<td>Walls to unconditioned roof spaces</td>
<td>0.35</td>
</tr>
<tr>
<td>Walls to unconditioned spaces (except roof spaces) and to garages</td>
<td>0.60</td>
</tr>
<tr>
<td>Walls adjacent to ground</td>
<td>0.40</td>
</tr>
<tr>
<td>Partition Walls between separated units inside of a building</td>
<td>0.90</td>
</tr>
<tr>
<td>Walls to neighboring buildings</td>
<td>0.50</td>
</tr>
<tr>
<td>Walls (small-scale, less than 2% of overall building’s envelope)</td>
<td>0.70</td>
</tr>
<tr>
<td>Partition walls inside of units of a building</td>
<td>-</td>
</tr>
<tr>
<td>Windows &amp; Glazed Doors (residential buildings)</td>
<td>1.40</td>
</tr>
<tr>
<td>Windows &amp; Glazed Doors (non-residential buildings)</td>
<td>1.70</td>
</tr>
<tr>
<td>Other vertical transparent building elements</td>
<td>1.70</td>
</tr>
<tr>
<td>Other tilted or horizontal transparent building elements</td>
<td>2.00</td>
</tr>
<tr>
<td>Vertical transparent elements to unconditioned spaces</td>
<td>2.50</td>
</tr>
<tr>
<td>Windows in sloped roofs</td>
<td>1.70</td>
</tr>
<tr>
<td>Opaque doors to outside air</td>
<td>1.70</td>
</tr>
<tr>
<td>Opaque doors to unheated spaces</td>
<td>2.50</td>
</tr>
<tr>
<td>Industrial doors / rolling shutter gates</td>
<td>2.50</td>
</tr>
<tr>
<td>Doors between rooms of the same unit</td>
<td>-</td>
</tr>
<tr>
<td>Sloped roofs and flat roofs, ceiling slabs to unheated atticas</td>
<td>0.20</td>
</tr>
<tr>
<td>Floors against unheated spaces</td>
<td>0.40</td>
</tr>
<tr>
<td>Floors between different units</td>
<td>0.90</td>
</tr>
<tr>
<td>Floors between rooms of the same unit</td>
<td>-</td>
</tr>
<tr>
<td>Floors above outside air</td>
<td>0.20</td>
</tr>
<tr>
<td>Floors to garages</td>
<td>0.30</td>
</tr>
<tr>
<td>Floors to ground</td>
<td>0.40</td>
</tr>
</tbody>
</table>

Table 15. R\(_{si}\) & R\(_{se}\) Values for the U-Value Calculation of ISO 6946.

<table>
<thead>
<tr>
<th>Direction of Heat Flow</th>
<th>R(_{si})</th>
<th>R(_{se})</th>
</tr>
</thead>
<tbody>
<tr>
<td>upwards</td>
<td>0.10</td>
<td>0.04</td>
</tr>
<tr>
<td>horizontal</td>
<td>0.13</td>
<td>0.04</td>
</tr>
<tr>
<td>downwards</td>
<td>0.17</td>
<td>0.04</td>
</tr>
</tbody>
</table>
8.6.2. Compliance checking toward condensation risk

The compliance check is based on the corresponding Austrian and German Standards (OENORM B8110-2, OENORM 2003, DIN 4108-3, DIN 2012). These standards are based on a simple graphical method for evaluation of diffusion processes, developed and published by German building physicist Helmut Glaser in the 1950ies (Glaser 1959). Although not considering any parameters apart from pure diffusion processes under constant temperature and relative humidity conditions, the method still allows a basic evaluation of the condensation risk within a layered building construction. Due to its simplicity, this standard approach was adopted to the SEMERGY environment.

Basically, this method assumes constant values for temperature and relative humidity on both sides of a construction. These standard conditions are -10 °C and 80% relative humidity for the outside environment and 20°C and 65% for the indoor climate. The water vapour transfer through the construction is modelled as a linear function of the different water vapour diffusion factors ($\mu$) of the layers of a construction. For each layer the corresponding saturation pressure is calculated and compared with the partial pressure assumptions for this location. If the partial pressure value exceeds the saturation pressure, the water vapour is assumed to condensate at this location. For higher accuracy, layers with a thermal resistance of higher than 0.25 m².K.W⁻¹ are virtually divided in sub layers with thermal resistances less than this threshold value. The resulting virtual boundary surfaces are consecutively evaluated for condensation risk. Figures 57 illustrates the resulting evaluation via the Glaser-method for a masonry wall with insulation on the inside. The examined building component shows condensation inside the construction.

![Figure 57. Condensation evaluation via the Glaser-method for a masonry wall with inside insulation. Lines for saturation pressure and partial pressure cross twice, therefore condensate needs to be expected inside of the construction. (Figure was generated with an spreadsheet-based implementation of the standard procedures, Pont 2009).](image-url)
Alternative building component configurations are evaluated toward condensation risk as described above. As different building materials and building products can be applied in different layers of the templates, certain combinations might show an increased risk of condensation, mould grow and damage, while others can be qualified as free of condensation risk. Combinations prone to condensation are currently omitted from the solution space. However, many of these combinations would be free of condensation with added vapour diffusion barriers. Therefore, efforts for automatic improvement of such constructions with added layers are explored towards their practicability within the SEMERGY environment. Some of these “enhanced” constructions are already existent in the pool of valid alternatives, due to other construction templates. Figure 58 illustrates this by means of two exterior wall constructions.

**AW007:**

*Wrong material combinations could lead to condensate*

**AW005 (“enhanced” AW007):**

*Identical material as in case with condensate with added water vapor barrier avoid condensate*

Figure 58. Exterior Wall AW005 as “enhanced” version of AW007.
8.7. External Tools intended to be coupled with the SEMERGY environment


The current Austrian Energy Certificate Method is a monthly method based on aggregated monthly input data, concerning climate data and other relevant input information. It is based on a couple of Austrian and international standards (CEN 2001, CEN 2008, OENORM 1999, 2003, 2004 2010, 2011a, 2011b, 2011c, 2011d, 2011e, 2011f) and guidelines (OIB 2011a, 2011b), and under constant development. An overview of the energy certificates in Austria, although already, is provided in Holzapfel et al. (2009). Although this method is based on the same principle equations as the annual method, there are a couple of differences. For instance:

- Higher resolution concerning input data: For instance the climate needs to be defined for each month instead of for the entire heating period. Additionally the method considers the radiation data for the exact orientation and not only for four cardinal directions as in the annual method.

- The heat storage capacity of the constructions is approximated following a different approach than in the annual calculation method.

- Aside from the heating demand, CO₂-emissions, and Primary Energy demand are also evaluated. For the last two, calculation needs to take also the building systems and services realized in a certain building into consideration.

As mentioned before, the constant development of the energy certification method in Austria forces vendors of commercial energy certificate tools to readjust their tools constantly and integrate changes. Therefore, an in-house development of the calculation schemes of the energy certificate was considered infeasible. Rather, coupling the existing energy certificate tools to the SEMERGY environment is planned. Therefore, two of the software tools offering energy certificate calculations were studied in detail with regard to their export and import capabilities. These include geq (geq 2014) and Archiphysik (Archiphysik 2014). The latter offers a convenient XML-based data interface based on the format aps. This xml representation of the building can be used for data transfer concerning geometry, semantic information about the building and calculation results. Additionally, a spreadsheet-tool, offered by the OIB (2011c), was considered as a calculation engine.

The current efforts in the SEMERGY project towards utilization of energy certification tools include:

- Preparing the input data derived from Graphical User Interface or CAD-Import and the alternative generation for export / mapping to the input data schemes of the proposed tools. This is performed within the SBM. The format the data is mapped to, include the XML-based APS-format of Archiphysik and the numeric format of the OIB-spreadsheet tool.

- Feasibility examination of the existing engines toward batch processing for the optimization. This includes performance benchmarking in comparison with the simple annual method.
8.7.2. PHPP

The first version of the PHPP (Passivhaus Projektierungs-Paket, PHPP 2014) was released in 1998. It is a spreadsheet-based environment for assessment of thermal performance of buildings. Core components include calculation schemes for heating demand, cooling demand, and mechanical ventilation systems. Major steps in the development of the tool were made in the framework of an international project focused on various aspects of passive houses (CEPHEUS 2001), where the results of computational assessment were compared with monitored data of realized passive houses in Europe. In general it can be said that the PHPP demands similar input data as the monthly method for energy certificates, however, there is no full congruency. Figure 59 illustrates the spreadsheet-based user interface of PHPP.

![Spread-Sheet based User-Interface of PHPP (PHPP 2014).](image)

The current efforts in the SEMERGY project towards utilization of the PHPP include:

Figure 59. Spread-Sheet based User-Interface of PHPP (PHPP 2014).
- Determination of necessary changes to the SEMERGY environment for implementation of the PHPP, especially concerning input data for the method.

- Enriching the SBM (SEMERGY Building Model) with necessary additional variables for the PHPP.

- Changing of the GUI if additional user-specified data needs to be captured from the user.

- Preparing of mapping routines within the SBM to be able to provide the PHPP method with sufficient data.

- Feasibility examination of the PHPP-method toward batch processing for the optimization. This includes performance benchmarking in comparison to the simple annual method.
8.7.3. DoE EnergyPlus

EnergyPlus (DoE 2014a) is an open source energy analysis and thermal load simulation software developed by the U.S. Department of Energy. It is based on two early simulation tools developed in the 1970ies and 1980ies (BLAST and DOE-2). These were originally intended for the use by HVAC-Engineers, while EnergyPlus is a simulation environment capable of addressing different building and energy related questions. Figure 60 illustrates the overall structure of the EnergyPlus environment.

![Figure 60. An overview about Energy Plus (from DoE 2014b).](image)

EnergyPlus was studied and used for the development of the SBM (see section 5. Building Data Representation). Therefore the SEMERGY environment can be considered to be well prepared for the utilization of EnergyPlus as a calculation engine.

EnergyPlus does not provide a graphical user interface, but uses text files for input and output data communication. Although several third party graphical user interfaces are available (DesignBuilder 2014, Openstudio 2014) on the web, the integration of the EnergyPlus simulation environment in the already existing web-based SEMERGY GUI is projected (both for input data transfer to the simulation and result documentation and visualisation).

However, as detailed dynamic thermal simulation due to its high resolution in analysis demands larger computational resources than simple normative procedures, an application within the optimization
procedures will probably need some additional consideration. Thereby, different solution approaches are currently examined (Figure 61):

(i) Examination of technical possibilities to shorten the elaboration time, for instance parallel computing or distributed computing.

(ii) Acceptance of a time-delay in derivation of results. This could be realized within the web-based SEMERGY environment in the following way: The user provides the required basic data for initialising of the simulation-supported optimization process and starts this process (time A). After accomplishing of the optimization steps the user gets notified via email (time B). Then the final selection of a solution from the SEMERGY environment can be performed based on the user’s individual preferences.

(iii) Implementation of a two-stage approach: Hereby, a reduction of the candidates for simulation is conducted in a first step (This could be done, for instance, with the current deployment of SEMERGY.) The remaining (fewer) solution candidates are then evaluated with the detailed thermal dynamic simulation. This approach seems to be most promising, as it could be realized within the already existing SEMERGY environment and preserves the coherence of the SBM workflow.

Figure 61. Approaches to use EnergyPlus for Optimization within the SEMERGY environment. Top: Utilization of distributed or parallel computing. Middle: Accepting the time delay caused by long elaboration times. Bottom: Two-stage approach based on the existing SEMERGY implementation.
8.7.4. Normative method for overheating evaluation

The methods currently implemented in the SEMERGY environment, as well as software tools that are intended for future integration and coupling, focus on heating demand, cost calculation or environmental impact estimation. The described KPIs might be sufficient for the optimization in terms of the cold season scenario, but do not guarantee thermal comfort in summer season as well. Therefore, a method to evaluate the temperature distribution inside the building in the hot season seems to be a promising feature for the future releases of the SEMERGY environment. EnergyPlus, as described in the prior section, is per se capable of calculating the temperature distribution in all spaces of a building. However, the implementation of simulation routines is as described above still hampered by the computational intensity of such processes. For the sake of future utilization in the optimization efforts of SEMERGY, therefore, a simple normative method was selected for implementation as well. The chosen method is described in the Austrian Standard OENORM B 8110-3 (OENORM 2012). This method evaluates the (hourly) overheating tendency for critical rooms (spaces) of a building based on the climate of one summer day (15th of July, the day's climate is assumed to repeat periodically after 24 hours to “simulate” long lasting heatwaves in the summer season). The room is considered as not overheated, if (i) the results for the maximum operative temperature on this day do not exceed 27°C and (ii) the night temperature (between 00:00 - 06:00 and 22:00 and 00:00) drops below 25°C. Results are benchmarked in a scale from D to A+ (D,C,B,A,A+). B means that based on the assumed outside temperatures the room is not overheating. If even lower outside temperatures cause overheating issues, the room is class C (outside temperatures -1,5K and no overheating) or D (room overheats even with outside temperatures reduced by 3K). A and A+ illustrate that the room does not overheat, even if outside temperatures rise by 1,5 (A) or 3K (A+).

Necessary input data for this method include information about the geometry of the evaluated room (net area, location), the internal heat gains, number, size, orientation and physical properties of the transparent building components including data about existing shading devices, heat storage capacity of the confining opaque building components, and the ventilation behavior. As the origin of the method is the same family of standards as the monthly energy certificate method, the majority of data is already available in the existing SBM structure. However, to store the data specifically useful for the overheating calculation, an extension of the SBM will be necessary: New classes and new attributes to existing classes are required to ensure the provision of all required data for this calculation. To illustrate this, the hourly outdoor climate data generation for this method is shortly described: Monthly average temperatures are represented within a class in the SBM (MonthlyWeatherData). These values come from a data repository storing the climate data based on tables from OENORM B 8110-5 (OENORM 2011b). The average temperature in July is utilized for generation of the hourly temperatures of the 15th of July. The conversion is based on conversion tables of OENORM B 8110-3 (OENORM 2012). These tables can be stored in an external repository as well. To be able to store the generated hourly temperature profile a new class HourlyTemperatureData could be generated, where these temperature values are stored. Figure 62 illustrates the temperature conversion and potential integration in SBM.
Though the normative overheating calculation method is - from view of algorithmic implementation - easy to integrate into SEMERGY, its in-house programing yet has to be studied for feasibility. The reason for this is that energy-certificate software tools such as Archiphysik (Archiphysik 2014) have integrated the method in their architecture. Therefore, a utilization of such an implementation would mean for SEMERGY that just the SBM has to be adopted with the necessary input data for performing this overheating calculations in a third party tool. Figure 63 illustrates the overheating rating of a sample project evaluated in Archiphsik (scaled overheating rating).

Figure 62. Generation and Storing of hourly temperature values for the overheating calculation within the SBM. Note that a majority of necessary input data for overheating calculations is already represented within the currently deployed SBM.

Figure 63. Overheating rating from a sample project from Archiphysik (Archive of the author).
9. OPTIMIZATION

The present chapter addresses the optimization procedures realized within the SEMERGY environment. Note that the text of this section includes references to and excerpts from a previously published conference paper (Heurix et al. 2013).
9.1. General Introduction

Optimization is understood in general as a mathematical technique for finding a maximum or minimum value of an objective function of several (user-defined) variables to a set of constraints. In the AEC-domain typical optimization objectives include minimizing the building operation cost, energy use, and environmental impact while maximizing occupants comfort (Coffey 2008). If an optimization problem features more than one objective function, the optimization process is called multi-objective optimization (MOO). The different objective functions can be contradictory sometimes. As an example, the optimal choice for a thermal insulation material of an exterior wall can be examined: If the “optimal” thermal insulation material would be selected just based on an objective function targeting at a low heating demand, the solution would always suggest the material with the lowest conductivity. This quite obvious result – which would not need an optimization environment at all – is not very helpful without considering other properties of the material. For instance, clients regularly would consider the minimizing of the building cost as an objective, therefore the price of the insulation material, and the labor cost of its application need to be taken into consideration as another objective. Another objective could be the ecological footprint of the material throughout its production. Concerning the contradiction in the example, it can be stated that most likely the materials with higher price would feature lower thermal conductivity values, but this is not necessarily the case. There could be cases, where the products with higher price show higher conductivity values and vice versa. Table 16 shows a list of different insulation materials with price (material cost), conductivity, Global Warming Potential (GWP), Acidification Potential (AP) and Primary Energy Content (PEC). The last three can be considered as indicators of the material’s ecological footprint. It can be clearly seen that the properties do not show clear correlations with each other: XPS, for instance, features the lowest conductivity in the list and rather poor values concerning environmental quality, but not the highest price, while foamglass is the most expensive one, but does neither show a very low conductivity nor outstanding ecological performance values. To find the optimal solution in such cases would typically involve trade-offs between the different, potentially conflicting objectives (Lowest price versus lowest conductivity versus lowest impact on the environment). If the different objectives cannot be weighted based on their importance, it might happen that there is not a sole optimal solution, but a set of solutions that can be seen as optimal. In such cases, the most reasonable trade-off between the different objectives needs to be chosen by involved decision makers, e.g. a client or a planner, based on individual preferences. As the basics of multi-objective optimization (MOO) were developed by the Italian economist Vilfredo Pareto, the solutions identified via MOO are called Pareto-optimal.
Table 16. Example list of different insulation materials for exterior wall insulation with their corresponding properties of Conductivity, Material Cost, Primary Energy Cost, Global Warming Potential and Acidification Potential.

<table>
<thead>
<tr>
<th>Product Name</th>
<th>Material</th>
<th>Conductivity [W·m⁻¹·K⁻¹]</th>
<th>Material Cost [€·m⁻³]</th>
<th>PEC [MJequi·kg⁻¹]</th>
<th>GWP [CO₂equi·kg⁻¹]</th>
<th>AP [SO₂equi·kg⁻¹]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation-Product 1</td>
<td>EPS</td>
<td>0.041</td>
<td>70</td>
<td>102</td>
<td>3.45</td>
<td>0.0223</td>
</tr>
<tr>
<td>Insulation-Product 2</td>
<td>Mineralwool</td>
<td>0.050</td>
<td>80</td>
<td>23.30</td>
<td>1.64</td>
<td>0.0105</td>
</tr>
<tr>
<td>Insulation-Product 3</td>
<td>Foamglass</td>
<td>0.045</td>
<td>280</td>
<td>15.70</td>
<td>0.84</td>
<td>0.0022</td>
</tr>
<tr>
<td>Insulation-Product 4</td>
<td>Sheep-wool</td>
<td>0.046</td>
<td>150</td>
<td>14.70</td>
<td>0.04</td>
<td>0.0000</td>
</tr>
<tr>
<td>Insulation-Product 5</td>
<td>XPS</td>
<td>0.040</td>
<td>250</td>
<td>102</td>
<td>3.44</td>
<td>0.0800</td>
</tr>
</tbody>
</table>

Seen as mathematical equations, multi-objective optimization problems in general can be formulated as follows (Jaszkiewicz 2004, Silva et al. 2004, Zitzler et al. 2001):

\[
\text{Optimize } \{ f_1(x) = z_1, f_2(x) = z_2, \ldots, f_j(x) = z_j \} 
\]

\[ x \in X, z \in Z \]  

(19)

where \( x \) is a vector of decision variables forming a solution, \( X \) is the set of all possible solutions (solution space), \( j \) is the number of objectives in the problem, \( z_j \) represents the derived result of objective function \( j \) when fed with \( x \), \( Z \) is the specific objective space and “optimize” can be “minimize” or “maximize”. The so called point

\[
 z^x = [z_1^x, z_2^x, \ldots, z_j^x] = f(x) 
\]

(20)

represents the image of solution \( x \) in the \( J \) objective space \( Z \), such that

\[
 z_j^x = f_j(x) \text{ for } j = 1, \ldots, J 
\]

(21)

To identify \( z \)-points that are part of the so called Pareto-Front, the concept of Pareto-Dominance is introduced: In case of minimization point \( z_1^j \) strictly dominates \( z_2^j \) if

\[
 z_1^j < z_2^j \text{ for } j = 1, \ldots, J; 
\]

(22)

and loosely dominates \( z_2^j \) if

\[
 z_1^j \leq z_2^j \text{ for } j = 1, \ldots, J \text{ and } z_1^j < z_2^j \text{ for at least one } j; 
\]

(23)

If neither point dominates (strictly or loosely), the points are called incomparable. A solution \( x \in X \) is called Pareto-optimal, if there is no \( x' \in X \) that dominates \( x \). The approximation of the Pareto front is
a set $\mathcal{A}$ of points, and their corresponding solutions are such that there are no $z^1, z^2 \in \mathcal{A}$ that $z^1$ dominates $z^2$. That means the set $\mathcal{A}$ is totally composed of mutually non-dominated points. Pareto-Optimization intends to find the Pareto-Front or a set that approximates that front. With this technique the difficulty of finding a sole solution to an optimization problem with not simple-to-rank solutions can be circumnavigated. Figure 64 illustrates the Pareto-Front of a MOO with two objectives that are maximized.

![Figure 64. Pareto-Front (black dots) in a multi-objective optimization problem with two objectives (maximizing criteria 1 and 2).](image)

A straight-forward approach to solve optimization problems is the iteration through all combinations of decision variables (solution vector) and manual identification of the “optimal” solutions. Even though it guarantees the determination of the Pareto-optimal front, this approach is not very feasible: when performed manually, even simple optimization problems would become incredibly time consuming and complex. If performed with the help of a machine, small and simple sets can be evaluated, but with a rising number of decision variables and complexity in the objective functions this task becomes computationally infeasible. Therefore, this approach should only be used if the solution vector does not have too many dimensions. For instance, the author of this thesis was involved in the development of a simple semi-automatic heating demand calculation tool named AUTOCERT, following the iterative approach (Pont et al. 2014). It was based on the same normative method for calculation of annual heating demand implemented in SEMERGY, programmed as Java code. For each decision variable a start value, a step width and an end value were defined (Figure 65), and to keep algorithmic cost at an acceptable level, the size of step-width and number of repetitions were limited. Decision variables included the U-Values of Walls, Roofs and Windows, as well as the percentage of glazing and the ventilation rate. The algorithm within the tool worked on base of loops (Figure 66). In a test run two issues could be watched: First, an increasing number of permutations (more decision variables) significantly slowed down the result generation. Secondly, as no sorting algorithm was implemented, the search for optimal combinations requires spread-sheet based post-processing of the results.
As not all MOO-problems can be reduced in their complexity to fit suit the iterative approach without losing a lot of explanatory power, alternative solving solutions and methods were developed in the past. Instead of identifying the exact Pareto-Front consistent of all points complying with the aforementioned definitions, these approaches try to find approximations to the Pareto-Front. Evolutionary algorithms, especially genetic algorithms (Holland 1992), are an example of such methods. The basic principle of these algorithms is to mimic the natural evolutionary process of survival of the fittest. Characteristically for such processes is that (i) after each step a set of solution candidates is maintained, (ii) a mating selection process is executed on the surviving set of solutions, (iii) and that selected solutions and random “new born” candidates are combined to generate new solutions by genetic processes such as crossover and mutations.

Candidates are named individuals in evolutionary algorithms, while the complete set of individuals is denoted as population. Each individual is characterized by its genes, which represent decision variables (solution vector). Based on the genes, one or more fitness threshold values are determined, following the calculation of one or more fitness (objective) functions. The optimization process is performed as iteration of the following steps:

(i) Selection: Two individuals from the population are selected.

(ii) Recombination: Based on a certain (high) probability the two selected individuals (parents) are recombined. This means that sections of their solution vectors are exchanged in a crossover operation to generate new individuals. In addition to the recombination, certain genomes are changed randomly based on a (low) probability in a “mutation” process. The crossover is intended to preserve the better performing code segments, while mutation helps to extend the search toward unexplored areas of the solutions spaces and should keep the process from being stuck in a “local”
maximum or minimum. The careful determination of the probabilities for crossover and mutation are crucial to the success of the optimization process.

(iii) Evolution: The new individuals (children) are evaluated in view of their fitness value, and eventually replace the parents, dependent on the comparison of fitness function results.

The termination condition of the process regularly is a predefined number of cycles of the above mentioned process. This means that the set of individuals determined in the last evolution step is considered to be the best approximation of the Pareto-front. Other termination conditions (for instance a certain number of non-dominated solution) are possible, however, are regularly not used due to their higher probability of being trapped in a local maximum or minimum. The number of cycles is a trade-off between a very close approximation of the Pareto-Front and the algorithmic cost of iterative derivation of the fitness function(s) results.
9.2. Optimization in the SEMERGY environment

The SEMERGY environment was intended to identify solutions for energy-efficient building design and optimization. Thereby, solution is understood as determination of optimal combinations of building material configurations with respect to certain objectives. The (additional) optimization of building envelope geometry in terms of glazing size or building layout was not addressed in the current state of SEMERGY, as it would have increased the complexity of the optimization process to a great extent, and is far from the original intent of the project’s utilization of data available on the World Wide Web via semantic technologies. However, approaches to the envelope geometry optimization, as illustrated for instance in Bogar et al. (2013), could be an optional future development target of the SEMERGY environment. As the structure of SEMERGY is modular, an extension in this direction is technically realizable.

At its current state, the SEMERGY environment targets the minimization of the following key performance indicators (KPI):

- Heating demand: This KPI is currently derived via the annual normative method, as described in the chapter Calculation and Simulation Modules.

- Investment cost: This KPI is currently calculated via a simple approach incorporating material cost (MC), labor cost (LC) and General Cost (GC).

- Environmental footprint: This KPI-calculation is utilizing the IBO systematic for generation of OI3-values, developed by the IBO (2006, 2011, 2013a).

Note that the calculation methods are described in detail in the section Calculation Modules.

All of these target objectives are dependent on the selected building component templates (walls, roofs, floors, etc.) and the applied building materials / building products. Therefore, the population in the optimization attempt consists of different combinations of building components constituted by layers of different corresponding building products. The initial design of a new building or the status quo of an existing building in the retrofit case, as provided by the user of the SEMERGY environment, acts as the starting point of the optimization. The SEMERGY environment generates alternative components as potential candidates for the optimization problem. The alternative generation is based on the templates for alternative generation, described in the corresponding chapter of this dissertation. These candidates are rated according to the target objectives. This means that the SEMERGY environment conducts for each alternative component set, appearing in the optimization attempts, the calculations of heating demand, investment cost and environmental footprint.

For utilization of the evolutionary algorithm approach within the SEMERGY environment, it is necessary to define the constituting elements of the optimization first: The population, as mentioned before, is the set of different combinations of building components. The genes of the different instances of the population are the building products with their corresponding properties within the
building component assemblies. The classification and constraints, as defined by the templates and the data stored via the building product ontology, ensure that only suitable products are applied to a specific position in a specific component. In the current approach, the calculation schemes for the three KPIs (=fitness values) constitute the three fitness functions of the optimization approach. The parent generation is made up of 500 individuals out of the population, and within the optimization up to 150000 iterations of the evolutionary algorithm process are conducted (Selection – Recombination – Evolution). This number is derived from a maximum of 5 (re-)initializations of the population with 30000 cycles each. The probability for matting (crossover) is in the current deployment set to 90% while the mutation probability is set to 1%. The optimization routines implemented in the current state of SEMERGY use a sophisticated form of evolutionary algorithms, named non-dominated sorting genetic algorithm 2 (NSGA2, Deb et al. 2002)
9.3. Workflow Example of the Optimization in the SEMERGY environment

The following example illustrates the optimization work-flow for a building retrofit as implemented in the SEMERGY environment:

(i) The user draws the floor plans of a proposed building design or retrofit incentive (Figure 67) in the SEMERGY GUI by means of pre-defined line types (Figure 68). Each line represents a different building component function (e.g. exterior wall, interior wall, window, and door). For each line type the user has to specify a construction type from a given list of choices (this list is based on the users stated initial preferences regarding the main construction method). Furthermore, the user is requested to state additional information important for calculation of fitness values and for reduction of the solution space. An example of the former is the definition of the north offset, which has a major effect on the solar gains of a building and therefore on the heating demand. An example for the latter is the definition of the maximum investment cost. This value will reduce the number of potential solutions, as unaffordable solutions will be omitted from the solution space.

Figure 67. Sample building.

Figure 68. Sample building plan in the SEMERGY as drawn in the SEMERGY GUI.
(ii) Based on the preferences and according to different pre-defined required characteristics for each layer within each specific building component template, the semantic interface identifies all suitable building materials / building products from the product ontology. For instance, the insulation layer of the external wall can assume all materials that follow specific rules, such as: *Function: insulation; Format: stiff; appropriate for MMB and can be mounted on the outer layer of external walls.* The insulation materials suited for this example were already depicted in table DDD in the beginning of this chapter. Note: The material / product property data required for the identification is either included in the material profile of the original data base (e.g. physical properties such as conductivity) or has been attached to the product after its integration in the ontology (format, function, position). The identified products are used to populate the layers of the templates used in the optimization. Layers with little influence on the overall performance of the construction are populated by default materials.

(iii) The generated alternative constructions are examined toward their compliance with certain requirements (minimum U-Value, condensate calculation). Valid alternatives constitute the gene pool in the optimization process, while alternatives failing in the compliance check are excluded. In the present example only external walls, windows and the roof were subjected to optimization.

(iv) The constructions are then combined to form complete design solution packages, including the construction alternatives for all different building components. Iterative optimization attempts are conducted following the evolutionary algorithms concept as described above, until either a set of Pareto-optimal solutions is derived or the process terminates after a certain number of iterations. If the latter is happening, the last set of leaving the latest generation construction combination. In the current state of the SEMERGY environment, the probability for crossover is set to 90%, while the probability for mutation is 1%.

Table 17 shows the resulting solution set for the given example. The table shows also three dominated solutions: Solution #3 is excluded, as solution #1 and #2 show lower results in all three objective functions, solution #6 is dominated by solution #2, and solution #8 is dominated by solutions #1 and #4. These solutions are omitted from the solution space.
Table 17. Exemplary set of solutions for the example building of Figure A01. Solutions in grey are dominated by others and thus excluded from the solution set.

<table>
<thead>
<tr>
<th>Solution</th>
<th>U-Value-Wall [W.m².K⁻¹]</th>
<th>U-Value-Roof [W.m².K⁻¹]</th>
<th>U-Value-Windows [W.m².K⁻¹]</th>
<th>Heating demand [kWh.m².a⁻¹]</th>
<th>OI3 [-]</th>
<th>COST [€]</th>
<th>Dominated / non-dominated</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>0.195</td>
<td>0.19</td>
<td>1.0</td>
<td>59.60</td>
<td>47.25</td>
<td>180000</td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td>0.164</td>
<td>0.155</td>
<td>1.0</td>
<td>51.51</td>
<td>53.22</td>
<td>200000</td>
<td>Dominated by #1 and #2</td>
</tr>
<tr>
<td>#3</td>
<td>0.213</td>
<td>0.20</td>
<td>1.0</td>
<td>61.17</td>
<td>93.85</td>
<td>220000</td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td>0.189</td>
<td>0.19</td>
<td>1.0</td>
<td>58.77</td>
<td>42.57</td>
<td>195000</td>
<td></td>
</tr>
<tr>
<td>#5</td>
<td>0.142</td>
<td>0.19</td>
<td>1.0</td>
<td>46.95</td>
<td>47.90</td>
<td>250000</td>
<td>Dominated by #2</td>
</tr>
<tr>
<td>#6</td>
<td>0.176</td>
<td>0.19</td>
<td>1.0</td>
<td>55.20</td>
<td>57.25</td>
<td>230000</td>
<td></td>
</tr>
<tr>
<td>#7</td>
<td>0.131</td>
<td>0.16</td>
<td>0.8</td>
<td>33.20</td>
<td>85.25</td>
<td>279000</td>
<td>Dominated by #1 and #4</td>
</tr>
<tr>
<td>#8</td>
<td>0.224</td>
<td>0.20</td>
<td>1.0</td>
<td>67.33</td>
<td>60.52</td>
<td>195000</td>
<td></td>
</tr>
</tbody>
</table>

As discussed earlier, multi-objective optimization problems regularly do not have one optimal solution, but a set of solutions that are considered to be optimal. The final selection of one of the solutions in case of SEMERGY has to be taken by the user. Therefore, SEMERGY presents the individuals of the solution space with the help of rulers: Here the user can set his individual preference toward one of the objectives (heating demand, investment cost or sustainability) within the minima and maxima of the specific objective. The results of the two other objectives are automatically adapted. A further auxiliary mean for individual selection of one suggested strategy is a diagram indicating the amortization time of the set of measures. Below this diagram, the detailed description of the actual constructive measures is provided. Figure 69 shows the Pareto-Front solution space of a refurbishment project as illustrated in the current state of SEMERGY (including amortization diagram and solution description).
Figure 69. Solution space presentation in the SEMERGY environment via user-changeable rulers for heating demand, investment cost and sustainability.
10. GRAPHICAL USER INTERFACE & DATA EXCHANGE

This section describes on the one hand the efforts towards development of a Graphical User Interface (GUI) for SEMERY. On the other hand Data Exchange routines examined and implemented in the SEMERGY environment are discussed. Note that the text in this section includes references to and excerpts from previously published conference contributions (Ghiassi et al. 2014)

10.1. Background

Stopper et al. (2012) define graphical user interfaces as follows:

*Graphical User Interfaces use pictures and graphics instead of just words to represent the input and output of a program. The program displays certain icons, buttons, dialogue boxes etc. on the screen and the user controls the program mainly by moving a pointer on the screen (typically controlled by a mouse) and selecting certain objects by pressing buttons, etc.*

Recent AEC related software tools in general feature GUIs. While architects started to use graphical user interface with the rise of CAD-tools in the 1980ies, building physics related tools for a long time did not feature proper graphical interaction modalities in their tools. Certain tools still do only offer their calculation or simulation kernels, and are dependent on either command-line data input, or third party graphical user interfaces. An example for this is the US Department of Energy's building performance simulation tool EnergyPlus (Doe 2014a). A basic manual for this simulation tool (Doe 2014b) explicitly mentions:

[…] Although it is important to note what EnergyPlus is, it is also important to remember what it is not: EnergyPlus is not a user interface. It is intended to be the simulation engine around which a third-party interface can be wrapped. Inputs and outputs are simple ASCII text that is decipherable but best left to a GUI (graphical user interface).[…]
10.2. General Design Criteria for usability of Graphical User Interfaces

There is a multitude of studies about Graphical User Interfaces, their design, strengths, weaknesses, opportunities, and threats. EN ISO 9241-11 (CEN 1999) states three design criteria for ensuring usability:

- Effectiveness: How precisely and completely does a user reach a goal
- Efficiency: What effort was necessary to reach a certain level of precision and completeness
- Satisfaction: Lack of adverse effects and positive attitude toward using a program.

Note that the current SEMERGY Graphical User Interface is undergoing a detailed usability testing with different user groups with different levels of expertise (novice, intermediate, professionals) to identify strengths and weaknesses of the current implementation. This is done in the course of a master thesis at the Department of Building Physics and Building Ecology of the Vienna University of Technology (Candidate: S. Keo-Orasarn).
10.3. Language of the deployed graphical user interface

The SEMERGY environment is currently (Beta version, August 2014) offered in German and English languages in the World Wide Web. The German version of the environment was deployed in the World Wide Web in February 2014, while the English version was deployed in July 2014. An implementation of SEMERGY for other languages or countries (the current SEMERGY deployment focuses on Austria / the D-A-CH area) is possible. For this purpose, language, queried semantic data ontologies (for instance for legal requirements or subsidy incentives of different countries and available building products and systems) and local calculation standards and methods (for instance cooling demand calculations in arid regions) have to be integrated in the environment.
10.4. General Outline of the Graphical User Interface within the SEMERGY environment

The SEMERGY environment is intended as a decision and design support tool for different use cases and user groups. Consideration of different requirements of these user groups leads to a design outline for Data Input via Graphical User Interface and data exchange within the environment. This general outline is illustrated in Figure 70.

![Figure 70. Data provision possibilities within the SEMERGY environment. Aspects highlighted with a check are already implemented in the current state of the SEMERGY environment.](image)

Generally speaking, necessary input information of the SEMERGY environment which are to be provided by the user can be expressed in the following categories:

(i) Use Case Determination: Is the building performance evaluation and optimization intended for a new building, a retrofit incentive, or a group of buildings? This information is important, as the evaluation of existing buildings that are intended for retrofit is, in many aspects different from the evaluation of a new construction. For instance, the evaluation of the environmental impact of the building measures use - dependent on the use case - different indicators ($\Delta OI3$ or $OI3_{Kon}$). Furthermore, the evaluation of building portfolios might require a simplified evaluation resolution.
(ii) Geometrical description of the building (Geometry Input). Geometry can be expressed through selection of a simplified template provided in the GUI, drawing on a grid-based, CAD-style drawing canvas, or imported via CAD (or BIM-) tools or from GIS-Data.

(iii) General building description. This incorporates location, age of existing building(s), general construction method, and building systems and services.

(iv) Semantic attributes of building components: Users can specify data pertaining to the building components based on templates. For instance, if users select massive construction as the general construction methods in the general building description, SEMERGY will preselect a typical construction from all templates of this general construction method. Users can change this preselection to different other massive constructions or even switch the main construction method to access other templates. Furthermore, they are requested to specify the thickness of each layer. However, by default SEMERGY suggests typical values to support users with little to no domain knowledge. Detailed data about different possible materials, their properties and possible thicknesses is retrieved from the building component ontologies.

(v) Space properties, including internal conditions toward occupancy, equipment, and temperature and relative humidity set points. To support unexperienced users, a taxative list of space functions is suggested for each space and the user is requested to select the best fitting. (for instance “living room”, “heated floor”, “unheated roofspace”). The stated space function acts as a key for lookup of numeric values from the stored internal conditions database. For the currently deployed heating demand calculation method as well as for the monthly method these values were derived from OENORM B8110-5 (OENORM 2011b).

Professional users will be able to override template data with their on input data. However, this will gain relevance with the implementation of dynamic thermal simulation tools.
10.5. Current State of the Graphical User Interface of the SEMERGY environment

Figure R2D2 – discussed in the above section - highlights methods of data provision already implemented in the current deployment of SEMERGY. Currently, the Graphical User Interface of SEMERGY offers two step-by-step workflow routines for data entry and optimization process: A simplified version with predefined geometry templates and reduced data input possibilities (“SEMERGY basic”) and a more advanced version with grid-based geometry drawing capability and higher data resolution (“SEMERGY”). Both versions utilize the same calculation schemes, however, the former is intended for simple one-zone-only models, and therefore utilizes external dimensions of buildings, while the latter is capable of multi-zone models and therefore considers the internal dimensions of these zones. The idea behind is, that users of the latter might be interested in performing simulation-based evaluation. Moreover, it is likely that users of the simple case will use plans highlighting external perimeter dimensions, while users choosing a space by space approach might use inner dimensions of their rooms. Figure 71 illustrates the geometry input in the SEMERGY basic, while Figure 72 illustrates the grid-bases geometry input in SEMERGY. Table XYZR illustrates the step-by-step workflow through both versions. Note that screenshots of all screens of both variants for an example building can be found in the annex.

Figure 71. Template-based geometry definition in the current “SEMERGY basic” deployment (L-Shaped building).
Figure 72. Grid-based geometry definition in the current “SEMERGY” deployment.
Table 18. Step-by-step workflow through SEMERGY basic and SEMERGY variants of the Graphical User Interface.

<table>
<thead>
<tr>
<th>Step</th>
<th>SEMERGY basic</th>
<th>SEMERGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>USER-DETERMINED DATA PROVISION</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Address</td>
<td>Specification of the building site (Street name, Postal code)</td>
<td></td>
</tr>
<tr>
<td>Basic Data</td>
<td>Specification of</td>
<td>Specification of</td>
</tr>
<tr>
<td></td>
<td>• Year of construction,</td>
<td>• Year of construction,</td>
</tr>
<tr>
<td></td>
<td>• General Construction Method,</td>
<td>• General Construction Method,</td>
</tr>
<tr>
<td></td>
<td>• Building Type,</td>
<td>• Building Type,</td>
</tr>
<tr>
<td></td>
<td>• Number of floors above and below ground</td>
<td>• Number of floors above and below ground</td>
</tr>
<tr>
<td></td>
<td>Specification of</td>
<td>Specification of</td>
</tr>
<tr>
<td></td>
<td>• Roof type,</td>
<td>• Roof type,</td>
</tr>
<tr>
<td></td>
<td>• Attic type,</td>
<td>• Attic type,</td>
</tr>
<tr>
<td></td>
<td>• Roof base shape (3 templates)</td>
<td>• roof specific information (ridge height, roof slope, jamb wall),</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• roof base shape (7 templates)</td>
</tr>
<tr>
<td>Heating Systems</td>
<td>Selection of Heating System</td>
<td></td>
</tr>
<tr>
<td>Geometry</td>
<td>Template based data entry of the main dimensions</td>
<td>Grid based data entry: Specification of external walls, internal walls, windows and doors (including dimensions) for each floor</td>
</tr>
<tr>
<td></td>
<td>Specification of number of transparent building parts within each external wall (and their width and height)</td>
<td>Orientation of the building</td>
</tr>
<tr>
<td></td>
<td>Orientation of the building</td>
<td>Roof windows specification</td>
</tr>
<tr>
<td></td>
<td>Roof windows specification</td>
<td></td>
</tr>
<tr>
<td>Constructions</td>
<td>Definition of the opaque and transparent constructions of initial case (construction template, thickness of layers); Specification if building construction should be optimized</td>
<td>Detailed Definition of the opaque and transparent constructions of initial case (construction template, thickness of layers); Specification if building construction should be optimized, replaced or ignored</td>
</tr>
<tr>
<td>Status quo</td>
<td>Status Quo results</td>
<td>Status Quo results</td>
</tr>
<tr>
<td></td>
<td>Specification of budget for retrofit</td>
<td>Specification if ecological parameters should be considered within optimization</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Specification of budget for retrofit</td>
</tr>
<tr>
<td>OPTIMIZATION</td>
<td>Optimization</td>
<td></td>
</tr>
<tr>
<td>Analysis</td>
<td>Communication of Results, User-specified prioritizing of different optimization criteria</td>
<td></td>
</tr>
<tr>
<td>Report</td>
<td>Report Generation (and download opportunity)</td>
<td></td>
</tr>
</tbody>
</table>
10.6. Building visualization technologies for the SEMERGY environment

Building performance evaluation needs to consider buildings as three dimensional entities. This is realized within the SEMERGY environment, more explicitly in the SEMERGY Building Model and in the calculation and simulation methods implemented within SEMERGY. However, the Graphical User Interface currently lacks a three dimensional visualization of the evaluated buildings. As SEMERGY is not only intended for experienced professionals of the AEC-context, but also for novice users with little to no knowledge in building design, a three-dimensional visual feedback in the Graphical User Interface can be considered a helpful auxiliary service. Furthermore, it could not only be used for visualization of the evaluated building itself, but also as basis for visualization of evaluation results. To realize this feature a concomitant study (Sadeghi Kafri 2014) on coupling of the SEMERGY environment (the SBM) with existing web-based visualization tools was initiated. BIMSurfer (2014) was identified as a promising existing environment capable of 3D-visualisation of BIM-Data. However, as it was designed originally to visualize IFC-Models, a major work of the study was to develop a prototypical mapping routine from the SBM-building representation to the BIMSurfers data structures. The developments are planned for integration within the future deployments of SEMERGY. Figure 73 envisions how the three-dimensional visualization of the SEMERGY environment could look like.

Figure 73. Vision of future SEMERGY GUI enhancement coupled with the BIMSurfer visualization possibilities (taken from Sadeghi Kafri 2014, p 48).
10.7. CAD-Import into the SEMERGY environment

Two dimensional computer aided drafting is still very widely practiced within the design community, even though advanced Building Information Modeling tools continue to grow in their importance for architects and planners. In the current practice, CAD systems such as Autocad (Autodesk 2014) or DraftSight (Dassault Systems 2014) are widely used as simple drawing tools. Regularly, such drawings do not utilize “intelligent” concepts such as object identification. It seemed useful to add a utility for importing 2D-CAD drawings to the SEMERGY environment. The implementation of such a utility offers a set of advantages:

- Such a utility could help increase the attraction of the SEMERGY environment for professional planners.
- For professional users, their commonly used CAD-tools are a more convenient geometry input medium than the grid-based drawing tool currently featured by the SEMERGY environment.
- Existing drawings do not need to be completely redrawn, but require small conversion work: Such drawings simply get an additional overlay in the CAD-environment following simple rules (the overlay needs to be drawn as polylines of the perimeters and follow the rules stated in the SBM-section for Simplification of enclosures to two dimensional entities) and then converted to XML-files that can be imported in the SEMERGY environment.

Therefore, in the course of the SEMERGY development, methods for exporting of standard CAD drawings were explored toward their utilization in the environment. A base for the research was the PTEXPORT code snipped developed in the programming language Autolisp (DotSoft 2014). This small program is able to extract polyline coordinates from dwg-files (Autocad standard format). As a result, two Plugins for Autocad were developed in the run of the SEMERGY project (Wolosiuk et al. 2013b). Basically the SBMLAYERS-plugin generates all necessary layers within an AUTOCAD drawing that are needed for a successful export to an XML-file. All geometry information that should be transferred to SEMERGY needs to be retraced as polylines on the corresponding layer and then be exported with the SBMEXPORT-plugin. This plugin generates an XML-File, ready for import to the SEMERGY environment. Figure 74 illustrates the process of conversion of a dwg-file to SEMERGY.

![Figure 74. Conversion of an existing dwg-drawing to a SEMERGY-usable drawing. The existing dwg-drawing (left) is extended by SBMLAYERS-plugin. Polylines are drawn on top of the existing drawings (middle) and exported to a SEMERGY-compatible XML file via SBMEXPORT (right)](image-url)
11. FUTURE DEVELOPMENT

This section points out two of the approaches for future developments in the SEMERGY context. The first approach addresses the exploitation of further building performance domains. This could include building- and space-related domains such as lighting evaluation and acoustical performance. Another performance enquiry could aim at thermal bridges. Thermal bridge evaluation, however, is a building-component related assessment area, and thus requires a set of extension work.

A second approach for further development could be the upscaling of SEMERGY to an urban level. In times of smart grids and growing cities building assessment could be seen as a part of urban decision making concerning retrofit and spatial development policy. An upscaled version of SEMERGY could help addressing common problems in this field of research.

Note that further future development efforts in specific domains of the SEMERGY project are described in the corresponding sections of this dissertation.
11.1. Calculation domains for the future SEMERGY environment

11.1.1. Lighting Calculation

The SEMERGY environment is intended to be a flexible and extendable building performance assessment and optimization environment. Simulation of lighting levels within a space or building could be a potential area of future development. The integration of daylight and artificial light simulation to SEMERGY would offer precious design support, as it

Following the basic idea to couple existing tools with the current core, a number of freely available software tools specializing on lighting simulation can be considered as candidates for integration. Examples of such (offline) tools or lighting simulation environments are Radiance (Ward 2011), Dialux (Dial 2014) or Relux (Relux 2014). Alternatively, efforts toward web-based lighting simulation based on radiance are worth examination as well (for instance Papamichael et al. 2002). Similar to tools for heating demand evaluation, lighting assessment tools demand different input data and feature different resolutions and result representations. Most of these tools feature import and export capabilities, therefore the integration in the SEMERGY environment demands two major steps:

(i) Identification of the input data necessary for different lighting evaluations (for instance illuminance, UGR, uniformity, energy consumption of luminaries via the Lighting Energetic Numeric Indicator LEI). These will include additional material properties of building materials (for instance reflectance and surface roughness, which are already integrated as attributes in the current SBM), additional properties for windows and skylights (spectral transmission, refraction indices, etc) as well as light distribution models and sky models for daylighting, and representations for market available electric luminaries and their attributes for artificial lighting. Hereby the existing data formats for representation of luminaries (for instance “.lum”) can be utilized. Data regarding luminaries generally could be administered via ontologies, comparable to building products in the current SEMERGY environment. Furthermore, information about control schemes and energy consumption data will potentially be of interest for in depth analysis. Once identified and hierarchically structured, this input data needs to be integrated in the SBM. It is, however, to expect that a substantial part of the necessary data (geometry) is already implemented within the current state of the SBM. Moreover, the space-based structure of the SBM complies to the requirements of geometry representation in light performance assessment, and only minor extensions and adjustments are needed to integrate other required data (for instance external obstructions).

(ii) In a second step, the data exchange routines for provision of input data to a lighting simulation tool as well as retrieval and representation of results has to be developed. Regularly, the data transfer should be operable with the utilization of existing data interfaces of such lighting simulation tools. This means, that the data available in the SBM should be mapped on the corresponding input data format of a lighting simulation tool. As an example, listing 2 illustrates the import/export format “.stf” of the software DIALUX for a sample building (Figure 75).
Figure 75. Sample room from DIALUX (Corridor with pending luminaries). The representation as .stf-file can be found in listing 01.

Listing 02. STF-File from DIALUX. Note that the text block at the end of the file is the semantic description of the luminaires used within this model (retrieved from Dial 2014).

```
[VERSION]
STFF=1.0.5 Progname=DIALux Progvers=4.12.0.0

[PROJECT]
Name=Project 2 Date=2014-07-04 NrRooms=1 Room1=ROOM.R1

[ROOM.R1]
Name=Room 1 Height=2.800 NrPoints=4
Point1=0.000 0.000 Point2=50.000 0.000 Point3=60.000 3.600 Point4=0.000 3.600
MeanLuxWorkingPlane=616.823 SpecificConnectedLoad=15.455 Isolines=corridor\ROOM.R1.dxf
NrStruct=1
Struct1=ROOM.R1.LUMFIELD.LF1 Struct1.Pos=6.000 0.450 2.273 Struct1.Rot=0.000 0.000 0.000
NrLums=0 NrFurns=0

[ROOM.R1.LUMFIELD.LF1]
Type=FIELD Lum=LUMINAIRE.L1 Lum.Rot=0.000 0.000 90.000 Extend=48.000 2.700
NrLums=5 4 Arrange=1
Lum1.Pos=6.000 0.450 2.273 Lum1.Rot=0.000 0.000 90.000
Lum2.Pos=6.000 1.350 2.273 Lum2.Rot=0.000 0.000 90.000
Lum3.Pos=6.000 2.250 2.273 Lum3.Rot=0.000 0.000 90.000
Lum4.Pos=6.000 3.150 2.273 Lum4.Rot=0.000 0.000 90.000
Lum5.Pos=18.000 0.450 2.273 Lum5.Rot=0.000 0.000 90.000
Lum6.Pos=18.000 1.350 2.273 Lum6.Rot=0.000 0.000 90.000
Lum7.Pos=18.000 2.250 2.273 Lum7.Rot=0.000 0.000 90.000
Lum8.Pos=18.000 3.150 2.273 Lum8.Rot=0.000 0.000 90.000
Lum9.Pos=30.000 0.450 2.273 Lum9.Rot=0.000 0.000 90.000
Lum10.Pos=30.000 1.350 2.273 Lum10.Rot=0.000 0.000 90.000
Lum11.Pos=30.000 2.250 2.273 Lum11.Rot=0.000 0.000 90.000
Lum12.Pos=30.000 3.150 2.273 Lum12.Rot=0.000 0.000 90.000
Lum13.Pos=42.000 0.450 2.273 Lum13.Rot=0.000 0.000 90.000
Lum14.Pos=42.000 1.350 2.273 Lum14.Rot=0.000 0.000 90.000
Lum15.Pos=42.000 2.250 2.273 Lum15.Rot=0.000 0.000 90.000
Lum16.Pos=42.000 3.150 2.273 Lum16.Rot=0.000 0.000 90.000
Lum17.Pos=54.000 2.250 2.273 Lum17.Rot=0.000 0.000 90.000
Lum18.Pos=54.000 3.150 2.273 Lum18.Rot=0.000 0.000 90.000

[LUMINAIRE.L1]
Manufacturer=TRILUX Name=Rasterhängeleuchten 505··· OrderNr=5051RSX-L/2x80 E
Box=0.160 1.518 0.053 Shape=0 Load=170.000 Flux=12300.000 NrLamps=1 MountingType=16
Picture=corridor\LUMINAIRE.L1.jpg Model=corridor\LUMINAIRE.L1.sat
Description=Hängeleuchte für Einzel- und Lichtbandanwendungen für 2 Leuchtstofflampen T5 80 W.
Für abgehängte Montage. Mit Parabolspiegelzaster, satiniert. Rastermaterial aus Reinataluminium 99,99% mit reflektionsverstärkend beschichteter Oberfläche. Mit direk- 
direkt strahlender Lichtstärkeverteilung. Bildschirmgerecht gemäß EN 12464-1. Maße (L x B) 1493 mm x 160 mm, Leuchtenhöhe 53 mm. Aufbaumass Kopfstück bei Endleuchten- oder 
Einzelleuchtenanwendung 11 mm pro Kopfstück. Kopfstücke für Einzelleuchten und Lichtbandenden 
bitten gesondert bestellen. Schutzklasse I, Schutzart IP20, Schlagfestigkeit 0,2 J, 
Glühdrahtfestigkeit 650°C. Mit elektronischem Vorschaltgerät, schaltbar.
```
11.1.2. Room acoustics evaluation

Taking parameters of room acoustics into account in architectural design can ensure comfortable sound perception inside a space. Depending on a space’s primary function, certain parameters for room acoustics are considered as optimal. For instance, a space designed as a lecture room should ensure a high level of speech comprehension. This can be promoted with keeping the reverberation time inside the space between certain threshold values (stated within german standard 18041, DIN 2004).

An approximation of reverberation time could be implemented in the current deployment of the SBM and the whole SEMERGY based on normative procedures. Toward this end, the material description in the SBM needs to be enriched with the absorption coefficients of the composing materials of enclosure, aperture and furniture surfaces and classes representing sound sources should be foreseen. In-depth acoustical performance inquiries would need, however, a program capable of performing room acoustic simulation. A possible candidate for this role is the room acoustic software Odeon (Bruel & Kjaer 2014), which is capable of performing the calculation of indicators such as the Sound Pressure Level and Early Decay Time of a space. Even auralisation is possible in this tool.

The coupling of Odeon with the SEMERGY environment would require extending work of the SBM. However, the geometrical space representation of the SBM is already compliant with the geometric requirements of ODEON, which are:

- Plane surfaces
- No duplicate points
- No surfaces without area
- Unique identifiers for surfaces.

Figure 76 illustrates a geometry representation ready for use in ODEON.

![Geometry representation for the ODEON room simulation tool (from Bruel & Kjaer 2014).](image)
Thermal bridge evaluation is considered to be a rather difficult matter for stakeholders in the AEC-process. Therefore, integration in the SEMERGY environment can be considered a valuable addendum to SEMERGY’s assessment capabilities. However, it is important to state that thermal bridge evaluation regularly is not a (whole) building performance simulation, but rather the evaluation of joints of building components. The reduction of the impact of thermal bridges in building design and retrofit is of interest due to the following of reasons:

- Avoidance of structural damages to constructions caused by condensation within building component joints (IWU 2014).

- Avoidance of mould growth. Mould growth on the inner surfaces of a building can cause serious health issues for the occupants (Umweltbundesamt 2014).

- Avoidance of radiant temperature asymmetries which can be considered as uncomfortable by building users. Thermal bridges can cause such asymmetries due to the reduced surface temperatures in their scope (PH-Tagung 2014, ASHRAE 2013).

- In highly-insulated building design, thermal bridges can be responsible for a large portion of the remaining required heating demand (Grosch 2008).

Within the SEMERGY environment, the impact of thermal bridges is currently approximated by defaulted factors in the heating demand calculations. These values origin from thermal bridge catalogues and normative examples (for instance Hauser and Stiegel 1990 or DIN 2008). Such literature regularly only considers standardized construction details or suggests approximations based on equations that consider the surrounding thermal behavior of building components and their area (equation XXX of calculation modules section). The current SEMERGY deployment uses a matrix of values based on such literature. However, these default values do not support a detailed evaluation of construction details in view of surface temperatures, mould growth and radiant temperature asymmetries. The integration of thermal bridge evaluation therefore seems to be a valuable addition to the SEMERGY environment. However, it seems obvious that evaluation of thermal bridges exceeds the scope of a novice user of the environment and is addressed at professionals. Out of the tools available, AnTherm (AnTherm 2014) was chosen as a reference tool. This tool utilizes a numeric finite-point method for evaluation of 2D and 3D thermal bridges and requires – in contrast to the underlying complex algorithms in numeric simulation - rather simple input data requirements. In general the tool requires the geometry of every building material / building component used in a building component junction as 2D / 3D coordinates in diameter of 1 meter from the junction of components, physical properties of the materials (including conductivity, density, specific heat capacity and diffusion resistance factors) and the hygrothermal ambient conditions of the adjacent interior and exterior spaces. Based on this data a numeric simulation can be performed and a comprehensive, standard-compliant (International Standard 10211 ISO 2005, Ward 2006) evaluation can be
performed. Figure 77 illustrates the input data requirements concerning building materials and building component joint’s geometry representation within AnTherm. Geometry is represented by a structured coordinate list implementing a layer-principle that allows to draw building components based just on rectangles (the tool considers just visible components, allowing to perform boolean-operations with the different rectangles above each other.

Figure 77. Input dialogues for Building materials’ geometry and physical properties in ANThERM.

To facilitate thermal bridges evaluation, the SEMERGY environment would require a number of extensions and modifications:
- Joints of building components need to be represented in the SBM in detail. These joints could be two dimensional (enclosure/enclosure or enclosure/aperture) or three dimensional (more than two enclosure/aperture elements in one junction). As the representation of such building joints can be considered as quite complex, it is suggested to develop templates for the most common thermal bridge configurations. However, the automated derivation of a thermal bridge configuration based on the data already provided within the SBM (for instance the order, thickness and physical properties of the different layers of building components) should be considered a matter of research. Figure 78 shows an example of a building component joint in reality, its required representation in a thermal bridging tool and its current representation in SBM (previously used in the section about building representation models).

- Complex geometry input in accordance with geometry requirements of AnTherm needs to be facilitated through the GUI (or through CAD/BIM-import functionality). Ideally a list of coordinates of all relevant elements being relevant for the thermal bridge evaluation should be acquired. It is necessary to ensure a complete representation of the corresponding building detail.

- Result representations and visualisations need to be designed and implemented within the GUI.

- The issue of algorithmic cost of iterative performance simulations (compare section 8.7.3) needs to be addressed for the thermal bridges evaluation as well. This problem might be increased in view of the fact that building regularly show not one, but a number of thermal bridges. Literally, each change in geometry or material of the thermal envelope can be considered as thermal bridge.

Figure 78. Attica detail of a flat roof (partially derived from Aalen 2014, modified): Left shows the detail as architectural drawing, in the middle the necessary level of detail for a thermal bridge evaluation tool, right the current representation in the SEMERGY environment.
11.2. Implementation of techniques to upscale SEMERGY for urban decision support

One of use-cases identified and targeted in the SEMERGY project was the case of building group assessments. Potential user groups of this scenario include municipalities, developers and managers of large portfolios of real estate. The major idea was that the SEMERGY environment could be utilized to identify strategies to optimize not a single building, but a compound of buildings up to the size of a small town or a city quarter. Examination of such strategies could for instance help answer questions such as

- What is the optimal policy for granting subsidies to building owners in a city? Should a subsidy incentive target all measures for improving the thermal quality of buildings, or rather focus on specific efforts?

- What is the impact of thermal retrofit on buildings of different ages in the same city?

- What levels of reduction could be reached with the optimal allocation of given financial resources for city renewal?

- What is the impact of density modifications in urban structures on their energy demand?

Moreover, the urban application of SEMERGY could offer beneficial as a modelling tool for other related research efforts. For instance, the research project ENUR (“Energie im urbanen Raum”, ENUR 2014) tries to evaluate aspects of increasing the energy-efficiency of municipalities from spatial planning and governance point of view. Hereby, SEMERGY could help to evaluate different strategies of increasing the urban energy-efficiency via offering automated large-scale energy-related calculation support.

In this context, also the utilization of already data repositories of existing certifications for buildings could be considered. Some Austrian provinces (Salzburg, Carinthia, Styria) store energy certificates of buildings within their regions in a centralized database (Zeus 2014). The use of already existing data could facilitate urban or regional evaluations, with SEMERGY as an tool to fill gaps in the data and to validate existing data.

Another example for the utilization of SEMERGY as calculation environment for impact analysis on an urban level is a recent research project (VIG-SYS-RENO 2014) examining a novel vacuum-glazing product for building retrofit. SEMERGY hereby could help to estimate implications of large scale application of such glazing products on heating demand.

To enable the use of SEMERGY on an urban level, the following aspects have to be considered and addressed in detail:

- Multi-instancing / Co-simulation: The current SEMERGY deployment is addressed for optimization of one building. Inquiries on urban scale would require the capability of performance assessment of multiple instances of buildings. Moreover many inquiries on urban level demand that buildings
should not be assessed as isolated objects, but understood as connected entities influencing each other.

- Urban resolution of data: Geometry data on urban scale might be rougher in resolution than the geometry data used regularly in building performance assessment. Building representations coming from GIS-systems might lack information about their building components and transparent building parts, therefore it could become necessary to default or estimate such information. Moreover, the larger scale of consideration could entail a reduced resolution in the performance indicators derived from SEMERGY. Another reduction in resolution could for example happen toward building component semantics: For instance, to keep urban scale calculations on a feasible and useful level, instead of layered building components simple building part representations could be used. In such a case, thermal building performance properties would rather be based on predefined U-Values than on detailed layerwise calculation.

- Introduction of “agents” and “fuzzy data”: Certain urban inquiries address smart-grid-related aspects. Hereby the values for energy demand (e.g. heating demand) and energy supply (e.g. via solar collectors) at a given particular point in time and at a certain location play a role. To be able to simulate realistic scenarios, the introduction of “agents” representing different user- or building-behavior could be useful. Such behavior that for instance influenced ventilation rates or internal gains in different buildings could be based on demographic data: Students might show different building operation than persons in retirement. Such model assumptions, however, can be considered as uncertain. The introduction of random values (fuzzy data) for certain input data could help capture such uncertainties and help develop more realistic models.
12. Conclusion

The present dissertation discussed different aspects of the SEMERGY environment, which can be considered as a comprehensive approach to web-enabled, optimization-based decision support for building design and retrofit.

The project’s structure demanded a versatile and modular research and realization approach. This determined a very close collaboration between specialists of building science and of computer science. The development tasks, in the end, determined the structure of this dissertation. It was considered important to prove the applicability of certain ideas and technologies. Therefore certain parts of the research were conducted very explicitly and brought forward, while other tasks were shifted to the later phases of the project. For instance, the development of semantic-web supported data retrieval for different building-performance-assessment tasks focused on the data regarding building products first. After a successful proof of concept (illustrated in the running prototype available at www.semergy.net) the efforts to implement ontology-based data management for other building-related information started and are under implementation. This includes the data-retrieval of subsidy programs, parsing of regulations and other similar tasks.

Despite various worldwide research efforts towards seamless exchange of building information and joint design and performance assessment, a universal solution for this challenge has not been developed until today. The ongoing efforts toward interoperability are developing fast but not necessarily focus on building performance evaluation. Moreover, existing tools of building performance evaluation not necessarily correspond with the requirements and expertise with the design community. In this specific area the SEMERGY approach can be seen as a step forward toward development of a comprehensive environment for building planning and retrofit. An important and central feature of the environment is the integration of semantic web technologies, which are expected to be a central feature of the next generation of the World Wide Web in the coming years.

SEMERGY can be considered as a proof of concept that the utilization of semantic web-technologies can be successfully implemented in the AEC-context, more specifically to address the challenge of data accumulation and retrieval for building performance assessment tasks. However, the vision of automated integration of all building-performance related information into the planning process, while possible from the technical point of view, requires the involvement of stakeholders (planers, building product vendors, governmental bodies) to collaborate in their efforts for facilitation of the planning and building process. Rules and standards for representation and web-publication of building product data need to be defined and proposed to ensure that domain data interoperability is ensured.

The developments described in the SEMERGY context should not be considered as a competitive effort to develop interoperability schemes or calculation tools. Rather SEMERGY envisions the existing methods and tools as valuable modules that can be used for data-exchange and building performance assessment. This is underlined by the fact that mapping schemes for interaction with the interoperability standards such as gbxml are currently under development and links to common performance assessment tools are being established.
The development of the SEMERGY environment involves a group of highly-motivated scientists of different fields. The SEMERGY research project is intended to be progressed in different related research efforts, where its role is determined as a robust and versatile calculation scheme.

As conclusion of this work, the novel accomplishments in various aspects of the SEMERGY project - as presented in this dissertation - are summarized:

The general architecture of the system emerged from and was built upon past efforts (SEMPER), with special attention to use-cases, user-groups and aspects of interoperability and extendibility.

As a core development, a building data representation that facilitates the interaction of calculation engines, data sources, optimization efforts and knowledge of building construction was developed: The SEMERGY Building Model (SBM). Inspired by previous developments and the general efforts toward interoperability, the SBM was designed to be an object-orientated, space-based, extendable and performance-assessment-compliant building model.

To enable automated identification of alternative design options within the SEMERGY environment, an extensive research effort was dedicated to the composition, structure and characteristics of past and contemporary building construction components. This resulted in creation of an extensive set of building component templates, and a corresponding rule-based logic used in alternative queries.

The retrieval and provision of building-related semantic data for population of the SBM and for use within the different attached simulation and calculation engines was supported by semantic web technologies as envisioned by Berners-Lee et al. (2009). As a first result, an extensive ontology of building components was generated based on existing data repositories that is used within the KPI-calculation and simulation and the optimization in the SEMERGY environment. However, ongoing efforts target various other types of data to be managed in ontologies and used in the SEMERGY environment (tax and subsidy incentives, climate data, etc.).

A number of calculation engines were either programmed or (as third party tools) coupled with the SEMERGY environment. These included tools for derivation of heating demand, ecological performance and investment cost, and are to be extended with dynamic thermal simulation and summer overheating evaluation. Moreover, other domains of building performance evaluation, such as lighting, room acoustics and thermal bridge evaluation are currently under examination for future coupling with the SEMERGY environment. Mathematical optimization was implemented in the SEMERGY environment to enable the identification of Pareto-optimal solutions. Thereby the evolutionary algorithm approach was deployed to keep the computational efforts feasible.

For interaction with different user groups, both a graphical user interface and import / export schemes were designed. While the former facilitates communication of design intentions, preferences and optimization results for novice users, the latter offers a feasible way of data integration into the SEMERGY environment for professionals.
12.1. Contribution to the SEMERGY development

The SEMERGY project brings together a number of different fields of scientific research including building performance, building construction, semantic web technologies and software engineering. The contributions of the Department of Building Physics and Building Ecology (BPI), VTU included all building related and building physics related aspects of the project, while the lead partner (the Information & Software Engineering Group IFS, VTU) was charged with project management and technical realization of the planned structure (programming the environment). As communication between researchers of different fields does not necessarily involve the same vocabulary, the project participants held regular weekly meetings to discuss unclear topics and concepts and work on the development of the environment.

The author’s contribution in the development of the SEMERGY environment, alongside the management and administration of the BPI-related project content, is illustrated via the SEMERGY-workflow scheme in Figure 79. Primary contributions included the

- Evaluation, examination and selection of calculation and simulation engines that should be coupled with the SEMERGY environment. “Examination” included the analysis of content and structure of required input and delivered output data, as well as considerations toward usefulness for the purposes targeted with SEMERGY and the tools’ technical and organizational aspects. Calculation and Simulation engines include furthermore the compliance checking routines within SEMERGY.

- Definition of objective criteria for optimization efforts.

- Development of the alternative identification module and the templates and their incorporated properties.

- Design of the SEMERGY workflow and management of interactions between Ontologies, Calculation and Simulation modules, templates and the mathematical optimization.

- Communication with third parties. This included professionals in the AEC-field, the representatives of architects from the Austrian chamber of architects, producers of building certification and simulation tools, and clients.
Figure 79. Author’s primary contribution in the development of the SEMERGY environment (grey underlay). The author contributed, however, to the majority of all other research activities within the project in collaborative efforts or as consultant.
13. REFERENCES


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Publications related to SEMERGY:


People involved in the Semergy project (* Department of Building Physics and Building Ecology, VTU; ** Department of Information and Software Engineering, VTU:

- Univ.Prof. Dr. A. Mahdavi*
- Univ.Ass. DI Ulrich Pont*
- Dr. Sokol Dervishi*
- Univ.Ass. DI Stefan Glawischnig*
- Neda Ghiassi, MSc.*
- Mahnameh Taheri, MSc.*
- Kristopher Hammerberg, MSc.*
- Dawid Wolosiuk, BSc.*
- Christian Sustr, BSc.*
- Andreas Wurm, BSc.*
- Isabella Merz, BSc.*
- Univ.Prof. Dr. A Min Tjoa**
- Dr. Stefan Fenz**
- Dr. Thomas Neubauer**
- Mag. Johannes Heurix**
ANNEX A: Further Description of the SEMERGY Building Model (SBM)

Figure A01. SEMERGY Building Model – Physical data: Geometry (from Ghiassi 2013)
Figure A02. SEMERGY Building Model – Physical data: Semantics (from Ghiassi 2013)
Figure A03. SEMERGY Building Model – Calculation parameters and Operational data (from Ghiassi 2013)
Figure A04. Classes Site, Location and Feature (from Ghiassi 2013)

Figure A05. Classes Building, Zone and Section (from Ghiassi 2013)
Figure A06. Classes Space, Partition and Enclosure (from Ghiassi 2013)
Figure A07. Classes Aperture, Simple and Adjustable shading (from Ghiassi 2013)
Figure A08. Classes Construction and associated sub-classes. (from Ghiassi 2013)
Figure A09. Classes Layer and associated sub-classes (from Ghiassi 2013)
Figure A10. Classes Material and its various instances (from Ghiassi 2013)
Figure A11. Operational data classes and properties (from Ghiassi 2013)
ANNEX B_01: Screenshots of GUI – SEMERGY Basic
**Windows**

**GF NORTH ORIENTATION**

Please specify the number of windows for each wall of the GF.

<table>
<thead>
<tr>
<th>Window</th>
<th>Width [in cm]</th>
<th>Height [in cm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Window 1</td>
<td>120</td>
<td>150</td>
</tr>
<tr>
<td>Window 2</td>
<td>120</td>
<td>150</td>
</tr>
<tr>
<td>Window 3</td>
<td>120</td>
<td>150</td>
</tr>
<tr>
<td>Window 4</td>
<td>120</td>
<td>150</td>
</tr>
<tr>
<td>Window 5</td>
<td>120</td>
<td>150</td>
</tr>
<tr>
<td>Window 6</td>
<td>120</td>
<td>150</td>
</tr>
<tr>
<td>Window 7</td>
<td>120</td>
<td>150</td>
</tr>
<tr>
<td>Window 8</td>
<td>120</td>
<td>150</td>
</tr>
</tbody>
</table>
## Constructions

**Loadbearing external wall**

<table>
<thead>
<tr>
<th>Singlelayer masonry walls with exterior insulation finishing system</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Masonry:</strong></td>
</tr>
<tr>
<td><strong>Insulation:</strong></td>
</tr>
<tr>
<td>Take construction into account during optimisation:</td>
</tr>
</tbody>
</table>

**Doublepitch roof**

<table>
<thead>
<tr>
<th>Completely insulated rafters with wood substructure and plasterboard</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rafters w/ full insulation:</strong></td>
</tr>
<tr>
<td>Take construction into account during optimisation:</td>
</tr>
</tbody>
</table>
Energy demand - Status Quo

Evaluation

The current energy demand of your building is approximately 3375 kWh/year, which is equivalent to 276 kWh/m².

Optimization

Maximum costs of optimization (in €): 50000

276 kWh/m² → Estimated heating costs: 2369 €
Evaluation
The current energy demand of your building is approximately 35.733 kWh/year, which is equivalent to 276 kWh/m².

Optimization
Maximum costs of optimization (in €): 50000
Energy demand - Status Quo

Evaluation

The current energy demand of your building is approximately 33,753 kWh/year, which is equivalent to 276 kWh/m².

Optimisation

Maximum costs of optimisation in €:

50,000

During the optimisation process, SEMERGY calculates renovation measures suited to your type of construction and budget. For each of the calculated renovation measures, cost, sustainability information and expected energy savings are shown. In addition, SEMERGY shows on which element (e.g., external wall or roof) the renovation work has to be performed in order to achieve the desired result.

33%
### Optimisation Results

<table>
<thead>
<tr>
<th>Heating demand (kW/m²) per m²</th>
<th>Investment costs (automated in euros)</th>
<th>Sustainability (total CO2)</th>
<th>Refurbished elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>139</td>
<td>2983</td>
<td>E0</td>
</tr>
<tr>
<td>2</td>
<td>129</td>
<td>2450</td>
<td>E0</td>
</tr>
<tr>
<td>3</td>
<td>126</td>
<td>2950</td>
<td>E0</td>
</tr>
<tr>
<td>3</td>
<td>123</td>
<td>2450</td>
<td>E0</td>
</tr>
<tr>
<td>2</td>
<td>123</td>
<td>2950</td>
<td>E0</td>
</tr>
<tr>
<td>2</td>
<td>122</td>
<td>2450</td>
<td>E0</td>
</tr>
</tbody>
</table>

**Refurbished elements**

- **Wall**
  - Single-layer Masonry wall with exterior insulation (new system, exterior renovated)
  - Lining (innermost to outermost):
    1. Masonry: Original material (2.0 cm)
    2. EPS Insulation: Wood fibre insulation panels (10.0 cm)
    3. EPS Plaster: Lime cement plaster (interior and exterior) (5.0 cm)

- **Roof**
  - Double-pitch roof: Insulated rafters with wood substrates and plasterboard, interior renovated
  - Lining (innermost to outermost):
    1. Douglas Fir: Douglas fir wood board (9.5 cm)
    2. Insulation: Engineered wood boards (1.5 cm)
    3. Insulation: Engineered wood bars (1.5 cm)
    4. Insulation: Engineered wood bars (1.5 cm)
    5. Insulation: Engineered wood bars (1.5 cm)
    6. Insulation: Engineered wood bars (1.5 cm)
    7. Insulation: Engineered wood bars (1.5 cm)
    8. Insulation: Engineered wood bars (1.5 cm)
    9. Insulation: Engineered wood bars (1.5 cm)
    10. Insulation: Engineered wood bars (1.5 cm)
    11. Insulation: Engineered wood bars (1.5 cm)

**Break-even point**

![Break-even point graph](https://www.semergy.net/content/)

**Energy savings**

**Investment costs**

[Previous step] [Next step]
The generated report contains your chosen solution. You can download it by clicking on the "Download" button. In addition, you can view the report in the overview at any time.

Download  

Go back  Complete
ANNEX B_02: Screenshots of GUI – SEMERGY

The construction or renovation of a building is a considerable and costly task. SEMERGY helps you plan energy-efficient buildings with consideration to your specific budget.

---

Reduce energy consumption
SEMERGY helps you identify energy-efficient renovation and construction measures.

Reduce costs
SEMERGY helps you reduce your building's annual energy costs and the renovation costs.

Efficient planning
SEMERGY includes current legal requirements and potential funding in its calculations.

Example single-family house
Based on the information you provide, SEMERGY creates an appropriate renovation strategy. See our example report on a single-family house for a demonstration of the full range of SEMERGY's services.

Download the PDF

Example multi-family house
SEMERGY takes your current living situation into account. Depending on the year of construction, structural considerations, and other factors, SEMERGY calculates the ideal renovation strategy.

Download the PDF

---

Basic data
Describe your building in four easy steps. Depending on the year of construction, typical constructions of the time period are provided and make entering further building information easier.

Roof data
Whether you have a developed attic or a single-pitch roof, SEMERGY helps you calculate your roof situation in just a few steps.

Building geometry
The building geometry can be described using simple drawing tools. SEMERGY automatically calculates the necessary wall and ceiling areas.

Status quo
Based on your input, SEMERGY calculates your building's status quo. This forms the basis for calculating the ideal renovation strategy best suited to your budget.

Interactive renovation planning
Based on your budgetary constraints, SEMERGY calculates specific renovation options individually tailored to your building. Choose the ideal option and you can immediately see the resulting costs and energy savings.
Log in

Email
whichpoint@tuwien.ac.at
Password

Forgot your password? Log In

Please enter your email address and password.
### SEMERGY

#### Roof Information

**Roof type**
- Flat roof
- Double pitch roof
- Hip roof
- Single pitch roof
- Tented roof

**Attic type**
- Attic conditioned
- Attic unconditioned
- Attic converted inside

**Additional information**
- **440**: Ridge height [in cm]
- **20**: Roof slope [in degrees]
- **250**: Jamb wall height [in cm]

**Roof base shape**
- Rectangular
- L-shape
- T-shape
- Cross
- H-shape
- S-shape
- U-shape

---

A34
Heating System

Address
- Basic data
- Heating systems
- Geometry
- Constructions
- Status quo
- Analysis
- Report

Heating system

Natural gas

Go back
Next
Add a roof window

Roof window type: [Flat, Vertical]
Orientation: [North, East, South, West]
Number of roof windows: 5
Roof window height (in cm): 150
Roof window width (in cm): 200
Shaded: [Yes, No]
### Load-bearing external wall

**Single-layer masonry walls with exterior insulation finishing system**

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Interior plaster</td>
<td>2.0 cm</td>
</tr>
<tr>
<td>2. Masonry</td>
<td>25.0 cm</td>
</tr>
<tr>
<td>3. Insulation</td>
<td>1.5 cm</td>
</tr>
<tr>
<td>4. Exterior plaster</td>
<td>5.0 cm</td>
</tr>
</tbody>
</table>

Take construction into account during optimisation: [Optimise] [Ignore] [Replace]

### Double-pitch roof

**Completely insulated rafters with wood substraction and plasterboard**

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Gypsum plasterboard</td>
<td>2.5 cm</td>
</tr>
<tr>
<td>2. Lathing</td>
<td>4.0 cm</td>
</tr>
<tr>
<td>3. Vapour barrier</td>
<td>0.1 cm</td>
</tr>
<tr>
<td>4. Rafters w/ full insulation</td>
<td>20.0 cm</td>
</tr>
<tr>
<td>5. Solid wood sheathing</td>
<td>4.0 cm</td>
</tr>
<tr>
<td>6. Permeable roof membrane</td>
<td>0.1 cm</td>
</tr>
<tr>
<td>7. Lathing/evaporation</td>
<td>8.0 cm</td>
</tr>
<tr>
<td>8. Roof lathing</td>
<td>5.0 cm</td>
</tr>
<tr>
<td>9. Roofing</td>
<td>5.0 cm</td>
</tr>
</tbody>
</table>

Take construction into account during optimisation: [Optimise] [Ignore] [Replace]

### Non-load-bearing internal wall

**Hollow brick partition wall, plastered**

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Plaster</td>
<td>2.5 cm</td>
</tr>
<tr>
<td>2. Masonry</td>
<td>10.0 cm</td>
</tr>
<tr>
<td>3. Plaster</td>
<td>2.5 cm</td>
</tr>
</tbody>
</table>

Take construction into account during optimisation: [Optimise] [Ignore] [Replace]

### Floor with soil contact (basement or ground floor)

**Cold basement/ floor slab, renovated**

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Floor finish</td>
<td>2.0 cm</td>
</tr>
<tr>
<td>2. Screed</td>
<td>5.0 cm</td>
</tr>
<tr>
<td>3. Fill</td>
<td>6.0 cm</td>
</tr>
<tr>
<td>4. Concrete slab</td>
<td>20.0 cm</td>
</tr>
</tbody>
</table>

Take construction into account during optimisation: [Optimise] [Ignore] [Replace]
SEMERGY

Doors and Windows

Signed as: Mike Root

Exterior window
Double glazing
Take construction into account during optimisation:
Optimize Ignore Replace

Flat roof window
Double glazing
Take construction into account during optimisation:
Optimize Ignore Replace

Interior door
Solid wooden / plastic door [area]
Take construction into account during optimisation:
Optimize Ignore Replace

Go back Next
Evaluation

The current energy demand of your building is approximately 8.325 kWh/year, which is equivalent to 221 kWh/m².

Optimisation

Optimisation will be performed with regard to heating demand and optimisation costs. Do you also want to take sustainability of construction materials into account?

Maximum costs of optimisation [in €]: 50000

Yes  No
Evaluation
The current energy demand of your building is approximately 8323 kWh/year, which is equivalent to 221 kWh/m².

Optimization
Optimization will be performed with regard to heating demand and optimization costs. Do you also want to take sustainability of construction materials into account?

Maximum costs of optimization (in €): 50000

The optimization process may take a few minutes to complete. Do you want to start the optimization?

[Cancel] [Perform optimization]
Evaluation
The current energy demand of your building is approximately 8332.5 kWh/year, which is equivalent to 221 kWh/m².

Optimisation
Optimisation will be performed with regard to heating demand and optimisation costs. Do you also want to take sustainability of constructive measures into account?

Maximum cost of optimisation [in €]: 50000

During the optimisation process, SEMERGY calculates renovation measures suited to your type of construction and budget. For each of the calculated renovation measures, costs, sustainability information and expected energy savings are shown. In addition, SEMERGY shows on which element (e.g. external wall) or which renovation work has to be performed in order to achieve the desired result.
The generated report contains your chosen solution. You can download it by clicking on the Download button. In addition, you can view the report in the overview at any time.

Download

Go back Complete
Your personal report contains recommendations for optimising the energy efficiency, the cost structure, and the sustainability of your planned construction.
WHAT IS SEMERGY?

The largest share of energy spent in buildings is used for heating and cooling. Implementing insulating measures is therefore essential for a long-term reduction of energy expenditure and the associated building costs.

One central goal of Austrian and European climate policy is the reduction of building energy consumption. To this end, SEMERGY provides a comprehensive solution for identifying the most cost-efficient measures needed to make existing and newly constructed buildings more energy-efficient. Among other things, SEMERGY helps the user answer the following questions:

- What measures can be implemented to achieve a particular building energy rating?
- How much do these measures cost compared against the expected long-term energy savings?
- Do the recommended measures comply with the legal requirements?
- Is there public funding for the implementation of these measures?

SEMERGY is ideally suited for planning energy-efficient construction and renovation projects, if you are a private individual, building contractor, architect/planner, component manufacturer and vendor, real estate agent, facility management company, public shareholder in the energy sector and a building "end user" (i.e. owner, tenant, etc.). Apart from identifying appropriate packages of measures (e.g. insulated-glazing windows, suitable insulation materials, energy-efficient wall and floor constructions) SEMERGY considers your available budget, sustainability of the used products, the products' compatibility, legal requirements, and the long-term energy and cost saving potential. Based on the specific situation of your construction, the user can go through several renovation or construction scenarios and determine the option that is best suited for their needs.

WHO WE ARE

Xylem Technologies was established in Vienna in 2009 with the aim of developing high-quality, research-driven software solutions in the areas of sustainability and energy efficiency. With SEMERGY, Xylem Technologies provides an innovative tool for planning energy-efficient renovation strategies for existing buildings.

WHAT WE DO

Our goal is the reduction of CO₂ emissions as a contribution to national and international climate targets. Our solutions help our customers directly realise cost advantages by optimising building energy efficiency and harmonising energy providers and consumers.

The optimisation recommendations, including all values (costs, etc.), shown here are for information purposes only.
YOUR ADVANTAGES

Based on your individual building configuration and your budgetary means, SEMERGY calculates a customized renovation package for your building’s facade, doors/windows, roof, basement slab and top floor.

The latest construction materials data and costs as well as their structural and ecological properties are used for the calculation of your renovation project. From the calculated results, you can easily choose your ideal solution regarding energy efficiency, sustainability and cost efficiency.

**ENERGY EFFICIENCY**

SEMERGY helps you identify efficient renovation and construction measures.

The calculations take compatibility and appropriate use of building materials into consideration, which rules out using the wrong construction materials (e.g. using moisture-sensitive insulation materials in areas with soil contact).

**SUSTAINABILITY**

SEMERGY allows you to plan an ecologically sustainable renovation or construction project.

The use of sustainable materials may be mandatory, subsidized or desired by the customer for personal reasons. That is why SEMERGY offers a separate optimisation parameter for calculating solutions with the highest possible proportion of sustainable building materials.

**COST EFFICIENCY**

SEMERGY helps you reduce your building’s annual energy costs and the investment required to a minimum.

In addition, SEMERGY provides a cost-benefit calculation for each calculated solution and visualises the time needed for amortising the investment in a concise graph. Rising energy costs are taken into account as well in order to give you the most realistic estimate possible.

---

The optimisation recommendations, including all values (costs, etc.), shown here are for information purposes only.
OVERVIEW

PROJECT TYPE: Renovation
Construction type: Solid masonry/concrete
Address: KARLSPLATZ 13, 1015, WIEN
North-facing orientation: 27°

BUILDING TYPE: Single-family house
Year of construction: 1970 - 1979

The renovation measures SEMERGY calculates and recommends are individually tailored to your construction and personal financial situation. However, the specific planning detail and implementation require the employment of a professional planner. With its clear presentation of your building’s status quo, the SEMERGY report saves you additional survey work and therefore additional costs when planning the details of your construction.

On the following pages, the information you provided will be summed up in a clear and understandable form. This allows you to archive the provided information independently, and also allows you to consult any planner of your choice for the practical implementation of your project. Your building’s key data is as follows:

- Roof shape: Double-pitch roof
- Roof slope: 2°
- Ridge height: 3.7 m
- Jamb wall height: 2.60 m
- Roof base shape: L-shape
- Heating system: Natural gas

The optimisation recommendations, including all values (costs, etc.), shown here are for information purposes only.
The floor plan shows a schematic of the rooms on each floor. Please note that the wall thickness is schematic and not to scale. The plan elements are designated as follows: RED: walls; BROWN: doors; BLUE: windows.

The room height given below designates the ceiling height, i.e. the vertical distance from the finished floor to the finished ceiling. The gross floor area (GFA) includes not only the floor area of the actual rooms but also the area taken up by external and internal walls and is therefore somewhat higher than the useable floor area (UFA).

| Room height | 2.60 m |
| Gross floor area (GFA) | 129.41 m² |
| Rooms | 1 |

The optimisation recommendations, including all values (costs, etc.), shown here are for information purposes only.
Rooms

The rooms below are listed with their respective functions. If there is more than one room per floor with a particular function, those rooms are numbered consecutively. Volume (room height multiplied by GFA) as well as GFA are given for each room. Please note that the GFA is larger than the UFA.

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Volume</th>
<th>Gross floor area (GFA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Living room (LRI)</td>
<td>433.12 m$^3$</td>
<td>129.41 m$^2$</td>
</tr>
</tbody>
</table>
Windows

For windows, sill height, as well as the actual window height, width, and orientation, are shown. Windows are also numbered consecutively.

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Sill height</th>
<th>Width</th>
<th>Height</th>
<th>Orient.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Window (W1)</td>
<td>0.9 m</td>
<td>1.2 m</td>
<td>1.5 m</td>
<td>West</td>
</tr>
<tr>
<td>2</td>
<td>Window (W2)</td>
<td>0.9 m</td>
<td>1.2 m</td>
<td>1.5 m</td>
<td>West</td>
</tr>
<tr>
<td>3</td>
<td>Window (W3)</td>
<td>0.9 m</td>
<td>1.2 m</td>
<td>1.5 m</td>
<td>North</td>
</tr>
<tr>
<td>4</td>
<td>Window (W4)</td>
<td>0.9 m</td>
<td>1.2 m</td>
<td>1.5 m</td>
<td>North</td>
</tr>
<tr>
<td>5</td>
<td>Window (W5)</td>
<td>0.9 m</td>
<td>1.2 m</td>
<td>1.5 m</td>
<td>North</td>
</tr>
<tr>
<td>6</td>
<td>Window (W6)</td>
<td>0.9 m</td>
<td>1.2 m</td>
<td>1.5 m</td>
<td>North</td>
</tr>
<tr>
<td>7</td>
<td>Window (W7)</td>
<td>0.9 m</td>
<td>1.2 m</td>
<td>1.5 m</td>
<td>South</td>
</tr>
<tr>
<td>8</td>
<td>Window (W8)</td>
<td>0.9 m</td>
<td>1.2 m</td>
<td>1.5 m</td>
<td>South</td>
</tr>
<tr>
<td>9</td>
<td>Window (W9)</td>
<td>0.9 m</td>
<td>1.2 m</td>
<td>1.5 m</td>
<td>South</td>
</tr>
<tr>
<td>10</td>
<td>Window (W10)</td>
<td>0.9 m</td>
<td>1.1 m</td>
<td>1.5 m</td>
<td>East</td>
</tr>
<tr>
<td>11</td>
<td>Window (W11)</td>
<td>0.9 m</td>
<td>1.1 m</td>
<td>1.5 m</td>
<td>East</td>
</tr>
<tr>
<td>12</td>
<td>Window (W12)</td>
<td>0.9 m</td>
<td>1.1 m</td>
<td>1.5 m</td>
<td>East</td>
</tr>
<tr>
<td>13</td>
<td>Window (W13)</td>
<td>0.9 m</td>
<td>1.2 m</td>
<td>1.5 m</td>
<td>South</td>
</tr>
</tbody>
</table>

The optimisation recommendations, including all values (costs, etc.), shown here are for information purposes only.
## Roof window group

Roof windows are specified in groups and divided into (pitched) flat and vertical dormer roof windows.

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Quantity</th>
<th>Width</th>
<th>Height</th>
<th>Orient.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Roof window group 1</td>
<td>5</td>
<td>1.2 m</td>
<td>1 m</td>
<td>North</td>
</tr>
</tbody>
</table>

The optimisation recommendations, including all values (costs, etc.), shown here are for information purposes only.
STATUS QUO ENERGY REQUIREMENTS

Based on the building configuration you entered, the current energy requirement and sustainability of currently used construction materials have been calculated. The building construction includes base areas, room heights, number of floors, room function, wall and floor construction as well as the geographical position of your planned construction or renovation.

The energy requirement has been calculated using an annual calculation method and cannot be equated to that used for the energy pass. However, it is a solid reference value sufficient for the rough plan of your project.

Estimated heating energy requirements per year: 276 kWh/m²a
Estimated heating costs per year: ca. 2360 €

Below is a list of all current constructions. The reference in the construction name indicates whether the optimisation takes the respective construction into account (to be optimised) or whether it is ignored (remains unchanged).

The optimisation recommendations, including all values (costs, etc.), shown here are for information purposes only.
STATUS QUO - LOAD-BEARING EXTERNAL WALL

Single-layer masonry walls with exterior insulation finishing system (U-value: 1.25 W.m⁻².K⁻¹) - To be optimised

Layers (innermost to outermost):

<table>
<thead>
<tr>
<th>No.</th>
<th>Layer name</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Interior plaster</td>
<td>2.00 cm</td>
</tr>
<tr>
<td>2</td>
<td>Masonry</td>
<td>25.00 cm</td>
</tr>
<tr>
<td>3</td>
<td>Insulation</td>
<td>4.00 cm</td>
</tr>
<tr>
<td>4</td>
<td>Exterior plaster</td>
<td>1.00 cm</td>
</tr>
</tbody>
</table>

External walls are completely optimised, i.e. regardless of whether the areas are actually part of the thermal envelope (adjacent to a heated room).
STATUS QUO - DOUBLE-PITCH ROOF

Completely insulated rafters with wood substructure and plasterboard (U-value: 0.75 W.m$^{-2}$.K$^{-1}$) - To be optimised

Layers (innermost to outermost):

<table>
<thead>
<tr>
<th>No.</th>
<th>Layer name</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Gypsum plasterboard</td>
<td>2.50 cm</td>
</tr>
<tr>
<td>2</td>
<td>Lathing</td>
<td>4.00 cm</td>
</tr>
<tr>
<td>3</td>
<td>Vapour barrier</td>
<td>0.10 cm</td>
</tr>
<tr>
<td>4</td>
<td>Rafters w/ full insulation</td>
<td>20.00 cm</td>
</tr>
<tr>
<td>5</td>
<td>Solid wood sheathing</td>
<td>4.00 cm</td>
</tr>
<tr>
<td>6</td>
<td>Permeable roof membrane</td>
<td>0.10 cm</td>
</tr>
<tr>
<td>7</td>
<td>Lathing/ventilation</td>
<td>8.00 cm</td>
</tr>
<tr>
<td>8</td>
<td>Roof lathing</td>
<td>5.00 cm</td>
</tr>
<tr>
<td>9</td>
<td>Roofing</td>
<td>5.00 cm</td>
</tr>
</tbody>
</table>

Roofs are completely optimised, i.e. regardless of whether the areas are actually part of the thermal envelope (adjacent to a heated room).

The optimisation recommendations, including all values (costs, etc.), shown here are for information purposes only.
STATUS QUO - DOORS AND WINDOWS

<table>
<thead>
<tr>
<th>No.</th>
<th>Type</th>
<th>Current product</th>
<th>U-value</th>
<th>Opt.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Exterior window</td>
<td>Double glazing</td>
<td>3.09</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>Roof window (flat)</td>
<td>Double glazing</td>
<td>3.40</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Exterior doors and windows are completely optimised, i.e. regardless of whether the areas are actually part of the thermal envelope (adjacent to a heated room). Roof window groups are considered in the optimisation if the attic is occupied.
OPTIMISED ENERGY REQUIREMENTS

Based on your individual energy consumption, investment cost and sustainability preferences, an ideal renovation recommendation has been calculated. The changed heating energy demand as well as the estimated investment costs and sustainability data are concisely shown in the table below.

Renovated layers/constructions in the table are shown in green type.

| Estimated heating energy requirements per year | 127 kWh/m²a |
| Estimated investment costs | ca. 23100 € |
| Estimated environmental footprint based on OI3 points | 3208 |

The optimisation recommendations, including all values (costs, etc.), shown here are for information purposes only.
OPTIMISATION
RECOMMENDATION

The diagramme below shows how long it will take for the recommended renovation plan to be amortised, i.e. when the annual energy savings exceed the investment costs (at the intersection of the red and green curve).

Depending on the chosen energy source, energy price increase estimates based on the increase rates of the past decade have been made. However, energy scarcity may accelerate these increases and so cause the savings to amortise the investment sooner than at the time shown.

Details about the used construction materials and implementation can be found on the following pages. Please note that the values shown are reference values calculated from limited data. Variances are possible depending on region.

The optimisation recommendations, including all values (costs, etc.), shown here are for information purposes only.
OPTIMISATION RECOMMENDATION - LOAD-BEARING EXTERNAL WALL

Single-layer masonry wall with exterior insulation finishing system, exterior renovated (U-value: 0.37 W.m\(^{-2}\).K\(^{-1}\))

Layers (innermost to outermost):

<table>
<thead>
<tr>
<th>No.</th>
<th>Layer name</th>
<th>Product class</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Interior plaster</td>
<td>Original material</td>
<td>2.00 cm</td>
</tr>
<tr>
<td>2</td>
<td>Masonry</td>
<td>Original material</td>
<td>25.00 cm</td>
</tr>
<tr>
<td>3</td>
<td>EIFS insulation</td>
<td>Wood fibre insulation panels</td>
<td>10.00 cm</td>
</tr>
<tr>
<td>4</td>
<td>EIFS plaster</td>
<td>Lime cement plasters (interior and exterior)</td>
<td>0.30 cm</td>
</tr>
</tbody>
</table>

Total gross floor area: 137.01 m\(^2\)
Total estimated renovation costs: ca. 9600 €

The optimisation recommendations, including all values (costs, etc.), shown here are for information purposes only.
# OPTIMISATION RECOMMENDATION - DOUBLE-PITCH ROOF

Insulated rafters with wood substructure and plasterboard, interior renovated (U-value: 0.15 W.m⁻².K⁻¹)

Layers (innermost to outermost):

<table>
<thead>
<tr>
<th>No.</th>
<th>Layer name</th>
<th>Product class</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Gypsum plasterboard</td>
<td>Gypsum plasterboard</td>
<td>0.95 cm</td>
</tr>
<tr>
<td>2</td>
<td>Lathing</td>
<td>Engineered wood boards</td>
<td>1.50 cm</td>
</tr>
<tr>
<td>3</td>
<td>Vapour barrier</td>
<td>Plastic vapour barriers and retarders</td>
<td>0.02 cm</td>
</tr>
<tr>
<td>4</td>
<td>Rafters w/ intermediate insulation</td>
<td>Straw insulation material</td>
<td>30.00 cm</td>
</tr>
<tr>
<td>5</td>
<td>Solid wood sheathing</td>
<td>Original material</td>
<td>4.00 cm</td>
</tr>
<tr>
<td>6</td>
<td>Permeable roofing underlayment</td>
<td>Original material</td>
<td>0.10 cm</td>
</tr>
<tr>
<td>7</td>
<td>Lathing/ventilation</td>
<td>Original material</td>
<td>8.00 cm</td>
</tr>
<tr>
<td>8</td>
<td>Roof lathing</td>
<td>Original material</td>
<td>5.00 cm</td>
</tr>
<tr>
<td>9</td>
<td>Roofing</td>
<td>Original material</td>
<td>5.00 cm</td>
</tr>
</tbody>
</table>

**Total gross floor area**: 131.71 m²

**Total estimated renovation costs**: ca. 9300 €

---

The optimisation recommendations, including all values (costs, etc.), shown here are for information purposes only.
# OPTIMISATION RECOMMENDATION - DOORS AND WINDOWS

<table>
<thead>
<tr>
<th>No.</th>
<th>Type</th>
<th>Current product</th>
<th>U-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Exterior window</td>
<td>Plastic-aluminium windows, double glazing</td>
<td>1.34</td>
</tr>
</tbody>
</table>

Plastic-aluminium windows, double glazing

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total area</td>
<td>22.96 m²</td>
</tr>
<tr>
<td>Total estimated renovation costs</td>
<td>ca. 4200 €</td>
</tr>
</tbody>
</table>

The optimisation recommendations, including all values (costs, etc.), shown here are for information purposes only.
POLICIES

This section lists violated renovation policies and other legal requirements. The policies are divided into the following categories: Exceeded maximum U-values for relevant areas (e.g. walls or windows), minimum room heights and areas, and minimum window areas per room not reached.

MAXIMUM U-VALUES EXCEEDED

<table>
<thead>
<tr>
<th>No.</th>
<th>Floor</th>
<th>Room</th>
<th>Element</th>
<th>max U-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ground floor</td>
<td>Living room</td>
<td>Floor (soil contact)</td>
<td>0.4 W·m⁻²·K⁻¹</td>
</tr>
<tr>
<td>2</td>
<td>Ground floor</td>
<td>Living room</td>
<td>Roof</td>
<td>1.7 W·m⁻²·K⁻¹</td>
</tr>
<tr>
<td>3</td>
<td>Ground floor</td>
<td>Living room</td>
<td>External wall (vs. exterior area)</td>
<td>0.35 W·m⁻²·K⁻¹</td>
</tr>
</tbody>
</table>

MINIMUM ROOM AREAS NOT REACHED

No floor area violations.

MINIMUM ROOM HEIGHTS NOT REACHED

No room height violations.

MINIMUM WINDOW AREAS NOT REACHED

No window area violations.

The optimisation recommendations, including all values (costs, etc.), shown here are for information purposes only.
THE NEXT STEPS

Based on your existing building, your budgetary means, and your chosen renovation preferences, an individual renovation recommendation has been calculated. The calculated energy savings as well as the investment costs are reference values and can vary depending on region. The report created by SEMERGY can only be used as a base for further planning by your builder or planner. You can find Austrian builders and planners in your area at http://firmen.wko.at, among others.

The information you enter is stored for future use and to allow you to modify or recalculate your planned renovation (e.g. regarding investment costs or the use of certain building materials). Construction materials as well as construction costs are continuously updated by the SEMERGY team, ensuring that your results are always up to date.

For information about funding in your state, follow the links below:

Vienna
http://www.wien.gv.at/amtshelfer/bauen-wohnen/wohnbaufoerderung/wohnungsverbesserung/thewosan.html

Lower Austria
http://www.noe.gv.at/Bauen-Wohnen/Sanieren-Renovieren.html

Upper Austria
http://www.land-oberoesterreich.gv.at/cps/rde/xchg/ooe/his.xsl/109741_DEU_HTML.htm

Salzburg
http://www.salzburger-wohnbaufoerderung.at/foerderungen/sanierung.html

Styria
http://www.verwaltung.steiermark.at/cms/beitrag/1679862/74575717/

Burgenland
http://www.burgenland.at/wohnbaufoerderung/sanieren

Carinthia
http://www.ktn.gv.at/143193_DE-Organisation-Wohnhaussanierung

Tyrol
https://www.tirol.gv.at/bauen-wohnen/wohnbaufoerderung/sanierung/

Vorarlberg
https://www.vorarlberg.at/vorarlberg/bauen_wohnen/wohnen/wohnbaufoerderung/weitereinformationen/wohnhaussanierung/wohnhaussanierung.htm
ANNEX D: CV of the author

ULRICH J. PONT

CURRICULUM VITAE

■ Personal information

Full name: Ulrich Johannes Pont
Date of birth: 06.06.1981 in Vienna / Austria
Current address Paradisgasse 62/2/6, A-1190 Vienna, Austria
Cell phone number +43 (0) 699 15678101
E-mail: ulrich.pont@tuwien.ac.at
Marital status unmarried
Family ao. Univ. Prof. i.R. Dr.med. Jörg Pont (father)
Dr.med. Elisabeth Pont (mother), 1 brother, 1 sister

■ Educational background

1987 – 1991 elementary school (23rd district of Vienna, Liechtensteinstraße)
1991 – 1999 high school (Kollegium Kalksburg, 23rd district of Vienna)
1997 language training in Dublin, Irland
1999 A-levels (cum laude)

■ Educational level - university

1999 – Architectural VTU
1999 - 2011 Architecture, VTU
In depth training in the fields of building physics & building ecology, digital architecture, project-management, light construction and membrane technology
Diploma thesis presenation 27.01.2011
Thesis topic: building energy performance calculation with static and dynamic calculation methods (grading: A)

2011 - Master of Building Science & Technology (VTU)
2003 ongoing attending of courses of business administration, civil engineering, information technology, and history of art.
### Work experiences & practice

1999
4 weeks internship at Austrian Chamber of Economics (WKO).

1999 - 2000
project work for Austrian Chamber of Economics (WKO), department for art, culture and design

2001 - 2004
catering organisation

2001
4 weeks internship with Architect Boris Podrecca, Vienna

2002 (ongoing *)
teaching & research activities at Department of Building Physics & Building Ecology, VTU (Univ.Prof. Dr. A. Mahdavi)


2003, Summer
sales assistant at Tony's Laufshop, Vienna 2nd district (store specialised on equipment for running sport)

2003 - 2006
event management (Formation dance sport club Perchtoldsdorf)

Social Services at Barmherzige-Brüder Hospital, Vienna 2nd district

2005
project work at Wehdorn Architekten

2005
Digitalising of plans of Austrian large scale residential buildings with Kotaschek Baumanagement

2005 - 2007
Data acquisition for facility management of UNIQA Tower (the new built office headquarters of a Austrian Insurance). Working with the company bergsmann pm.

2007 (ongoing)
diving instructor at academic sport club, section scuba-diving, (including performing practical training of beginners, organisation, …)

2009 (ongoing)
Partner at exikon arc & dec (www.exikon.at) in Vienna Austria

2011 – 2012
Lecturer at FH Schwechat for Bauphysik

2013 (ongoing)
Development partner and trainer for AnTherm (simulation tool for 3D evaluation of thermal bridges)

Working as search-and-salvage-diver in the Danube area.

Furthermore: small-scale project work in building’s refurbishment

*) including the following tasks and fields of work:

Preparation, administration, teaching and support: bachelor and master lectures of building physics and energy performance and simulation courses (find list as annex of this CV); coordination of external adjunct teachers, library, documentation of publications; content management and web design of www.bpi.tuwien.ac.at; creating teaching materials, project research (find publication list as annex), project management of and research work in five third-party funded research projects (SEMERGY, VIDEA, AGELFA, BEMOFA, VIGSYSRENO).
Research Interests

- Building Physics (Thermodynamics, Lighting, Acoustics, Fire Safety)
- Building Ecology (Life Cycle Assessment)
- Building Certification
- Building Construction
- Environmental Protection
- Structural engineering
- Building Information Modeling
- Project Management
- Art History

Languages:

- German: mother tongue, seminars on rhetorics
- English: excellent (speaking, writing and understanding)
- Latin: high-level knowledge
- Spanish, French, Italian: basic knowledge

Other Qualifications:

- Office applications: excellent knowledge of MS Office (Word, Excel, Powerpoint, etc.); Adobe Acrobat Professional, and other standard applications
- CAD & 3D: Autocad / Revit; Archicad; form-Z; Sketch-Up, Cinema 4D und 3D Studio Max, DraftSight
- Programming: Basic Knowledge in Java and C
- HTML & Webdesign (www.bpi.tuwien.ac.at; www.uni-tauchen.at; www.pont.co.at; et.al)
- Project management: MS Project, Visio
- Graphics: Adobe Creative Suite (Photoshop, Illustrator, Dreamweaver, etc.)
- Building physics related tools: Archiphysik; geq; PHPP (energy certification)
- EDSL TAS, Autodesk Ecotect (dynamic thermal simulation)
- Dialux (artificial and daylight)
- AnTherm (3D thermal bridges evaluation)
- Further Qualifications: working and teaching - Diving experience in handling of nitrox and compressed air, navigation, deep diving, dry suit diving, and many other special qualifications in this field
Leisure:

Diving, rock climbing, cycling, running, swimming, badminton

Traveling (long term stays in India, Thailand, Malaysia, Singapur, Cuba, South Africa, Israel, Egypt, Tunisia, Marocco, USA and most EU countries)

Languages and culture exchange, history of art, Nautics (nautic patent)

Selection of courses (co-)taught in the past years at Vienna University of Technology

(comprehensive list available via http://tiss.tuwien.ac.at):

253039 Bauphysik und Humanökologie VO (together with A.Mahdavi, A.Fail, M.Schuss);
253040 Bauphysik Übung UE (together with A. Mahdavi, et al.);
253062 Technischer Ausbau UE (together with A. Mahdavi, et al.);
259394 Design Studio 'rising*8 – interdiszipl. Planungsprozess UE (with S. Swoboda, A. Jonas, K. Tavoussi);
253146 Wahlseminar Bauphysik und Bauökologie SE (together with A. Mahdavi et al.);
259.302 Current Topics in Building Performance SE (together with A.Mahdavi et al.);
259305 Building Ecology VU (together with A. Mahdavi);
259309 Project Course UE (together with A. Mahdavi et al.);
259310 Thermal Building Performance Simulation (together with A. Mahdavi et al.);
259.314 Building Monitoring and Diagnostics VU (together with A. Mahdavi et al.);
259.340 Visual Building Performance Simulation VU (together with A. Mahdavi et al.);
259.342 Bauphysik des öko-effizienten Bauens VU (together with A. Mahdavi et al.);
259.343 Building Ecology Workshop SE (together with A. Mahdavi et al.)

Vienna, 29.07.2014
ANNEX E: Publication List of the Author

Publication list for
Ulrich Pont
E259 - Institute of Architectural Sciences
as any person named in the publication entry

59 records (2010 - 2014)

Books and Book Editorships (2)
"Journal of Building Physics - CESBP 2013 Special Issue Editors";

"Fassadenbautag 2014 - Zukunftsperspektiven im Fassadenbau";

Publications in Scientific Journals (8)
G. Adam, U. Pont, A. Mahdavi:
"Evaluation of thermal environment and indoor air quality in university libraries in Vienna";

P.P. Housez, U. Pont, A. Mahdavi:
"A comparison of projected and actual energy performance of buildings after thermal retrofit measures";

N. Saipi, M. Schuss, U. Pont, A. Mahdavi:
"Comparison of simulated and actual energy use of a hospital building in Austria";

L. Skoruppa, U. Pont, M. Schuss, A. Mahdavi:
"Thermal comfort in a refurbished low-energy house: The OEKOHAUS case study";
Advanced Materials Research - Web, 899 (2014), 70 - 76.

B. Sommer, U. Pont:
"Energy Design by Evolution: Applying Evolutionary Computing to Energy Efficient Architectural Design";

D. Wolosiuk, N. Ghiassi, U. Pont, F Shayeganfar, A. Mahdavi, S. Fenz, J. Heurix, A. Anjomshoaa, A. Tjoa:
"SEMERGY: Performance-Guided Building Design and Refurbishment within a Semantically Augmented Optimization Environment";

K. Kiesel, U. Pont, A. Mahdavi:
"Including sustainability criteria in architectural completion: A critical case study of current practices";

U. Pont:
"Eine Kubareise...";
Contributions to Proceedings (2)
A. Mahdavi, E. Finz, K. Kiesel, J. Lechleitner, K. Oreouhounig, U. Pont, M. Schuss, R. Zach:
"The performance paradigm: The key to knowledge-based building design and operation";
in: "MEHR-WERT Architektur & raumplanung - Programmheft zum Wissenschaftstag 2012"; Fakultät für Arch &
RPL (ed.); issued by: TU Wien, Fakultät für Architektur und raumplanung; Fakultät für Architektur und

U. Pont, K. Kiesel, J. Lechleitner, K. Oreouhounig, R. Zach, M. Schuss, A. Mahdavi:
"Über den Mehrwert der forschungsgeleiteten Lehre in der technikbezogenen Architektur-Ausbildung";
in: "MEHR-WERT Architektur & raumplanung - Programmheft zum Wissenschaftstag 2012"; Fakultät für Arch &
RPL (ed.); issued by: TU Wien, Fakultät für Architektur und raumplanung; Fakultät für Architektur und

Talks and Poster Presentations (with Proceedings-Entry) (35)
C.A. Calistru, U. Pont, A. Mahdavi:
"Estimation of Electrical Lighting Energy Use in Buildings: A method comparison";
accepted as talk for: BauSim2014 - Gebäuden für Menschen, Aachen, Deutschland; 2014-09-22 - 2014-09-24; in:
"BauSim 2014 - Gebäude für Menschen", C. van Treeck et al. (ed.); Eigenauflage mit wissenschaftlichem

U. Pont, N. Ghiassi, F Shayeganfar, A. Mahdavi, S. Fenz, J. Heurix, A. Anjomshoaa:
"SEMERGY: Utilizing semantic web technologies for performance-guided building design optimization";
accepted as talk for: ECPPM 2014, Wien, Österreich; 2014-09-17 - 2014-09-19; in: "ECPPM 2014", A. Mahdavi,

B. Sommer, G. Moncayo, U. Pont:
"Ecological Ballet - A design research towards environmental-reactive adaptive architectural design";

U. Pont, S. Glawischning, A. Mahdavi:
"AUTOCERT: A web-based approach for heating demand calculations for Building Performance Evaluation and
Optimization";
Talk: 2nd ICAUD - International Conference on Architecture and Urban Design, Tirana, Albanien; 2014-05-08 -
pages.

U. Pont, C. Sustr, A. Wurm, Y. Wu, A. Mahdavi:
"Exploring Indoor Thermal environment and cognitive performance in a short-term occupancy setting";
Talk: 2nd ICAUD - International Conference on Architecture and Urban Design, Tirana, Albanien; 2014-05-08 -
pages.

U. Pont, C. Sustr, A. Wurm, Y. Wu, A. Mahdavi:
"Exploring indoor thermal environment and cognitive performance in a short-term occupancy setting (";
accepted as talk for: 2-ICAUD, Tirana, Albanien; 2014-05-08 - 2014-05-10; in: "ICAUD 2014 - International

B. Szasz, U. Pont, A. Mahdavi:
"A comparison of straw-bale and conventional brick buildings in view of energy efficiency and environmental
performance";
accepted as talk for: 2-ICAUD, Tirana, Albanien; 2014-05-08 - 2014-05-10; in: "ICAUD 2014 - International

B. Szasz, U. Pont, A. Mahdavi:
"A Comparison of Straw-Bale and Conventional Brick Buildings in View of Energy Efficiency and Environmental
Performance";
Talk: 2nd ICAUD - International Conference on Architecture and Urban Design, Tirana, Albanien; 2014-05-08 -
N. Ghiassi, S. Glawischnig, U. Pont, A. Mahdavi:
"Toward a Data-Driven Performance-Guided Urban Decision-Support Environment";

G. Adam, U. Pont, A. Mahdavi:
"Evaluation of thermal environment and indoor air quality in university libraries in Vienna";

N. Ghiassi, F. Shayeganfar, U. Pont, A. Mahdavi:
"SEMERGY: Performance-Guided Building Design and Refurbishment within a Semantically Augmented Optimization Environment";

B. Sommer, U. Pont:
"Energy Design by Evolution: Applying Evolutionary Computing to Energy Efficient Architectural Design";

A. Sustr, N. Ghiassi, U. Pont, F. Shayeganfar, A. Mahdavi, S. Fenz, J. Heurix, A. Anjomshoaa, A. Tjoa:
"Multi-objective optimization in the SEMERGY environment for sustainable building design and retrofit";
V. Müller, U. Pont, H.T. Pak, A. Mahdavi:
"Thermal implications of radiant roof barriers: A field study in a hot and humid climate";
Talk: CESBP - 2nd Central European Symposium on Building Physics, Wien, Österreich; 2013-09-09 - 2013-09-11;

H.T. Pak, U. Pont, V. Müller, A. Mahdavi:
"Thermal performance of a test cell in a hot and humid climate: the impact of thermal insulation";
Talk: CESBP - 2nd Central European Symposium on Building Physics, Wien, Österreich; 2013-09-09 - 2013-09-11;

U. Pont, F Shayeganfar, N. Ghiassi, M. Taheri, C. Sustr, A. Mahdavi, J. Heurix, S. Fenz, A. Anjomshoaa, T. Neubauer, A. Tjoa:
"Recent advances in SEMERGY: A semantically enriched optimization environment for performance-guided building design and refurbishment";
Talk: CESBP - 2nd Central European Symposium on Building Physics, Wien, Österreich; 2013-09-09 - 2013-09-11;

L. Skoruppa, U. Pont, M. Schuss, R. Zach, A. Mahdavi:
"Oekohaus: A case study of monitoring-based building performance assessment";
Talk: CESBP - 2nd Central European Symposium on Building Physics, Wien, Österreich; 2013-09-09 - 2013-09-11;

Y. Wu, U. Pont, M. Schuss, A. Mahdavi:
"Assessing thermal comfort conditions in transitional states";
Talk: CESBP - 2nd Central European Symposium on Building Physics, Wien, Österreich; 2013-09-09 - 2013-09-11;

F Shayeganfar, A. Anjomshoaa, J. Heurix, C. Sustr, N. Ghiassi, U. Pont, S. Fenz, T. Neubauer, A. Tjoa, A. Mahdavi:
"An ontology-aided Optimization Approach to Eco-Efficient Building Design";

Y. Wu, K. Orehounig, U. Pont, M. Schuss, A. Mahdavi:
"Assessing Thermal Comfort Conditions in Transitional States";

L. Skoruppa, U. Pont, K. Kiesel, M. Schuss, R. Zach, A. Mahdavi:
"Field Station of the national park academy in Petronell, Austria, A case Study of evolving thermal performance expectations.";

B. Sommer, U. Pont:
"Evolutionäre Algorithmen im Entwerfen energieeffizienter Gebäude";

N. Ghiassi, F. Shayeganfar, U. Pont, A. Mahdavi, S. Fenz, J. Heurix, A. Anjomshoaa, T. Neubauer, A. Tjoa:
"Improving the usability of energy simulation applications in processing common building performance inquiries";
Talk: Simulace Budov a Techniky Prostredi - 7. narodni konference s mezinarodni ucasti, Brno, Tschechien;
2012-11-08 - 2012-11-09; in: "Simulace Budov a Techniky Prostredi", O. Sikula, J. Hirs (ed.);

K. Kiesel, U. Pont, A. Mahdavi:
"Including sustainability criteria in architectural competition: A critical case study of current practices";
Talk: envibuild Buildings and Environment 2012, Brno, Tschechische Republik; 2012-10-25 - 2012-10-26; in:
"envibuild Buildings and Environment 2012 digital proceedings", M. Kalousek et al. (ed.);

A. Mahdavi, U. Pont, F. Shayeganfar, N. Ghiassi, A. Anjomshoaa, S. Fenz, J. Heurix, T. Neubauer, A. Tjoa:
"Exploring the utility of semantic web technology in building performance simulation";
Talk: BauSim2012 - "Gebäudesimulation auf den Größenskalen Bauteil, Raum, Gebäude, Stadtquartier", Berlin;
2012-09-26 - 2012-09-28; in: "BauSIM 2012 - "Gebäudesimulation auf den Größenskalen Bauteil, Raum, Gebäude, Stadtquartier"",
C. Nytsch-Geusen et al. (ed.); Eigenverlag / wissenschaftliches Komitee der IBPSA Germany-Austria, 1 (2012), Paper ID 114, 7 pages.

A. Mahdavi, U. Pont, F. Shayeganfar, N. Ghiassi, A. Anjomshoaa, S. Fenz, J. Heurix, T. Neubauer, A. Tjoa:
"SEMERGY: Semantic web technology support for comprehensive building design assessment";
Talk: ECPPPM2012 eWork and eBusiness in Architecture, Engineering and Construction, Reykjavík, Island;

K. Orehounig, U. Pont, A. Mahdavi:
"Short-term occupancy implications of digitally provided outside views in window-less rooms";

U. Pont, K. Kiesel, M. Schuss, B. Sommer, K. Orehounig, A. Mahdavi:
"A critical case study of decision criteria in architectural competitions";

U. Pont, D.P. Espinosa, M. Schuss, A. Mahdavi:
"Indoor environment, user evaluation and energy use in a "passivhaus" student dormitory";

U. Pont, B. Sommer, A. Mahdavi:
"Sources of uncertainty in compilation of energy certificates";

U. Pont, B. Sommer, A. Mahdavi:
"Ein Vergleich der Ergebnisse von stationärer und instationärer Berechnung von thermischen Energiekennzahlen anhand bestehender Objekte in Wien";

**Talks and Poster Presentations (without Proceedings-Entry) (5)**

**U. Pont:**
"Schallschutz/Lärmschutz - Impulsreferat im Rahmen der Concrete Trophy 2014."

**U. Pont, M. Kornicki:**
"Berechnung von Wärmebrücken und Dampfdiffusion mit AnTherm in Zusammenhang mit Energieausweis bzw. PHPP, stationäre und Harmonische Betrachtung";

**U. Pont, M. Kornicki:**
"Einführung in das Arbeiten mit AnTherm Wärmebrücken und Dampfdiffusion";

**U. Pont:**
"A comparison of projected and actual energy performance of buildings after thermal retrofit measures";

**U. Pont:**
"SEMERGY - Exploring the Utility of Semantic Web Technology in Building Performance Simulation";
Talk: Current Topics in Building Performance (Ringseminar WS2012), Wien, TU Wien; 2012-12-07.

**Diploma and Master Theses (authored and supervised) (1)**

**U. Pont:**
"Eine komparative Studie zur Berechnung thermischer Energiekennzahlen von Bauwerken mit stationären Berechnungsmethoden und dynamischer Simulation";

**Scientific Reports (2)**

"SEMERGY - Identifying optimal building refurbishment strategies";

**U. Pont, N. Ghiassi, A. Mahdavi:**
"Report: SEMERGY-related inquiries (Report about the findings of the project course Winterterm 2012/2013)";
Report for Project Team SEMERGY; Report No. 1, 2013; 178 pages.

B. Sommer, U. Pont, B. Schwaighofer, F. Waldmayer:
"Anwendungsrecherche LIGHTGLASS";
Report for ARGE Lightglass; Report No. -, 2010; 18 pages.

**Reviews (2)**

A. Grancy (Reviewer):
"Gebäude sind keine autarken Einheiten";
Personal review about U. Pont; Die Presse, 2014-08-09, p. 29.

A. Grancy (Reviewer):
"Intelligent sanieren: Wie unsere Häuser fit für morgen werden";

**Participations in Exhibitions without Catalogue (1)**

N. Ghiassi, K. Hammerberg, U. Pont, A. Mahdavi et al.:
"SEMERGY - Planung energieeffizienter Gebäude";