Federal University of Rio Grande do Sul

Program for Research and Post-Graduation in Architecture (PROPAR)

Energy Assessment in Early Architectural Design Stages

Framework and Validation Methodology for Architect-friendly Computational Energy Assessment

Doctoral Thesis

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This work is dedicated to my daughter Lina Katerina.

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ABSTRACT

Today's buildings are responsible for about 40% of the global energy demand. To reduce energy consumption by using *Energy Assessment* (*EA*) methods, the *Early Architectural Design Stages* (*EADS*) are especially suitable to implement the best cost-benefit measures. To integrate *EA* into *EADS*, two main challenges must be simultaneously tackled: (a) the architect-(un)friendliness of computational models and (b) the results' reliability. To accomplish both goals a *Framework for Energy Assessment Tools in Early Architectural Design Stages* (*FORwArDS*) and a validation methodology, *Relative Validation* (*RV*), is presented.

FORwArDS feature three components: *Input Model*, *Assessment Model*, and *Output Model*, but focuses on the creation of a *Simplified Input Model* (*SIM*) throughout parameters reduction, the creation of alternative values for the chosen parameters and exemplary mathematical and geometrical simplification steps. In the case study, a *SIM* is created according to the exemplary simplification rules described in *FORwArDS*, springing from a detailed project model; a validation procedure follows the proposed methodology.

The results are presented, analyzed and conclusions are drawn regarding the framework's and validation methodology's contributions to the improvement of the *EADS*. The framework's open structure and the applicability of the validation methodology to any simulation contribute to the discussion about the integration problems of energy assessment in *EADS* and present useful tools for the creation and test of model simplification methodologies and *EA* for architects during *EADS*.

RESUMO

Edifícios são responsáveis por cerca de 40% da demanda global de energia. Para reduzir este consumo utilizando métodos de avaliação de energia (*Energy Assessment – EA*), as primeiras etapas de projeto arquitetônico (*Early Architectural Design Stages – EADS*) são especialmente adequadas para implementar medidas eficientes com a melhor relação custo-benefício. Para integrar a *EA* na *EADS*, dois desafios principais devem ser abordados simultaneamente: (a) a (não-)amigabilidade para arquitetos dos modelos computacionais e (b) a confiabilidade dos resultados.

Para realizar ambos os objetivos, é apresentado neste trabalho um ambiente para o desenvolvimento de ferramentas de aferição de energia em *EADS* (*Framework for Energy Assessment Tools in Early Architectural Design Stages –FORwArDS*) e uma metodologia de validação, a validação relativa (*Relative Validation – RV*). *FORwArDS* possui três componentes: o modelo de entrada, o modelo de avaliação e o modelo de saída, mas o trabalho concentra-se na criação de um modelo de entrada simplificado (*Simplified Input Model – SIM*) através da redução de parâmetros, da criação de valores alternativos para os parâmetros escolhidos e, por fim, passos de simplificação matemática e geométrica. A estrutura aberta do ambiente permite uma ampla variedade de aplicações em pesquisa, prática e educação.

A metodologia de validação proposta baseia-se no conceito de que a contextualização dos resultados obtidos representa a mais importante contribuição para a orientação de projeto no *EADS*. Este trabalho confronta pares de resultados, representando a mudança de projetos arquitetônicos similares originados em dois modelos de entrada diferentes, visando avaliar a precisão de seus correspondentes. No estudo de caso, um *SIM*, proveniente de um modelo de projeto detalhado*,* é criado de acordo com as regras de simplificação descritas no *FORwARrDS*. Os resultados são apresentados e analisados permitindo conclusões sobre as principais contribuições deste trabalho. O trabalho apresenta uma ferramenta útil para o desenvolvimento de metodologias de simplificação de modelos e *EA* para arquitetos durante *EADS*.

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ABBREVIATIONS

AEC	Architecture, Engineering and Construction
BA	Building Assessment
BIM	Building Information Modelling
CFD	Computational Fluid Dynamics
CS	Case Study
DDS	Design Decision Support System
DDST	Design Decision Support Tool
DV	Direct Validation
EA	Energy Assessment
EADS	Early Architectural Design Stages
EP	EnergyPlus
FORwArDS	Framework for Energy Assessment Tools in Early Architectural Design Stages
HSA	Horizontal Shading Angle
HVAC	Heating, Ventilation and Air-Conditioning
ODM	Original Detailed Model
RIBA	Royal Institute of British Architects
RV	Relative Validation
SIM	Simplified Input Model
VSA	Vertical Shading Angle
WWR	Window-To-Wall-Ratio

GLOSSARY

alternative value:

Each parameter used in this work assumes a base value (see base value) and may assume additional alternative values, differing from the base value (see base value). Alternative values must be chosen from inside the parameter's allowed range. The number of alternative values a parameter may assume as well as the methodology to create the alternative value may differ from parameter to parameter and with the different applications of the framework.

architect-friendliness:

This idea describes the ease of use of a tool during the architect's design process and may be measured using the following criteria: (a) Usability and information management of interface, (b) integration of intelligent design knowledge-base (c) interoperability of building modelling, and finally (d) the accuracy of the tool and its ability to simulate complex and detailed building components.

azimuth:

The azimuth as used in this work is measured in degrees, using clockwise steps of 1° from 0° to 359°. This work considers 0° as north and a cone of 90° as northwards. In more detail, these cones include the lower (or left-hand) degree while excluding the high (or right-hand) degree. The cone considered northwards therefore is from 325° to 44°. The corresponding cones apply for westwards, southwards, and eastwards.

base value:

Refers to the first (default) value each parameter in this work assumes. It must lie inside the parameter's allowed range and may or may not be base for the creation of alternative values (see alternative values).

Building Assessment (BA):

The assessment of any quantitative criteria of a building. Among examples are energy consumption, natural lighting, water use, thermal comfort, and costs. Energy Assessment and Life-Cycle Assessment are considered specific forms of building assessment.

Case Study (CS):

Documented study of a specific scenario in order to analyse a specific or unspecific situation as it might occur in real life. A case study does not automatically allow for generalized conclusions about the analysed facts, but may serve as example for the application of methodologies or tools.

configurational models:

Configurational models combine graphical symbols (from iconic models) and numerical data (from mathematical models) to represent entities and their qualities.

construction:

In conformation with the use in the manuals of EnergyPlus, this term describes a set of materials defining their order, thickness and orientation (inside and outside). In order to function correctly the materials defined in the construction must be defined with their physical characteristics inside the same .idf file. A construction may be attributed to any surface defined in the geometrical model; note that the geometrical model does not define thicknesses.

data model:

A set of numbers that describe the past, present, or future state of something. In order to describe an architectural project, architects create data models with different degrees of complexity.

Design Decision Support System (DDS):

Set of methodologies or instructed steps with intrinsic capability to support ad hoc data analysis and reduction, as well as decision modelling activities. Such systems are to guide the design professional with the intention to optimize the outcome of one or more indicators or benchmarks, as in case of this work the energy efficiency of the building and may or may not be composed of more than one tool.

Design Decision Support Tool (DDST):

A Design Decision Support Tool herein is a supportive (software) tool that provides structured aid to specific steps of the Design Process based on patterns and strategies of design. As used in this work, Design Decision Support Tools possess a type of graphical user interface.

Direct Validation (DV):

Direct Validation refers to the classical validation methodology. In this work specifically referring to the validation of the results accuracy (in percent) as benchmark. It may be defined as the fraction of the result of a model to be validated and a model serving as target.

Energy Assessment (EA):

Refers to the quantitative assessment of a building's electrical energy consumption.

Early Architectural Design Stages (EADS):

Early Architectural Design Stages are the initial stages of the architectural design process. Often referred to as preliminary design phase or sketch, they are defined by the use of iconic models and a low degree of detail.

.epw:

Is the file extension of the file containing the weather data for simulations in EnergyPlus and stands for "Energy Plus weather-file". The file contains hourly information regarding temperature, humidity, rain and sky conditions, among others.

evaluation:

Evaluation is the systematic determination of merit, worth or significance, using criteria governed by a set of standards and/or benchmarks.

facade:

A facade is a vertical surface that separates the interior from the exterior. It may be composed of transparent (glazed) surfaces and opaque surfaces and receive horizontal and/or vertical shading elements. When used in combination with a solar orientation (north-facade, east-facade, south-facade, west-facade) it refers to all facade elements (see facade elements) that lie in the range of angles that comprise that solar orientation (see azimuth).

facade element:

In contrast to facade, facade element refers to a single (vertical) rectangular geometry from the building's geometrical model.

footprint:

A 2D polygonal shape on the ground plane, projection of the built form. Defines the outer extremity of the building.

framework:

A basic conception, structure or set of structured ideas, that may host a variety of specific combinations. In case of this work, the framework describes the sub-components for the transformation of iconic input data into a mathematical model for energy assessment simulations. This contrasts a framework from a paradigm (purely theoretical construct of ideas) and tools (applicable and practical-oriented systems).

iconic models:

Iconic models are constituted of graphical symbols to represent relations between entities; they are fit for documentation and representation. They are unfit for quantitative analysis.

.idf:

The file extension abbreviates "input data file" and is the file format used by EnergyPlus. The .idf file contains all geometrical and physical information regarding the model as well as input parameters and output options for the simulations. Weather data is not included in this file (see .epw).

Heating, Ventilation and Air-Conditioning (HVAC):

Refers to all active (electrical) systems, measures and installations that provide heating, cooling, air movement or any other kind of air quality change to the indoor environment.

Horizontal Shading Angle (HSA):

This measure describes the angle in the horizontal plane between the shading device's outermost point and the opposite edge of the transparent surface in order to describe vertical shading devices (basically using their depth).

Life-Cycle Assessment:

Specific Building Assessment dealing with certain criteria, especially environmental impacts, analysing them during all the stages of a building's life; from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling.

mathematical models:

Mathematical models employ numerical data only to represent entities and their qualities; all computation simulation is based on such machine-readable mathematical description of the project. They are fit for quantitative analysis.

model:

see data model

Original Detailed Model (ODM):

Refers to the initial model that includes all geometrical and numerical information provided by the architect or any other input source and is used as starting point for all reduction and simplifications herby presented.

parameter:

In this work defined as a single information (numerical or other) whose values determine the characteristics or behaviour of a part, the whole or specific elements of the building.

procedural model:

In differentiation to data models, these models may be described as mental models used in order to read, handle and express a given entity. This work distinguishes three procedural models: (a) iconic models, (b) configurational models, and (c) mathematical models.

Relative Validation (RV):

Refers to the proposed validation methodology, validating the accuracy (in percent) as benchmark, measuring the relative changes in the outputs that occur due to equal changes to one input. It may be defined as the fraction of the difference of result deriving from two different sets of inputs of the model to be validated and the difference of the target model's results from the same set of inputs.

Simplified Input Model (SIM):

The Simplified Input Model is obtained by applying geometric and mathematical simplification steps to an original model. It therefore reduces the input data with respect to the original model.

solar orientation:

see azimuth

validation:

Describes the test procedure to confirm a product or service meets certain criteria, normally oriented by the needs of its users.

Vertical Shading Angle (VSA):

This measure describes the angle in the vertical plane between the shading device's outermost point and the opposite (lower) edge of the transparent surface in order to describe horizontal shading devices (basically using their depth).

Window-To-Wall-Ratio (WWR)

Measures the ratio between transparent surfaces and opaque surfaces of a set of facade or single facade element.

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“It has often been said that a person doesn't really understand something until he teaches it to someone else. Actually a person doesn't really understand something until he can teach it to a computer [...].”

Donald Ervin Knuth, 1973

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1. INTRODUCTION

Architecture aims at creating interior spaces to protect users from the exterior's undesired impacts. Over the last decades, the development of *Heating, Ventilation, and Air-Conditioning* systems (*HVAC*) that can guarantee the hydrothermal comfort with relative independence from the architectural form have been developed. Nevertheless, the challenge of assuring indoor comfort has been dealt with at the expense of great quantities of energy demanded by the built environment around the globe.

With 51% of the global electricity consumption deriving from buildings, architects are faced with great responsibility due to the exhaustion of energy resources (Berardi, 2016). The use of the correct passive design strategies, such as solar orientation, window size and shading, may reduce this share by up to 40% (Sadineni, Madala, & Boehm, 2011). Architects need to take the correct design decisions during the *Architectural, Engineering and Construction* (*AEC*) design processes, hence adopt adequate passive strategies, to reduce building's share on energy consumption.

The necessary adjustments to the architect's creative process need to deal with architecture's complex mixture of aesthetical and technical criteria, that should, ideally, compose the final project – as Louis Isadore Kahn puts it:

> "To accomplish a building, you must start in the unmeasurable and go through the measurable. It is the only way you can build, the only way you can bring the building into being – it is through the measurable. You must follow the laws, but in the end, when the building becomes part of living, it must evoke unmeasurable qualities. The design phase involving quantities of brick, methods of constructions and engineering is over, and the spirit of the building's existence takes over"
> Louis Isadore Kahn apud (Stöckli, n.d.)

The *AEC* Design Process is classically dominated by decisions founded on the designer's experience, conjecture or intuition (Finger & Dixon, 1989a; Lawson, 2005; Steven V. Szokolay, n.d.). Using conjecture, architects base decisions on a qualitative analysis whereas some criteria are associated with quantitative measurements. For example, assessment tools for the energy consumption are underrepresented in the architect's overall process today. To establish a more balanced and optimized design process, the two components (conjecture and assessment) should be intertwined (Pedrini & Szokolay, 2005). Therefore, this work identifies the lack of superposition of conjecture and assessment as the first problem to be overcome. It is proposed to denominate that desired superposition *Certaindipity*, as combination of the words certainty (representing assessment-based decisions) and serendipity (representing conjectural decisions). Figure 1-1 depicts the concept schematically.

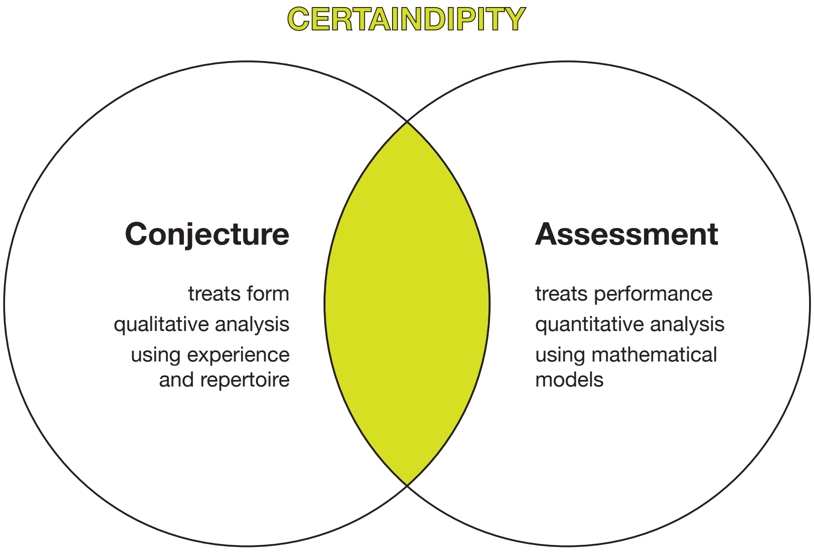

Figure 1-1: Certaindipity as superposition of conjecture and assessment.

Since the 1980s various assessment tools that allow the quantitative analysis of criteria have been developed. Digital *Building Assessment* (*BA*) tools and, more specifically, *Energy Assessment* (*EA*) tools are widely available to architects. It is assumed that the employment of *BA*, and specifically *EA*, help to guide the architect towards a more efficient final project. Nevertheless, *EA* tools do not play a significant part of the architect’s design process.

Traditionally, *EA* tools have been employed during the advanced stages of design. At these stages, the building’s project presents a detailed resolution and offers a high degree of input information to the tool leading to analytical results with high reliability. As architect’s decision support tool, this positive effect of postponed employment causes an important downside: a poor cost-benefit relation of decisions in later stages. Figure 1-2 depicts the MacLeamy curve to demonstrate the relation between cost and design change (benefit) as well as effect (benefit) and design effort (cost) over time during the design process (Naser, Ghani, & Abas, 2011; The American Institute of Architects, 2007).

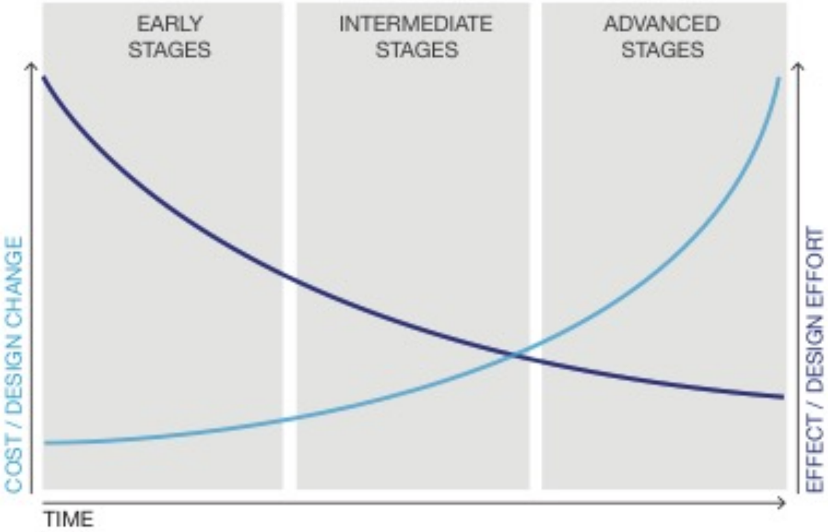

Figure 1-2: MacLeamy curve.

To take full advantage of the cost-benefit relation of *Early Architectural Design Stages* (*EADS*), the integrated analysis using conjecture and assessment needs to take place during these early stages but, in practice, the separation between the two spheres of analysis is prevalent in *EADS*. In other words, the segregation between conjecture and assessment happens especially in those stages that would be most indicated for optimizing the design process; whereas today's assessment tools are integrated mostly in later stages, when decisions for design changes over important aspects of buildings usually lead to significant costs. This situation is schematically presented in Figure 1-3.

Figure 1-3 shows that integration problems must be overcome to accomplish complete integration. In this context, the difficulties of assessment tools' practical integration during *EADS* are identified as the second main problem faced by this work.

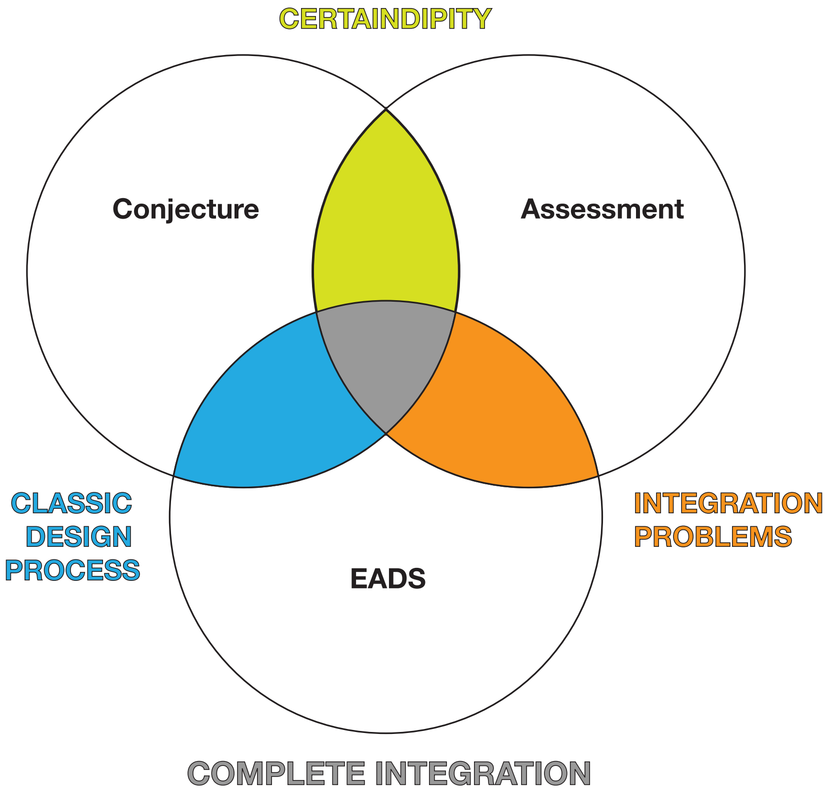

Figure 1-3: Complete Integration of Conjecture and Assessment in *EADS*.

To tackle the identified problems and improve the integration, three distinct objectives, described in sub-chapter 1.1, are set for this work.

The remainder of this text is divided into the following chapters: 2. *Literature Review*, 3. *Framework*, 4. *Validation Methodology*, and 5. *Final Considerations*.

A description of the theoretical background of *EA* and the design process in architecture as well as the state-of-the-art regarding energy assessment tools and energy simulation model simplification is presented in Chapter 2. The work's methodology towards the proposed framework is described in Chapter 3, while the proposed validation methodology and a case study are laid out in Chapter 4. The conclusions, possible applications and indications for future works are presented in Chapter 5.

1.1. Objectives

The obstacles architects meet when dealing with the integration of conjecture and assessment as well as *EA* tools into *EADS* define the subsequent specific objectives. With decisions in *EADSs* being predominately taken on the base of conjecture, on the one hand, and the advantages of *Certaindipity*, on the other hand, it is straightforward to propose the advantages of integration of assessment-guided and conjectural design decisions. With today's digital technology and its inherent processing power at their disposal (Attia, Beltrán, Herde, & Hensen, 2009; Drury B. Crawley, 2011; Gero & Saunders, 2000), *EA* tools related to numerous criteria regarding the buildings' sustainability are available (Anderson, 2014; Attia et al., 2015; Attia, Gratia, De Herde, & Hensen, 2012; Godfried Augenbroe, 1992; Drury B. Crawley, Hand, Kummert, & Griffith, 2008; Haymaker & Riker, 2009; Kajikawa, Inoue, & Goh, 2011; Østergård, Jensen, & Maagaard, 2016; Whalley et al., 2005). Nonetheless, in practice, the use of such tools is mainly restricted to the lesser efficient later design stages (Attia et al., 2012; Godfried Augenbroe, 1992), when all necessary details and preceding decisions have already been defined (Anderson, 2014). This occurs because the integration of *EA* tools into the design process is obstructed by various problems restricting the integrated use of such tools in today's architectural practice.

It is therefore necessary to define the precise obstacles architects encounter when using *EA* Tools in the early stages of their designs and, by the same token, it would be also desirable to remove or mitigate these obstacles, according to the MacLeamy curve (Naser et al., 2011; The American Institute of Architects, 2007).

A recent study shows that professionals, when asked about their reasons for not being satisfied with the Digital *BA* Tools they use in practice, the most common barrier reported was that 'tools are too complex'. The next most important answers include 'tools are too expensive', 'tools are not integrated in *Computer Aided Architectural Design* software' (including those with *Building Information Modelling* (*BIM*)), and 'tools take too much time'. Respondents also stated that existing tools are not integrated in the normal workflow and that they do not adequately support conceptual design. Less than 2% of the questioned Architects replied that the tools are satisfactory. (Kanters, Horvat, & Dubois, 2014). With exception of the cost factor of such software products, all of the above can be explained by the especially finite resources at this point of the overall process (Farrell & Hooker, 2013). Also denominated as lack of *architect-friendliness* of existing *EA* tools (Anderson, 2014; Attia et al., 2009; Kanters et al., 2014), three of the main challenges may be described as (a) input model complexity, (b) input model incompatibility, and (c) output model incompatibility which are important to be separately analysed. The following text details the posed challenges and this work's approach on how to tackle the issues.

1.1.1. Specific Objectives

As for the first challenge, a model is defined as a set of numbers describing the past, present or future state of something. To avoid ambiguity throughout this work, this is referred to as a data model. To describe an architectural project, architects create data models with different degrees of complexity. Complexity refers to the quantity of information inherent to a model and hereby may be augmented by increasing the project's detail level or by generating additional project data on the same level of detail.

During the design process, it is assumed that the project's level of complexity raises over time; Figure 1-4 depicts this concept by assuming a linear growth of complexity over time.

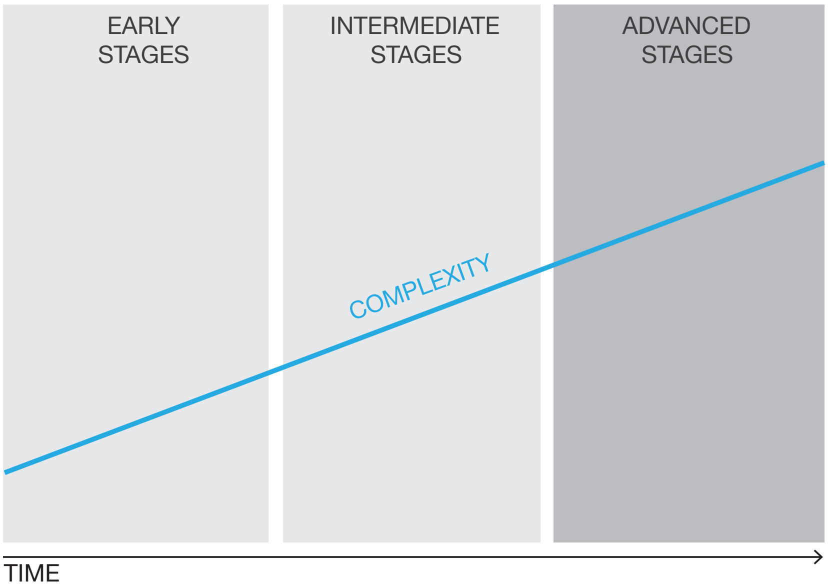

Figure 1-4: Complexity during the design process.

Along with *EA* tools' demand for a data set as input to provide reliable output results, the application of such tools at any stage of the design process is directly linked to the complexity stage of the project. If we assume that the minimum data complexity required by today's tools is constant, it may be described as a horizontal line. Designers are able to use *EA* tools only in stages that satisfy the tool's complexity requirements and data input needs. In Figure 1-4 these stages are marked as a dark area, representing the later stages of the design process.

The proposed *Framework for Energy Assessment Tools in Early Architectural Design Stages* (*FORwArDS*) hosts three sub-components: (a) the input model, (b) the assessment model, and (c) the output model. All need to be adapted to the necessities of architects for *EA* integration into *EADS*, but special attention should be given to the input model or the interface between the architect and the simulation. *FORwArDS* is meant to function as a supporting framework for the creation of any part of any of the sub-components. This work's first objective consists in creating a *Simplified Input Model* (*SIM*) which, even with reduced data input, would guarantee that the obtained results are reliable for decision making. It should be noted that this work adapts the term *model simplification*, while terms like *model reduction* or *model abstraction* may be found in literature to describe equivalent procedures and methodologies.

In this context, this work analyses the factors involved in the design process during *EADS* and proposes a reduction of *EA* parameters to be considered part of the input model. Further, exemplary simplification steps from state-of-the-art methods are applied to a case study. A validation methodology denominated *Relative Validation* (*RV*) is proposed to identify if the created input model produces results accurate enough to serve as reliable decision support for architects in *EADS*.

Along with the reduction of the input data model's complexity, the time needed to model and to simulate the resulting mathematical data model is likely to be reduced. This can be described as an additional positive step towards the architect-friendliness of the model.

The second challenge arises from the designer's need to transit between different models used in the procedural processes. In differentiation to data models, these models may be described as mental models used to read, handle and express a given entity. This work distinguishes three such models: (a) *iconic models*, (b) *configurational models*, and (c) *mathematical models*. *Iconic models* are constituted of graphical symbols, in other words drawings or mock-ups, to represent relations between entities; they are fit for documentation and representation and consequently are the most commonly employed mental model of architects, especially during *EADS*. They are unfit for quantitative analysis though. *Configurational models* combine graphical symbols and numerical data to represent entities and their qualities. Finally, *mathematical models* employ numerical data only to represent entities and their qualities; all computation simulation is based on such machine-readable mathematical description of the project.

Architects need to interrupt the use of *iconic model* they work with during *EADS* and switch to a less used model (as the mathematical) in order to perform computational simulations during *EA*. This interruption generates an important rupture of the design process' flow.

This work's second objective consists of creating an interactive framework whereby the architect would use an *iconic model* while integrating *EA* by executing background actions inside a *configurational model*. This integration will enable to transfer the architect's iconic information into the mathematical model for the computational simulation.

The integration of iconic descriptions of designs with EA tools may help to provide the necessary contextualization of the obtained performance simulation results. To achieve this goal, architects need to be presented with (a) a manageable combination of the input (cause) and output (consequence) representation and (b) a possibility to compare *informed scenarios* of more than one combination of such cause and consequence results. These *informed scenarios* allow architects to emulate specific cognitive capabilities which then can be used to structure knowledge and, consequently, to generate a base for educated design decisions.

Consequently, this work's third specific objective is to build up a framework for the automatic creation of a solution space with cause-consequence *scenarios* to allow the architect's contextualization.

Architect-friendly *EA* is only possible, if its underlying framework is: (a) architect-friendly for the data input, (b) the model is able to generate reliable results, (c) and architect-friendly contextualized outputs. With problems and objectives outlined, this work's hypothesis might be formulated as follows:

> *EA* may work as a design support in *EADS* if the design process follows specific requirements for a systemic integration (architect-friendly input, complexity / reliability, architect-friendly output).

To clarify the requirements of such model and its functional and quantitative aspects, a framework is described in Chapter 3, while the application of the proposed validation methodology is detailed in Chapter 4.

FORwArDS will specify the reduction of parameters and the creation of alternative values, but considers any specific *User Interface* as outside of this work's scope. The framework does not specify an automated or generally applicable tool or interface, but proposes a methodology for automatic multi-solution space creation and exemplifies output representation, therefore allowing future works to create multiple combinations of and specializations for the framework.

Further, an adequate validation methodology, that better represents the accuracy needs of architects in *EADS*, is described and applied in this work.

As a framework, on the contrary to a tool or a *Decision Support System* (*DDS*), *FORwArDS* does not propose a *Graphical User Interface* or concrete sequence of the proposed representations. These may vary depending on the goal of the application of the assessment. More details are given in the chapter 5.1 Future Works.

FORwArDS does not aim at presenting neither an automatized assessment process, nor an automated or non-automated model simplification. Both may be created based on the framework presented, but are out of the scope of this work.

Generalized assumptions about the importance of certain parameters or generalized indications about energy efficient design are not scope of this work. A huge set of case studies would be necessary to be able to draw such conclusions, this work presents a single case study in order to exemplify the framework as well as the validation methodology. In order to maintain a controlled environment, the case study's base model is chosen from a very limited set of conditions, precisely office buildings in the climate conditions of Porto Alegre, Brazil. Further, certain restrictions had to be made regarding the designer's freedom of form and consequently the presented framework allows volumes that represent extrusions of floor plans with 90° angles only as input.

The case study's results are not evaluated, as all important benchmarks would require user interaction and consequently be out of the scope of this work.

2. LITERATURE REVIEW

One of architecture's primary goals is to shelter the vast array of human activities (Bristol, 1992). Modern technology has made the creation of comfortable indoor spaces independent from the natural outdoor conditions possible (Lamberts, Dutra, & Pereira, 2014). Architects, throughout history and with no distinction for specific climates, have tackled the creation of thermal comfort.

To fulfil this need, all buildings, varying in quantity, consume energy (Vitruvius, 1914). In more detail, various works show a direct correlation between the active systems aiming at thermal and other aspects of comfort and the buildings' energy consumption (Englemann, Roth, & Tiefenbeck, 2013; Harvey, 2013; Martínez, Pacheco, & Ordó, 2012; Ürge-Vorsatz, 2012; Ürge-Vorsatz, Cabeza, Serrano, Barreneche, & Petrichenko, 2014).

Today's world energy consumption leads to concerns over supply difficulties and claims that exhaustion of energy resources is imminent. Further, environmental impacts, such as the ozone layer depletion, global warming, and climate changes have proven links to energy production and its by-products. (Englemann et al., 2013; Harvey, 2013; International Energy Agency, 2014, 2015; Nordhaus, 2014; Pérez-Lombard, Ortiz, & Pout, 2008; Weitzman, 2007; Yildiz & Arsan, 2011)

With the existent tendency of ever raising energy needs, if no changes in the energy production or requirements are implemented, these problems tend to worsen in the future. The need to be concerned with the sustainable use of non-renewable (energy) resources has been recognized since the oil crisis in

1973 (Lamberts et al., 2014). Furthermore, the share of the built environment in mankind's overall energy consumption has been sufficiently laid out in literature. (International Energy Agency, 2013, 2015; Kajikawa et al., 2011; Lamberts et al., 2014; Nordhaus, 2014; Saelens, Parys, & Baetens, 2011)

In order to reduce the share today's constructions represent for the total energy consumption two basic lines of action are being identified: (a) the use of renewable energy resources and (b) the reduction of the needed energy consumption itself (Harvey, 2013).

The first one has progressed on various levels over the last decades (Twidel & Weir, 2015; Zuo & Zhao, 2014), but does not fall within the scope of this work, as it does not directly influence the *AEC* design process. This work focuses on the second line of action, the reduction of buildings' energy demand.

Pursuing this line of action, again, two different manners of attaining this goal are identified: (a) active strategies and (b) passive strategies, both seeking to reduce the building's energy demand (Keeler & Burke, 2009; Sadineni et al., 2011; Sozer, 2010; Stevanović, 2013; Yildiz, 2015).

Active strategies include the use of systems with electricity such as air conditioning, forced ventilation and alike. More efficient versions of energy consuming parts inside the building has been a challenge especially in the fields of electrical and mechanical engineering. (Pérez-Lombard, Ortiz, Coronel, & Maestre, 2011; Yang, Yan, & Lam, 2014)

Passive strategies are defined as those that do not need the use of electrical energy. The building form and orientation, the size and position of translucent surfaces, thermal mass and various other strategies are to be included in this category. The adequate application of such strategies should emphasize the relationship between passive conditioning of the indoor environment and the reduction in the demand for energy from conventional resources while minimizing the environmental impacts (Evans, 2007). The energy savings that can be achieved through passive strategies are considered to reach up to 35% while reducing the peak energy demands by up to 47% (Givoni, 1994; Sadineni et al., 2011).

It is straightforward that the energy efficiency of active strategies mainly depends on the efficiency of the devices composing the system itself, while passive strategies highly depend on the architectural – formal and material – decisions.

> “Energy Efficient Architecture [...] implies certain emphasis in the efficiency of installations for artificial conditioning, illumination, heating, cooling and ventilation, although [...] energy efficiency mainly depends on appropriate design decisions for the building and not simply the efficiency of the heating, artificial lighting and cooling installations.” (Evans, 2007)

Therefore, this work will exclusively focus on passive strategies and their implications on the design process, for the work’s focus lies on the *AEC* design process.

The theoretical background regarding the restrictions for building assessment tools to be applied to the first *AEC* design stages and criteria for thermal comfort are presented in order to identify the sources used to define the framework and the case study. The state-of-the-art regarding the guidance towards educated design decisions is presented following the description of the theoretical background.

2.1. Theoretical Background

The following sub-chapters serve to introduce the necessary background knowledge with respect to (a) *BA* and the tools used to integrate assessment into the *AEC* design process, and (b) the design process itself, specifically the first phases of the architect's design process and the related decisions. Both subchapters introduce the topics' necessities and restrictions when vising the integration of *BA tools* into early *AEC* design stages.

2.1.1. Building Assessment

To reduce the importance of buildings on world energy consumption, it is necessary to provide quantitative data to building's designers using either active or passive strategies. This data, independent from its origin, may be employed to optimize not only the energy efficiency of buildings, but assist regarding all aspects of sustainability during development, construction and life cycle of constructions using *BA*. (Andaloro, Salomone, Ioppolo, & Andaloro, 2010; M. U. Hensel, 2011; Zuo & Zhao, 2014).

BA measures how well or poorly a building is performing against a declared set of criteria and generally *BA systems* attempt to measure improvements in the environmental performance of buildings relative to current typical practice or legal requirements (Cole, 1999; M. Hensel, 2013).

> "The design analysis involves the 'creation' of a behavioral model of a building design, [...] and analyzing the outputs of the simulation runs. Models are developed for a problem domain by reducing the physical entities and phenomena in that domain to idealized form on a desired level of abstraction, and formulating a mathematical model through the application of conservation laws."
> (G. Augenbroe, 2000)

A sheer number of *BA systems*, including *EA tools*, have emerged to provide an objective evaluation of resource use, ecological loadings and indoor environmental quality of buildings (Cole, 1999). Since the 1990s, the concept of sustainable building design and its increasing adoption of these concepts in the marketplace, have been furthered by the development of *BA* tools. Such tools helped define this emerging field and provide a structure for communication between architects, engineers and the various other stakeholders involved in the construction process. (D. Crawley & Aho, 1999; D. B Crawley, Hand, Kummert, & Griffith, 2008; Larsson & Cole, 2001)

BA tools vs. BA systems

The term 'Building Assessment Tool', often used to generically describe all assessment techniques, is here used to describe a technique that predicts, calculates or estimates one or more environmental performance characteristics of a building, such as energy consumption, greenhouse gas emissions or embodied energy. There are a variety of tools, varying in complexity and having different underlying methodologies – the most important distinction being between those based on *Life-Cycle Assessment* principles and those that are not. (Cole, 2005; Ebert, Eßig, & Hauser, 2010)

The term 'Building Assessment Systems' is used here to describe a technique having assessment as one of its core functions, but which may be accompanied by a third-party verification before issuing a performance rating or label, include reference to or use of a number of tools and may offer supporting educational programs for design professionals. *BA systems* possess recognizable frameworks that organize or classify environmental performance criteria in a structured manner with assigned points or weightings. Further, *BA systems* are managed by and operate within known organizational contexts. Although parts of a *BA system* may be used selectively by design professionals at their discretion, full engagement of a method involves some form of registration or certification. (Cole, 2005; Ebert et al., 2010)

Moreover, *BA tools* and *BA systems* have different learning curves on the part of their users – the former typically being steeper than the latter by virtue of being used more independently. (Cole, 2005; Larsson & Cole, 2001)

Historic Development of BA for Buildings

Since its start, the scope of *BA* has changed: with the increased awareness of the inevitability of climate change assessment systems have extended from solely mitigation approaches to embracing adaptation to changing conditions and the conscious restoration of previously degraded natural systems (Cole, 2005). Building *EA* is part of more complete building assessment approach since the first studies appeared (Bundesministerium für Verkehr Bau und Stadtentwicklung, 2013; Ebert et al., 2010).

BA's employment has impacted on the construction market and assessment systems today have moved beyond voluntary market place mechanisms (Larsson & Cole, 2001). Their performance thresholds are increasingly specified by public agencies and other organizations to define building performance requirements and are considered potential incentives for development approval, bonus density and other concessions. (Attia et al., 2015; Cole, 2005; Ebert et al., 2010; Haapio & Viitaniemi, 2008; Lützkendorf & Lorenz, 2006)

The *BA systems* used in today's construction market are improvements of previous BA systems. Their structure as well as their procedures are based on various earlier experiences. The pioneer system was the British *BREEAM* by the *Building Research Establishment*, whose evaluation catalogue was first published in 1990. The French *Haute Qualité Environnementale* (*HQE*) followed in 1996, but until today has only reduced application due to its availability in French only. In 1998 the North American label *Leadership in Energy & Environmental Design* (*LEED*) of the *U.S. Green Building Council* (*USGBC*) started with first assessments for new commercial buildings. The Japanese *Comprehensive Assessment System for Building Environmental Efficiency* (*CASBEE*) and the Australian Green Star system were launched in 2001 and 2002 respectively. These systems form the so-called first generation of *BA systems* and focused mainly on the ecological and energetic aspects of construction. (Ebert et al., 2010)

The second generation of systems, among them the German *Deutsche Gütesiegel für Nachhaltiges Bauen* (*DGNB*), the European *LEnSE* and the *SBTool* of the International Initiative for a Sustainable Built Environment among others, are developed on the base of different first generation systems, but try to incorporate a more holistic approach including also socio-cultural and economical aspects, as well as technical, regional and process quality. (Ebert et al., 2010)

Today's *LEED*, *BREEAM*, *Green Star*, *Green Mark Scheme* (Singapore), *DGNB*, *CASBEE* are considered to be the leading sustainable *BA* systems and tools (Zuo & Zhao, 2014).

Along with the refinement of the existing systems, the importance of regional characteristics like climate, construction materials available and socio-cultural aspects have been implemented and the thereby generated a number of regional sub-systems such as the *LEED Canada* in 2004 or *LEED Brazil* in 2009. (Ebert et al., 2010)

The need to have easy access to tools as well as systems, and the desire to enable assessments to be made quickly and cheaply, is spurring the increased deployment of web-based methods and tools or attendant software support tools (Cole, 2005).

Assessment Tools

Many of the existing *BA system* are used as design guidance, even though they may not have been specifically designed for this purpose (Cole, 2005). This leads to three potential problems during the integration into the *AEC* Design Process: (a) by over-simplifying the model to a degree that all stakeholders can at least acknowledge and institutionalize the idea of sustainability, when, for the purpose of design guidance, exploration and innovation should be encouraged; (b) by committing designers to achieving a high-performance score using a specific assessment method they may result in 'points-chasing'; and (c) by exploring the given requirements of the system in order to yield the greatest score for the least cost or effort ('gaming') rather than delivering the most appropriate environmental performance. (Cole, 2005; Haapio & Viitaniemi, 2008)

While complete BA systems, due to the previously mentioned shortcomings, are not promoting the integration of building's *EA* into the architect's design process, some tools might integrate sufficiently even into *EADS*. If considering that *BA systems* do provide a framework for evaluating different criteria, they operate like toolboxes, unifying specialized tools being utilized to assess specific aspects of the complete set of criteria. These tools generate separate results which are weighted and, using the system's parameters, condensed into one single result. It is important to highlight that inside different toolboxes, different tools are employed; different systems apply different tools for the same criteria and even more tools exist to evaluate the same criteria without the application of the whole system and it's procedural implications. (Attia et al., 2015; Attia, Hamdy, O'Brien, & Carlucci, 2013; Haapio & Viitaniemi, 2008; Haymaker & Riker, 2009; Lützkendorf & Lorenz, 2006; B. K. Nguyen & Altan, 2011; Pérez-Lombard, Ortiz, González, & Maestre, 2009; Yang et al., 2014)

BA tools are hereby defined as utilities to describe and assess a specific building functionality, serviceability and the compliance of user requirements with corresponding building characteristics and attributes indicating the importance of quantitative data, either from simulation or measurement for this concept. (Anderson, 2014; D. Crawley & Aho, 1999; Lützkendorf & Lorenz, 2006)

The interconnection and interdependence of the involved phenomena makes comfort and/or energy efficient *AEC* design a highly complex subject (Steven V. Szokolay, 2004). The use of *BA tools* to achieve performative design results is important but complex, time consuming and – today – requires a high level of expertise as well as not available software packages (Attia et al., 2012).

> "Simulation in theory handles dynamic and iterative design investigations, which makes it effective for enabling new knowledge, analytical processes, materials and component data, standards, design details, etc., to be incorporated and made accessible to practicing professionals." (Attia et al., 2012)

With raising complexity, uncertainty rises as well: this is especially true during the early design phases. The architect's constant search for design direction makes it important to assure informed decisions regarding, for example, energy efficiency from the first design decisions onwards. Also, decisions taken during an early stage may determine the success or failure of the final design. To design and construct performance oriented buildings it is consequently of the utmost importance to ensure informed decision-making during the early design phases. Such informed or educated design decisions are only possible if the designer can base his successive design steps on qualitative analysis or assessment of his project's data. (Anderson, 2014; Attia et al., 2012, 2013; Haymaker & Riker, 2009; Rizzoli, 1997)

Digital Assessment Tools

In order to obtain quality assessment results, the necessary design space normally becomes too vast to be grasped in its entire extension by designers without support (Rizzoli, 1997). With the development of computational power, modelling of design proposals allows a fair prediction of expected future states and therefore represents an important tool for informed decision making. (Anderson, 2014; Godfried Augenbroe, 1992; Cerezo, Dogan, & Reinhart, 2014; Drury B. Crawley et al., 2001; Rizzoli, 1997)

> "A few design alternatives are usually created for comparison and discussion and it is during [the early design stages] that the most important building performance decisions are made. Frequently, architects rely on past experience or known rule-of-thumb solutions. However, these may have never been validated, and their possible correctness may vary from location to location as well as context." (Attia et al., 2012)

A sheer number of digital analytical tools created to help designers to assess specific performative aspects of their projects post-facto, i.e. after an initial design is developed, are available. However, none of these provide dynamic generative capabilities allowing for conceptual exploration in *AEC* design and specially in its early design phases (Whalley et al., 2005).

It is a fact that the architectural practices have adopted digital tools into their work flows. *Computer-aided architectural design* software, including *BIM*, is one of the basic tools of today's architects. (Attia et al., 2009; Papamichael & Pal, 2002) Nevertheless, digital assessment tools have not found widespread adoption. (Attia et al., 2015; Dubois & Horvat, 2010; C. Hopfe & Hensen, 2011; C. J. Hopfe, 2009; Kanters et al., 2014; Oxman, 2006, 2009; Rodrigues, Gaspar, & Gomes, 2014)

Design Support Systems

While single digital models can support the architect's decision making process, often the complexity of environmental systems, and the multi-faceted nature of many environmental problems, do require access to a range of models, data and other information. (Rizzoli, 1997)

An important category of systems, contrasting the *BA systems*, are *DDS*s, defined as systems with intrinsic capability of ad hoc data analysis. These systems are to guide the design professional with the intention to optimize the outcome of one or more indicators or benchmarks, as in case of this work the energy efficiency of the building. (Juan et al., 2010; Moore & Chang, 1971; Rizzoli, 1997)

DDS may or may not be composed of more than one digital tool, each *Design Decision Support Tool* (*DDST*) herein would represent a supportive tool that providing structured aid to specific steps of the design process based on patterns and strategies of design. (Moore & Chang, 1971)

The use of the terms *DDS* or *DDST* implies the integration of such system or tool into the design process. Therefore, the analysis of the process itself and the identification of arising limitations and necessities for such tools is an important part of this work.

2.1.2. Design Process

The discussion on how to guide or even to describe the architectural design process is not consensual. A concise review of important design theories associated to architecture and architectural processes using digital design tools is presented as follows.

Design Process Theories

Design processes might be classified according to different aspects, such as method or attitude towards design (Pedrini, 2003). But, if thinking of design as the process to define a solution to a given problem, the concepts of wicked and tame problems (Rittel & Weber, 1973) and their association with either design and engineering problems respectively come to mind.

> "[...] contrary to common-enough talk where it is made to look as if a problem domain is either all fully tame or all fully wicked, with nothing in between, the tame/wicked distinction is not a unitary whole but is made up of a number of different features each varying in its degree of tameness and wickedness across problems" (Farrell & Hooker, 2013)

Accepting the complex nature of the architectural design problem, solutions to any problem necessarily are, at least, constrained by the following aspects: (a) finitude: because a given problem has to be resolved with a limitation of resources such as cognitive capacity, time or other and these resources might be insufficient for reaching an optimal solution; (b) complexity: caused by the interactions between partially nested hierarchies in complex systems causing the impossibility to distinguish between consequences of action or interaction and to predict the outcome even with a given set of input; and (c) normativity: as rules that intertwine with and contradict possible problem definitions as well as problem solutions. (Cross, 2008; Farrell & Hooker, 2013)

Different theoretical approaches have tried to shed light on the process and have attempted to map methods that designers use to get from the problem to a satisfying solution (Lawson, 2005).

The *Royal Institute of British Architects* (*RIBA*) Architectural Practice and Management Handbook of 1965 uses four phases:

- phase 1: assimilation: the accumulation and ordering of general information and information specifically related to the problem in hand;
- phase 2: general study: the investigation of the nature of the problem. The investigation of possible solutions or means of solution;
- phase 3: development: the development and refinement of one or more of the tentative solutions isolated during phase 2;
- phase 4: communication: the communication of one or more solutions to people inside or outside the design team.

In 1968, (Broadbent, 1968) introduced a similar distinction using five steps:

- briefing: in which the designer finds out what the problem is, and collects information about it;
- analysis: in which the information is sorted out, classified and put into usable form;
- synthesis: in which a variety of solutions to the problem is generated;
- evaluation: in which the various solutions are tested, and one of them selected for development;
- implementation: in which drawings and other material are prepared, so that the design can be put into production.

The division into phases, steps or stages is common to all related studies and due to the, at least, partly wicked behaviour of architectural problems.

The *RIBA* Handbook's design process defines a linear structure, the process is sequential, and no iterations are foreseen. Any retracing of steps from a more advanced phase to an earlier would have to be seen as a design failure. The importance of completing each phase before starting the next is generally emphasized. Thus each phase has an output, which is the input of the following one. (Pedrini, 2003)

Literature review reveals important critics regarding the linear design structure, and claim that to see strategies for the early stages of design in such manner might be misleading.

> "It is quite difficult to know what information to gather in phase 1 (assimilation) until you have done some investigation of the problem in phase 2 (general study)." (Lawson, 2005)

Lawson (2005) understands the *RIBA* Plan of Work to be a map that eases the general design understanding. This map just tells the designers that they must gather information about a problem, study it, devise a solution and draw it, though not necessary in this order. Furthermore, the *RIBA* handbook declares that there are likely to be unpredictable jumps between the phases (Pedrini, 2003). The *RIBA* Plan of Work is not a process description but the description of the products of the process (Lawson, 2005). As defence of the Plan of Work proposed by RIBA, the most widely used model of design process, it is stated that exclusively presents the details of work to be carried out by each profession during each stage of the design process rather than indicating how particular tasks are related (Pedrini, 2003).

Anyhow, all relevant studies agree that a more realistic description of the design process, especially in the EADSs, needs to be based on a non-linear process.

> "[...] the complete design process itself may follow a sequence of events similar to the decision sequence in other cases, the complete process may be represented by a re-cycling or looping through several such stages." (Broadbent, 1966)

Figure 2-1 presents 4 graphical representations of non-linear sequences found in literature (Pedrini, 2003).

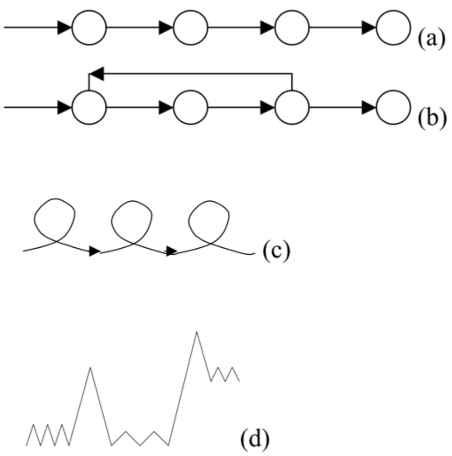

Figure 2-1: Graphical representation of design process sequences according to (Pedrini, 2003) (Lawson, 2005)

In more detail Figure 2-1(a) represents a linear representation, Figure 2-1(b) a linear representation with feedback, Figure 2-1(c) represents looping, while finally, Figure 2-1(d) represents an adaptive process. Maps in literature that use non-linear descriptions of the design process basically include three steps applied in varying compositions and systems: (a) analysis, (b) synthesis, and (c) evaluation (Lawson, 2005). Figure 2-2 schematically represents such process map.

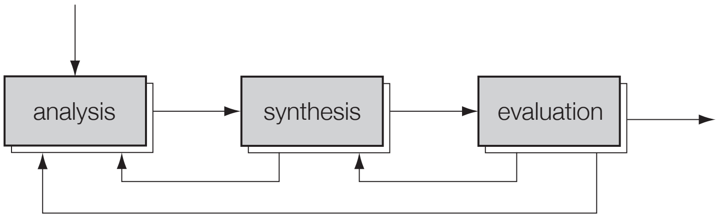

Figure 2-2: Basic Design Stages according to (Lawson, 2005)

(S. Szokolay & Pedrini, 2000) understands that analysis and evaluation are based on rational thinking, and, therefore, scientific methods are employed, and computer programs may be useful. The synthesis, is hard to grasp or define, it is an irrational, subconscious, intuitive and artistic process -a 'black box' or the 'act of creation'.

The repeated iteration of these steps finally leads to the solution. Despite the effort, it is agreed that all these maps are mere approximations to the real design process. (Cross, 2008; Lawson, 2005; Pedrini, 2003)

From the organizational point of view, many studies have tried to identify sequential macro-stages. These stages may include different iterations and their borders are defined either by milestones or by the level of detail of the solution in elaboration.

> "A building delivery process has traditionally been a discrete and sequential set of activities. Designers start with rules of thumb to create a design, and then model it to verify its compliance with the performance goals. If the proposed design did not meet the goals the designers would go back and start again. This tedious trial and error approach continues until finding the design that meets the performance conditions." (Attia et al., 2012)

Literature provides little evidence for design methodology in practice. The intimate and personal nature of process as well as the complexity of its rationalization makes studies and even individual statements difficult to obtain. The process is so complex to be rationalized that few designers are willing to talk about it. Further, the subject is extensive, and a serious study would demand time intensive observations and a large number of case studies. (Lawson, 2005; Pedrini, 2003)

In this context, some observations and conclusions are pertinent:

- Design process maps are not completely representative and designers follow more routes than theory predicts;
- Along their experience designers generate some set of guiding principles;
- Protocol studies reveal that most designers adopt strategies that are heuristic in nature because relying more on experience and rules of thumb than theoretical first principles.

For architectural design, widely accepted sequences of such stages have been defined by organizations such as the American Institute of Architects (AIA) and, with slight differences, include: (a) pre-design, (b) schematic design, (c) design development, (d) construction documents, and (e) construction. (Bundesregierung der Bundesrepublik Deutschland, 2013; The American Institute of Architects, 2007)

Early Design Stages

Special attention has been given to the first stages of the *AEC* design process. This is due to the elevated relevance of the actions taken during the early phases with respect to creativity (Dorst & Cross, 2001; Koskinen, Zimmerman, Binder, Redström, & Wensveen, 2011; Lawson, 2005; Oxman, 1997; Schon & Wiggins, 1992; Suwa, Purcell, & Gero, 1998; Steven V. Szokolay, n.d.; van Leeuwen & Timmermanns, 2006), originality (Dorst & Cross, 2001; Fasoulaki, 2008; Koskinen et al., 2011; Lawson, 2005), complexity (Farrell & Hooker, 2013; Finger & Dixon, 1989a, 1989b; Gero & Sarkar, 2006; Lawson, 2005; Mancarella, 2014), stakeholders involved (Cole, 1999; Ebert et al., 2010; Haymaker & Riker, 2009; Lawson, 2005; Saaty & Vargas, 2012), tools (Attia et al., 2009; Bueno & Turkienicz, 2014; Cole, 2005; Papamichael & Pal, 2002; Weytjens, Attia, Verbeeck, & Herde, 2010) and methods (D. Crawley & Aho, 1999; Mahdavinejad, Dehghani, & Shahsavari, 2013; Saaty & Vargas, 2012) applied and, in this context most importantly, the importance these stages have for the successive decisions and solutions of the architectonical process (Das & Chaudhurri, 2011; The American Institute of Architects, 2007). The decisions taken during this stage can determine the success or failure of the design itself (Attia et al., 2012).

> “Twenty percent of the design decisions are taken during the early design phases and subsequently influence eighty percent of all design decisions.” (Bogenstätter, 2000)

With respect to the building’s energy performance, early design decisions play an important role (G. Augenbroe, 2000; Pedrini, 2003). When attempting to quantify the consequences of decisions at this stage of design, the number of possible cases increases this each additional variable element introduced. As consequence, assessments are generally postponed until the final stages of design, when detailed information are available. References of the use of quantification as a base of design decisions in the schematic phase are rare in literature, although it is during the schematic phase that important early design decisions are made. (Pedrini, 2003)

In this context it is important to recall the MacLeamy curve (The American Institute of Architects, 2007) representing the favourable cost-benefit relation of decisions taken in early stages of the design. The efficiency of the overall process rises with the shift of decisions to earlier stages; the shaded area represents the decisions that should be migrated to early design phases in order to achieve an integrated *AEC* design process.

An integrated design process refers to the integration of both tools and professionals from other disciplines, such as mechanical or structural engineering, into the architect's design process (Keeler & Burke, 2009).

> "In the early stages of designing, by taking a general approach, the designer sees the need to define some aspects and leave other diffusely or partially defined, giving space for future interpretations and construction of further arguments. Once the process evolves, advancing in sublevels of nested problems; decisions are on a closer scale and framed by previous general approach, allowing a better definition of these specific problems." (Bueno & Turkienicz, 2014)

It is straightforward that decisions at the earlier stages are based on less data than those taken in later steps (Godfried Augenbroe, 1992; Keeler & Burke, 2009; Lützkendorf & Lorenz, 2006; Pérez-Lombard et al., 2008; Rizzoli, 1997). As consequence, the support for such early decisions must be specifically designed for the conditions with reduced data availability.

To design efficient buildings, it is necessary to assure an efficient *AEC* Design Process. Such process must be already based on informed decision making during the early design phases. To achieve this, the integration of building performance simulation tools or other support mechanisms into the early *AEC* design process is necessary. (Attia, 2012; Attia et al., 2012)

Integrated Design Process

Hiller and Schuler (1999) state that regular design processes are not suitable for economic and ecological buildings and suggest what the authors denominate *integrated design process*. The cooperation between architects and engineers is not only recommended, but mandatory. In this sense, integration arises from the combination of intuitive and assessment-guided design decisions. While classically intuitive decisions dominate the architect's design process, especially in the *EADS*, it is this work's goal to unify the advantages of implementing both digital tools and early design decisions into the *AEC* design process laid out above to raise the energy efficiency of buildings.

> "[...] if sustainability is to mean anything, it must act as an integrating concept and will require new concepts and tools that are integrative and synthetic, not disciplinary and analytic; and that actively creates synergy, not just summation." (Robinson, 2004)

Architects tend to emphasize the use of intuition, guidelines, or rules-of-thumb during *EADS*, which decrease as the design progresses while rational thinking, rules and consequently the use of assessment, have tendency to increase as the design complexity rises with time. Due to the complexity of the problem and the solution space (Eastman, n.d.; Finger & Dixon, 1989a; Lawson, 2005) of architectural problems, including the buildings energy efficiency, the designer is not capable to fully evaluate the consequences of his/her design decisions. Tools, and recently digital tools, have been employed to assist architects with their task. The repetition of the iterations inside one *AEC* design process and of the design process have, via trial-and-error, led to experiences that in certain cases have evolved to guidelines or rules of thumb. These guidelines and rules have been integrated into the design process due to their simplicity, ease of use and little or no investment or specialized knowledge required.

> "Due to the fact that the building design search space becomes prohibitively large with an increase in the number of design parameters, many researchers focus the optimization studies on particular passive solar design strategies with fewer design parameters, such as the building form, the opaque envelope components or the properties of glazing and its shading." (Stevanović, 2013)

To successfully integrate more precise digital assessment, therefore guiding the architect towards informed design decisions, the employed tools need to attend certain necessities.

Pedrini (2003) lists the following problems for the integration of *EA* tools:

- cumbersome and time-consuming data input;
- user unfriendliness;
- limited graphic visualization;
- uneasy output visualization.

This work will consider the following 4 necessities (Anderson, 2014), or finite resources (Farrell & Hooker, 2013), with respect to the architect's work flow during early design stages: (a) demand only input data available at that stage, (b) respect time constraints of the designer at that stage, (c) use only architect-friendly models, and (d) produce manageable output representations.

The following paragraphs describe the 4 applied resources and the subsequent demands and/or benchmarks to be applied during the framework's creation and evaluation in more detail.

Firstly, the data available in *EADS* is restricted and, therefore, demands to depend on a fraction of possible parameters only. The problem space's resolution level is low and consequently, only a reduced number of information is treated and only a reduced number of data is available in order to model and finally simulate the design at these stages. As early decisions have low level of detail, they tend to be based on generic recommendations, which may have low sensitivity to local characteristics such as climate, occupancies, schedule of use and others. In Mitchell and Burberry (1983), a list of available elements is related to the stages indicated in the *RIBA Plan of Work*, an partial result is documented in Figure 2-3. Note that this necessity is congruent with this work's objective to reduce the input model's complexity.

Secondly, the architect's need to provide a number of viable solutions in order to assess each of them while framed by a finite time span, leads to the benchmark of time. If the assessment to be integrated into these stages exceeds a certain time limit, the flux of work is disrupted, and the creative process is interrupted. Therefore, too long assessment processes, due either to necessary modelling or simulation, make integration difficult if not impossible. Pedrini (2003) confirms that one obstacle to the widespread use of assessment tools is the time-consuming procedure of describing the building in a suited form (modelling), but also the required time for learning each computer program's particular characteristics. The steps taken to achieve a reduction of time necessary to assess a solution also collaborate with the objective to reduce the input model's complexity.

Thirdly, the need for integration is foremost dependent on the ease of use of the new methodology and its tools. Therefore, it is this works main goal to adapt the input model, the architect's main interaction with assessment happens here (Weytjens et al., 2010), in order to facilitate the integration of *EA*.

Fourthly, the need to present the results to the architect in a form that allows his contextualization and eases the decision-making process, leads to the necessity to generate a graphical output. The architect will base his decisions on experience. The results from assessment must be presented in a form that the architect may quickly and easily obtain the necessary information. It is necessary to transform technical output reports from *EA tools* into manageable information for architects, otherwise they will be more satisfied with rules-of-thumb, which supply simple and short answers (Pedrini, 2003).

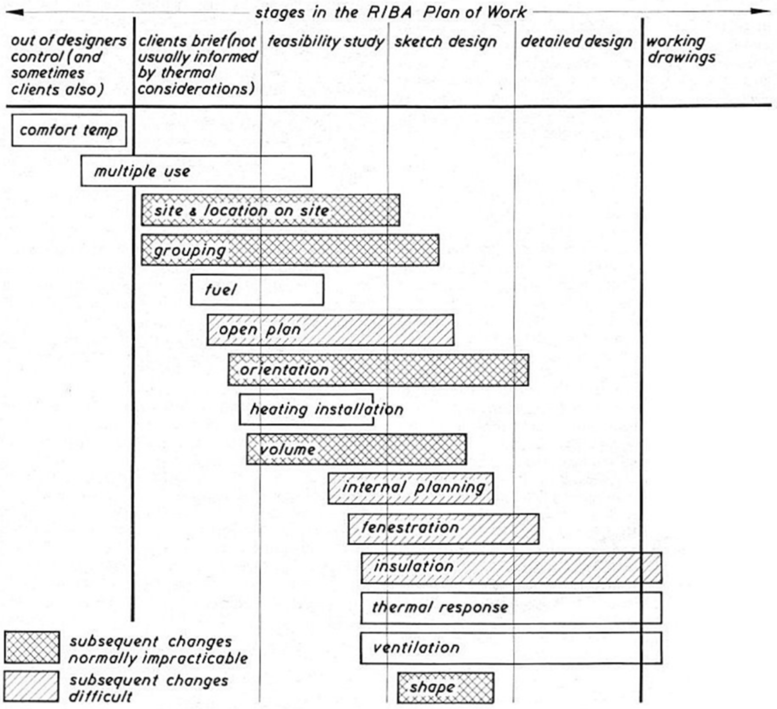

Figure 2-3: Relation between available elements and design stage according to Mitchell and Burberry (1983).

2.2. State-of-the-Art

This sub-chapter presents a brief overview regarding the state-of-the-art of existing methodologies for energy modelling, assessment tools, as well as model simplification.

2.2.1. Energy Modelling

Energy Modelling refers to the creation of a mathematical model that allows to predict a building's energy consumption. This value is directly related to the building's thermo-energetic behaviour among other physical and geometrical qualities such as natural lighting.

> "[...] scientists and engineers frequently resort to various and numerous simulation techniques. Depending on the use cases, several approaches are available: some of them based on the thermal knowledge and physical equations of the building and others based on the data collected inside the building."
> (Foucquier, Robert, Suard, Stéphan, & Jay, 2013)

As for this work, basically, two main approaches are to be distinguished: (a) white box approaches and (b) black box approaches. White box approaches refer to those using physical models to describe the building's thermo-energetic behaviour, while black box approaches that aim to predict results based on a relevant database using statistical methods. Literature proposes hybrid approaches denominated grey box and couple physical models and statistical deduction.

> "For example, [...] [Teeter and Chow (1998)] combined an artificial neural network with a single-zone thermal model to improve the efficiency of the HVAC control by performing the HVAC parameters identification. Other more recent examples are the works of [...] [Paris, Eynard, Grieu, & Polit (2011)] who combined the fuzzy logic, a PID controller and a dynamic model describing the thermal behaviour of the building for implementing several heating control schemes. Furthermore, [...] [Nassif, Kajl, & Sabourin (2005)] applied an optimization process to HVAC system for monitoring issues."
> (Foucquier et al., 2013)

Grey box approaches are highly complex and bring "difficulties for users to understand" (Foucquier et al., 2013). In the following sub-sections the state-of-the-art regarding white box approaches is described as black box approaches require a large amount of data and presents problems when dealing with multi-collinear parameters or non-linear problems.

The following sub-sections detail state-of-the-art white box approaches. It is important to recall that all white box approaches are based on solving mathematical equations describing the physical behaviour of heat transfer inside the building's model.

Computational Fluid Dynamics Approach

Computational Fluid Dynamics (*CFD*) is a three-dimensional approach, which creates a detailed model of the flow field. *CFD* generate detailed descriptions of different flows inside the model, allowing the study of very complex geometries at the expense of huge computation time (Glicksman & Tan, 2005).

A considerable number of *CFD* software tools is available today, the application field is wide and not restricted or intended for building simulation. Common tools are ANSYS FLUENT (ANSYS, n.d.), COMSOL Multiphysics (COMSOL, n.d.), MIT-CFD, and CHAM Phoenics (CHAM, n.d.). Literature also reports the combined use of these tools with tools for Energy Assessment such as EnergyPlus (Foucquier et al., 2013). None of the above-mentioned tools is intended to be used for assessment in early design stages.

Zonal Approach

The zonal approach is a first degree simplification of the *CFD* approach and has been introduced by Bouia and Dalicieux (Bouia & Doliciaux, 1991) and Wurtz (Wurtz apud. Foucquier et al. 2013) in the 1990s. It basically consists in dividing the building's model zones into several cells, each cell corresponding to a small portion of the space.

This approach can reasonably reduce the computation time while accurately estimating the temperature field and thermal comfort.in a space.

Several zonal modelling software in buildings are available, the most frequently employed is called SimSPARK (Laurent apud. Foucquier et al. 2013).

With the reduction of the complexity some shortcomings appear such as the need for previous knowledge of flow profiles and the model's lack of detail, which may lead to insufficient accuracy of eventually obtained results.

Nodal Approach

The nodal approach, also denominated multi-zone approach, assumes that each building zone is a homogeneous volume with uniform state variable qualities. Each zone is described as a node of a system and described with a single temperature, pressure, concentration etc. The entire system is composed of nodes that may represent spaces, building components such as walls or windows, the exterior, but also more specific items like internal loads. The thermal transfer equations are solved for every node individually and consequently is considered a one-dimensional simplification.

TrnSys (e-Media resource, n.d.), EnergyPlus (*EP*) (United States Building Tecnology Office, 2017), EQUA IDA-ICE (EQUA Simulation AB, n.d.), ESP-r (Engineering & Strathclyde, n.d.) (Hand, 2010), Clim2000 (Bornneau, Rongere, Covalet, & Gautier, 1993), BSim (Grau, Rode, & Grau, 2010) and BuildOPT-VIE (Technical University Vienna, n.d.) are among the most common software tools using this approach. Another methodology for the nodal approach, introduced by (Rumianowski, 1989), drastically simplifies the physical problem by linearizing the equations, thereby reducing the computation time, but is rarely adopted by software.

The major advantage of the nodal approach is its ability to describe a multi-zone model over a long period of time with a very small computational time.

> “It is a particularly well- adapted tool for the estimation of the energy consumption and the time evolution of the space-averaged temperature into a room. Moreover, it can be used to predict the building air exchange rates and the airflow distribution between different rooms of a building.” (Foucquier et al., 2013)

While the simplification into zones brings advantages when assessing the overall building, certain limitations arise: assessments of internal zone behaviour, especially in large spaces, are difficult and local effects of heat sources are hard to visualize.

2.2.2. Assessment Tools

Beside the before mentioned standalone tools representing the nodal approach (TrnSys (e-Media resource, n.d.), EnergyPlus (United States Building Tecnology Office, 2017), EQUA IDA-ICE (EQUA Simulation AB, n.d.), ESP-r (Engineering & Strathclyde, n.d.) (Hand, 2010), Clim2000 (Bornneau et al., 1993), BSim (Grau et al., 2010) and BuildOPT-VIE (Technical University Vienna, n.d.)) some tools have been developed based on tools that provide the mathematical model to solve the necessary equations. These assessment tools create interfaces that aim at the ease of use, but use the calculation engine of a third-party tool.

(Østergård et al., 2016) presents an overview of the existing tools, classifying these according to their interoperability mode with the calculation module. Three groups are identified: (a) run-time interoperability, (b) file exchange, (c) stand alone. Examples for the first group are: "*Grasshopper* and *Dynamo* plugins, *SketchUp* or *Revit* with *Sefaira*, *OpenStudio*", for the second group are named: "Building Information Modeling", file formats like "*.dwg*, *.rvt*, *.gbXML*, *.osm*" while "*EP*" is one example for the third group.

Using the criteria of who the software is intended for, which stage of design it is to be used for and how energy assessment is possible, the authors create the overview resumed in Table 2.1.

Table 2-1: Resumed overview of available assessment tools, information obtained fromØstergård et al. (2016)

Assessment Tools

software	user:		design stage:				objectives:			
	architects	engineers	conceptual	preliminary	detailed	management	energy	thermal	daylight	other
Be10	(A)	E		•			•	(•)		
Bsim		E		•	•		•	•		•
DOE2		E			•		•			
EnergyPlus (E+)		E			•		•	•		•
EPC	(A)	E	•	•			•		•	
ESP-r		E			•		•	•	•	•
IDA-ICE		E		•	•		•	•	•	•
iDBuild		E	•	•			•	•	•	•
IESVE	(A)	E		•	•	•	•	•	•	•
Radiance	(A)	E		•	•				•	
VELUX Daylight Visualizer	A	E	•	•	•				•	
A+E3D	A		•	•			•	(•)	(•)	
Daysim	(A)	E	•	•	•				•	
DesignBuilder	(A)	E		•	•		•	•	•	•
eQuest		E		•	•		•			
N++		E	•	•	•		•	•		
OpenStudio		E		•	•	•	•	•	•	•
Riuska		E		•	•		•	•		
Sefaira	A		•	•			•	•	•	
DIVA for Rhino	A	(E)	•	•	•				•	
Green Building Studio	A	(E)	•	•			•			
HoneyBee (GH)	A	E	•	•	•		•	•	•	•
jEPlus (+JESS)		E		•	•		•	•	•	•
Parametric Anlysis Tool		E		•	•		•	•	•	•
Solon	(A)	E		•	•		•			
Dynamo	A	E	•	•						
Grasshopper (GH)	A	E	•	•						

When looking at Table 2.1, it is possible to conclude that only four tools have been designed both: for architects and for tackling energy assessment during *EADS*: (a) *A+E3D*[1], (b) *Sefira*[2], (c) *Green Building Studio*[3], and (d) *HoneyBee (GH)*. While the first two are intended as software, *Green Building*

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[1] Unfortunately, it was not possible to find any further reference to this software. The reference provided in (Østergård et al., 2016), a link accessed in 2015, does not exist anymore. According to the table and research in (Østergård et al., 2016) this tool could be an interesting candidate for integrated energy assessment as it is made for architects, for initial design phases and assesses energy.

[2] This promising software tool, seems to provide a very interesting user interface and, as it is based on the EP calculation engine, is also cited as in the overview of available "Third-Party Graphical User Interfaces" for EP that can be found on the official EP website. As this software is relatively new, no additional research was yet conducted regarding its use and as no trial or student version exist it was not possible to test the tool within this work. Screenshots and some short videos give a general idea of the interface, which, according to the overview given in

Table 2-1, is designed for architects, useful for initial phases, and assesses energy. Further, it seems to provide an iconic modelling interface and generate graphical representations of the simulation results within this iconic environment. In addition, its creators were apparently concerned with the possibility of comparison of different solutions, the contextualization stated as important for the integration of tools for architects in design phases in this work. Nevertheless, no evidence of widespread use of this tool amongst architects has been found.

[3] As mentioned beforehand, this tool does not work as a standalone tool, but is intended to generate results using file formats widely used by drawing or design tools for architects. This indicates the use of at least two distinct tools, *Green Building Studio* and for example a standard *Computer-aided architectural design* tool. On the one hand this allows for the continued use of a program that is already part of the toolset of the architect, on the other, it generates a certain complication during the workflow. As *Green Building Studio* itself does not provide an iconic interface and does not provide the possibility to return iconic results this tool does not attend important integration necessities. It must be positively mentioned that high importance has been given to the comparison of multiple results. According to (Østergård et al., 2016) it is adapted to be used by architects in the first phases of design and provides energy assessment. The main use of this tool though has been indicated to be *Life Cycle Assessment*, here especially the building's carbon footprint.

Studio communicates with design software via file exchange, while *HoneyBee (GH)* works exclusively as a plug-in inside Grasshopper, an existing design software. The following subchapters provide a brief look at software tools taking into consideration this work's main idea to provide energy assessment with a purely iconic interface for the architect during *EADS*.

HoneyBee (GH)

HoneyBee (GH) for Grasshopper (Davidson, 2017) is an interface between *EP* and the *Grasshopper* plugin for the modelling software *Rhinoceros* (Robert McNeel & Associates, 2017). *Grasshopper* does not provide an iconic modelling but attends architects working with parametric models. As its internal logic is similar to that of programming languages like C or C+, using *HoneyBee (GH)* would require additional software training and would represent a major change of design paradigm for a wide majority of architectural design practitioners.

Ecotect

Autodesk Ecotect Analysis (Autodesk, 2015) is a standalone software tool including geometric modelling capabilities. It is meant for architects to be used in the first design stages and presented a quite steep learning curve. Unfortunately, the software was discontinued in 2015, which might explain it was not included in the study of (Østergård et al., 2016).

No documentation is provided on the factors taken into consideration or the method or model used to provide the results. The output, presented in form of charts, does not present the necessary sensibility to evaluate minor design changes to fenestration, shading and/or materials.

Some additional software tools, denominated “Third-Party Graphical User Interfaces” for *EP* can be found on the official *EP* website (*https://energyplus.net/interfaces*) such as *Design Builder* and *EFEN* presented in more detail as follows.

Design Builder

Design Builder (DesignBuilder Software Ltd., 2017) is a interface that provides basic geometric modelling and drag&drop elements in order to render the input of building information into the EP software more comfortable. Its special focus lies on the input of HVAC systems, therefore indicating its use in later design stages and by professionals focussing on such systems.

EFEN

EFEN (DesignBuilder Software Ltd., 2016) aims at the analysis of fenestration in commercial building. Providing pre-established options and fenestration database access, it is not intended to serve for the assessment of other parameters.

2.2.3. Model Simplifications

One of the most important downsides of energy simulation is the amount of time to be invested to (a) model and (b) simulate the building. In this scenario, the study of methodologies to reduce the complexity of models for simulation are of importance to reduce the time to be invested and consequently allow the integration of simulation as assessment during early design stages. (Chwif, 1999)

Beyond the length of the computational time, the need for the building to be described to each computational program in a distinct form can be understood as an additional obstacle to the dissemination of assessment tools. Modelling becomes a time-consuming exercise and requires the learning of each program's idiosyncrasies. (Pedrini, 2003)

In order to reduce the time needed to execute a model's simulation, model simplification presents the most prominent solution (Picco, Lollini, & Marengo, 2014; Saltelli, 2004; Zeigler, Praehofer, & Kim, 2000). While it may be generally assumed that every model simplification, even if not linearly, creates faster modelling and simulation, the omission of important factors may cause a so-called super-simplification (or over-simplification), which results in a model that fails to represent the reality and therefore loses utility. (Chwif, 1999; A.-T. Nguyen, Reiter, & Rigo, 2014)

In this context, Saltelli (2004) defines the relevance R of the model as the ratio between the number of factors that truly induce variations in the output of interest and the total number of factors. A perfect simplified model would achieve relevance $R=1$, while lower values would indicate models theoretically allowing further simplification.

In one of the earliest efforts to simplify simulation models, Zeigler proposed 4 basic approaches (Zeigler et al., 2000):

- (1) Eliminate insignificant components from the model;
- (2) Change parts of the model into aleatory variables;
- (3) Reduce the allowed range of the model's variables;
- (4) Group parts of the model into blocks.

The following text describes two state-of-the-art methodologies for model simplification and one study related to the reduction of the number of parameters, understood as significant components of any energy assessment model. Model simplification in this context must be understood as the simplification (as in reducing complexity) of the geometrical or mathematical model that describes the building inside the simulation software tool.

> “Accurate energy analysis requires time, up to several weeks in more complex cases, and the more accurate the analysis must be the more time it will require. This is in contrast with the necessity to minimize the time requirements of the analysis so that it can be compatible with design times, but to do so simplifications of the building model and a simulation methodology are needed, with the drawback of a loss in accuracy. “
> (Picco et al., 2014)

Successful model simplification must deal with reducing the model’s complexity as much as possible to speed up simulations while maintaining an adequate accuracy. Three attempts to simplify the geometric and mathematical models are presented: Picco et al. (2014) and Beyer (2016) proposed geometrical simplifications, while Versage (2015) attempted to identify a reduced set of parameters with significant impact on the energy consumption.

Picco et al.

The aim of the methodology of Picco et al. (2014) is to deliver fast results to designers in order to support decision making during the early design stages. It aimed at identifying which design factors have the highest impact on energy use. The authors alert that the methodology does not allow precise performance prediction of the final building design.

Basically, 8 simplifications steps to generate a simplified model are proposed:

- (1) Simplified Constructions[4]
- (2) Removal of External Obstructions
- (3) Zone Lumping
- (4) Simplified Transparent Surfaces
- (5) Single Floor Standardization
- (6) Zone Squaring
- (7) Standardization of Transparent Surfaces
- (8) Number of modelled Floors

The authors further report a step-by-step evaluation of the results accuracy as compared to the simulation with the detailed model the steps were applied to.

This methodology proposes very significant geometric simplifications, while maintaining a promising accuracy for the shown case study.

Beyer

This methodology aims at the reduction of modelling as well as simulation time in order to allow users of *EP* to quickly generate building models during early or later design stages. The methodology was demonstrated to the author of this Thesis by Professor Beyer during discussions about model simplifications. It proposes one simple, but drastic simplification: Zone Lumping for the entire building.

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[4] The term construction (or constructions) is used in conformation with the manuals of EnergyPlus and describes a set of materials defining their order, thickness and orientation (inside and outside).

In more detail, a normally detailed *EP* model would make necessary modelling the geometry of all interior slabs and walls, creating also numerous *Thermal Zones* for each geometrical closed compartment (room, office, etc.) or, at least, for similar groups of such in every floor. The proposed *EP* model is reduced to the components that separate the exterior from the interior of the building, comprising in one single *Thermal Zone* the entire building indoor space. To compensate for the loss of information, this new zone is declared to have its *Internal Mass* parameter set to a value that is based on the interior walls and slabs of all floors of the detailed building. Other parameters such as air change rates, people density, equipment and lighting density are set to standard values that represent intermediate values for office buildings.

The thereby created simplified model was resulting in practically identical results for the annual energy consumption as the detailed model.

Versage

Versage (2015) proposes the development of a meta-model to assess the overall energy building performance. A database of 1.29million thermal zone cases has been constructed by parametric combination of building parameters. While the author's main focus lies on the meta-model's construction, his work elaborates an important list that contains the parameters considered of influence on the building's final energy consumption. This list, divided in thermal and geometrical parameters and internal thermal loads, contains a total number of 21 parameters as well as a number of values each of these parameters may assume. The total number of 5.881.705.552.800.000 combinations is the base for all further assumptions taken in Versage (2015).

It is important to highlight that 21 parameters it is an extremely reduced number for even a very early architectural design stage and that Versage (2015) at no point claims that this list would generate an architectural model. Numerous further input information, that may or may not be kept constant during energy assessment, are necessary to describe a typical iconic model as generally created by architects. As Versage (2015) did not specifically aimed at the early design stages, the list of 21 parameters comprise elements, which are not available or thought about to/by architects in *EADS*.

2.2.4. Identified Lacuna

The state-of-the-art identified a lacuna of theoretical work dealing with the integration problems of computational energy assessment tools into the early stages of architectural design: the need to develop architect-friendly tools makes it necessary to understand and tackle the specific problems that arise from the use of iconic models during the decision-making process. Both, the proposed framework – described in chapter 3 – and the proposed validation method – described in chapter 4 – are set to demonstrate that a specific tool for *EA* geared towards an architect-friendly interface in early design stages is not only possible but feasible.

3. FRAMEWORK

This chapter specifies the methodology to create the proposed model's components and describe the case study and lay out possible applications of the methodology.

While this chapter also presents the remaining framework's components, the work's focus will lie on the support for the methodological creation of a *Simplified Input Model* (*SIM*). The simplification involves three basic actions: (a) the reduction of input parameters according to the design stage, (b) model simplification rules in order to reduce the time to be invested in modelling as well as in simulation, and (c) a procedure, starting from one single design proposal, to create a contextualized controlled multi-solution space in order to allow comparisons during the design process. The *Assessment Model* in *EnergyPlus* (*EP*) is described and an architect-friendly *Output Model* is suggested to complete the architect-friendliness of *FORwArDS*[5].

The following sub-chapters specify the proposed framework and lay out possible applications of the methodology.

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[5] The framework specified below is one possibility inside the methodology's potentials, changes to certain procedures are easy to implement and possibilities are indicated where applicable.

3.1. Specification

This sub-chapter specifies the three components of the proposed framework, namely (a) *SIM*, (b) *Assessment Model*, and (c) *Output Model*. The description includes all necessary information to define and/or reproduce the respective models.

3.1.1. Simplified Input Model

The level of user friendliness of the Energy *Assessment Model* is strongly influenced by the complexity of its *Input Model*. Close attention has been devoted to this specific issue assuming from the previous analyses that user friendliness is one of the architect's main requirements.

Two distinguished starting points are possible: (a) an existing project or model and (b) the direct creation of a simplified model. The first actions for each of these two starting points, until reaching the definition of the base values for each parameter, are different; as to unify the two starting points into a single one, it is assumed that a certain degree of detail, superior to that of the *SIM*, has been created outside the framework's work space. This can be originated on an existing project or a design belonging to the *AEC* design process in *EADS*. This model's single requirement is to contain, at least, all necessary information to generate the base values for each parameter. Here on this model will be called the *Original Detailed Model* (*ODM*).

Starting from the *ODM*, three actions will be taken in order to build up the *SIM*: (a) parameter reduction, (b) creation of alternative value options, and (c) exemplary model simplification. Figure 3-1 depicts this structural composition schematically.

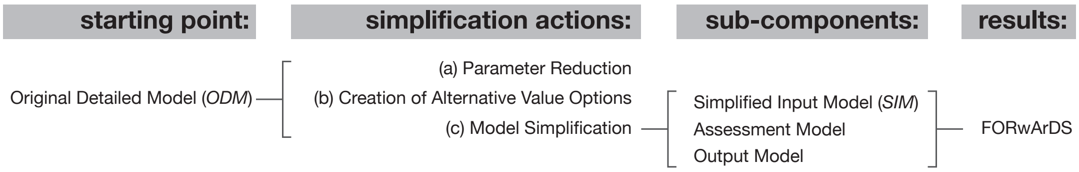


Figure 3-1: *FORwArDS* schematic representation.

The following sub-sections will describe the three actions composing the *SIM* in more detail.

Parameter Reduction

A reduced number of parameters used as inputs potentially lead to a reduction of complexity, to the augment of processing speed and to the improvement of the model's architect-friendliness.

A secondary aspect of the parameter reduction is related to the project's energy efficiency. In other words, the selected parameters have to have direct impact on the project's energy demand, either positively or negatively.

It is worth mentioning that this work will use two different groups of inputs, (a) the ones directly related to the formal aspects known or elaborated by the architect during *EADS*, such the volumes of *External Obstructions* (such as existing buildings), the buildings *Footprint* and *Number of Above Ground Floors*, (b) a reduced set of numerical input parameters defined below. This work assumes that the three parameters from the first group as fixed once they are given to the framework, while the parameters of the second group are variables and may assume alternative values.

An overview of the steps taken to reduce the number of parameters is presented in Figure 3-2. The following paragraphs specify the total of eleven input parameters in more detail.

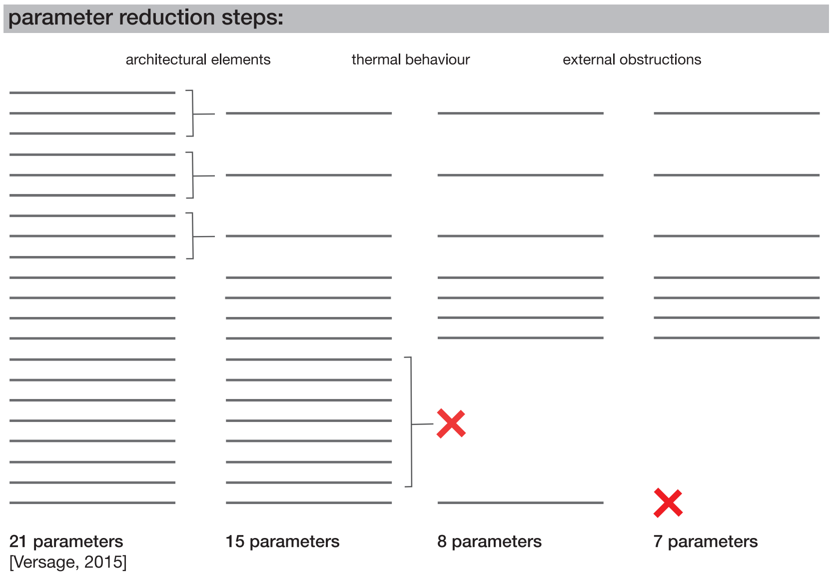


Figure 3-2: Parameter reduction overview.

Firstly, the following parameters related to the project's formal aspects are defined.

As the surrounding buildings are generally given and changes to them out of the project's scope, their volumes are assumed as given. For this work, the geometry of these external obstructions may be defined without restrictions for the model's input. Figure 3-3 exemplifies inputs for external obstructions.

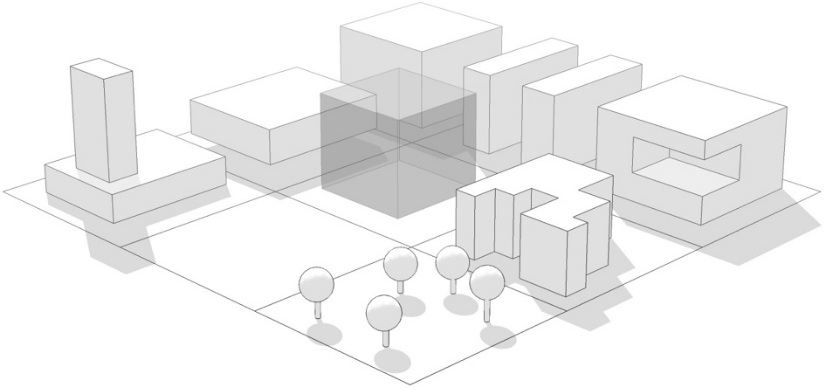


Figure 3-3: Exemplary inputs for external obstructions.

With respect to the geometry of the project itself, only polygons are permitted as input for the model. This polygon, resulting from the projection of the built form, is hereby denominated *footprint*; it is extruded along the z-axis by the value for total building height (*h)*, defined as follows:

$$h = f * c \tag{3.1}$$

where h is the total building height
f is the number of floors above ground
c is the ceiling height (which is defined later as one of the parameters of the second group)

Figure 3-4 shows exemplary options for *footprint* and *Number of Floors Above Ground* to demonstrate those allowed or not allowed as input.

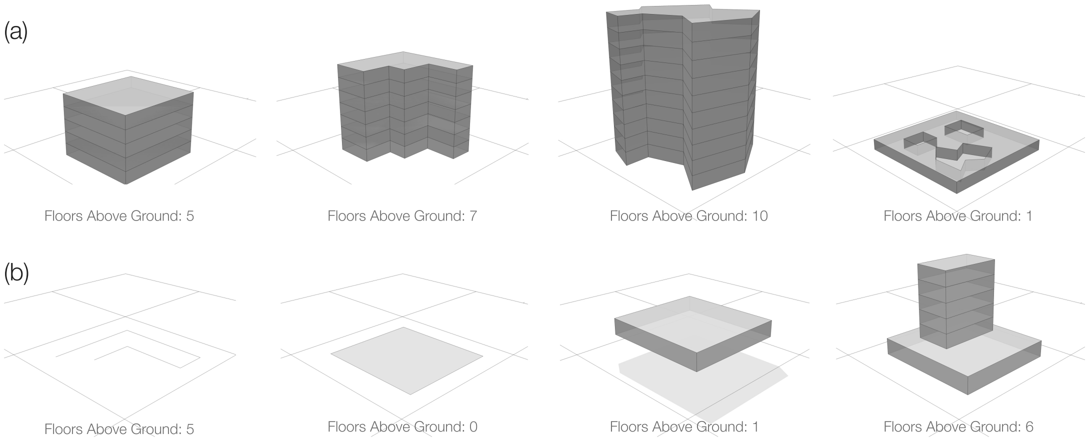


Figure 3-4: Exemplary inputs for footprints and *Number of Floors Above Ground*: (a) permitted, (b) not permitted

In more detail, the four examples from Figure 3-4b fail due to the following problems (from left to right): polygon not closed, no volume defined, footprint not on ground plane, and volume is not an extrusion of footprint. The eight numerical input parameters are detailed below.

Secondly, the numerical parameters used are defined. This work starts with the parameters proposed by Versage (2015). Melo, Versage, Sawaya, & Lamberts (2016) also proposed these parameters due to their importance for the project's energy performance. Therefore, all parameters are assumed to satisfy the second requirement for parameters to be used in the proposed framework, each of them having an impact on the energy consumption of the final project.

In more detail, Versage (2015) suggests to use the following 21 parameters:

- (1) Thermal Transmittance External Wall (U_{wall})
- (2) Thermal Capacity External Wall (C_{wall})
- (3) Solar Absorbance External Wall (A_{wall})
- (4) Thermal Transmittance Roof (U_{roof})
- (5) Thermal Capacity Roof (C_{roof})
- (6) Solar Absorbance Roof (A_{roof})
- (7) Window-to-Wall-Ratio (*WWR*)
- (8) Solar Factor
- (9) Thermal Transmittance of Glazing ($U_{glazing}$)
- (10) Vertical Shading Angle (VSA)
- (11) Horizontal Shading Angle (HSA)
- (12) Neighbourhood Obstruction Angle (NOA)
- (13) Solar Orientation (Azimuth)
- (14) Ceiling Height
- (15) Internal Thermal Mass
- (16) Infiltration Rate (ACH)
- (17) Occupation
- (18) Lighting Power Density (LPD)
- (19) Occupation Density
- (20) Roof Exposure Type
- (21) Floor Exposure Type

It is important to highlight that Versage (2015) defines varying quantities of alternative values for each parameter.

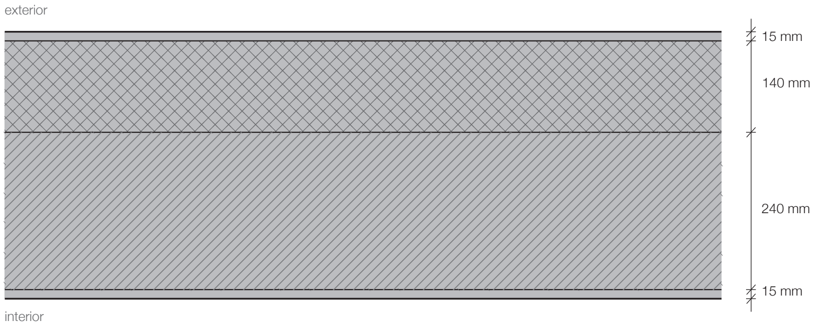
Starting with these parameters, a further reduction of the number of parameters to be used in the *SIM* is proposed. In the following paragraphs, the reduction steps are explained and the methodology to generate a reduced number of alternative values for each of the final eight parameters will be laid out in the sub-chapter *Creation of Alternative Value Options*.

In a first step, the physical parameters are grouped into the architectural elements they refer to. This decision originates new parameters: *Wall Type*, *Window Type* and *Roof Type* and eliminates the original parameters 1, 2, 3, 4, 5, 6, 8, and 9, thus, reducing the number of parameters to sixteen. This regrouping is possible by changing the type of input from a group of numerical values to one abstract input. Such input allows to unify each element's layer composition, which contains all physical information while being additionally closer to the architect's concerns during *EADS*. An example for such abstract input is given in Figure 3-5.

Figure 3-5: Example for *Wall Type*.

Figure 3-5 shows the composition of a wall and the resulting physical parameters of such construction. It is interesting to state that this reduction also limits theoretically possible combination of the physical parameters of each architectural element, which makes the input to be related more closely with the real world and the architect's experience. Without this step,

construction type: exterior wall
name: example wall



layers:
15 mm exterior plaster; 140 mm insulation board; 240 mm lightweight concrete;
15 mm interior plaster

physical qualities:
u-value: 0.288 W/(m^2.K)

some physically impossible combinations of, i.e., *Thermal Transmittance* and *Thermal Capacitance* would be still possible and would need to be eliminated differently.

In a second step, all parameters that refer to the internal thermo-energetic behaviour of the building are fixed to standard values. More precisely, the original parameters 15, 16, 17, 18, 19, 20, and 21 are set to one fixed value each and therefore will be no longer considered as input parameters; this action reduces the number of input parameters to nine. Below the corresponding values are specified, justified and their source identified:

- Internal Thermal Mass:

  The *Internal Thermal Mass* represents the mass of internal architectural elements.

  All components and materials used here represent values accepted by the local construction standards for Porto Alegre, Rio Grande do Sul, Brazil (Município de Porto Alegre, 2001; Poehls, 2012)

  The *Internal Thermal Mass* of the model, *ODM* or *SIM*, is composed of the following components: (a) thermal mass deriving from slabs between floors, and (b) thermal mass deriving from the interior walls. As both architectural elements are subject to alterations in the simplification steps described in sub-section

> Model Simplification, both elements are defined using composition and materials; the actual thermal mass is than calculated using the specific model's geometry for either slab's area (m^2) or interior walls (linear extension (m) multiplied by Ceiling Height (m).

Layer composition, thickness, and materials constitute relevant information for slabs and interior walls respectively. Standard compositions, thickness values and materials are to be assumed in case no specified information is given in the *ODM*. If materials were specified, the given information would be used to calculate the internal mass.

Interior slabs are described through two components, *Interior Floors* and *Interior Ceilings* in the *Energy Plus* input file. For *Interior Ceilings*, the description starts from the outermost layer, specifying the thickness as well as the material from the *EP* library. The layer's specifications are: (a) 10.0 cm concrete slab (*M11 100mm lightweight concrete*), (b) 18.0 cm air gap (*F05 Ceiling air space resistance*), and (c) 2.0 cm ceiling board (*F16 Acoustic tile*).

Interior walls are described in the *Energy Plus* component *Interior Wall*. As the component is assumed symmetrical, the layers' order is not critical. The following description specify the thickness as well as the material from the *EP* library for each layer. The layers are: (a) 1.9 cm gypsum board (*G01a 19mm gypsum board*), (b) 15.0 cm air gap (*F05 Ceiling air space resistance*), and (c) 1.9 cm gypsum board (*G01a 19mm gypsum board*).

- Infiltration Rate (ACH):

  The ACH represents the air tightness of the modelled building describing how often the entire internal air volume of the thermal zone changes per hour, not considering any specific active actions, including opening of windows.

  The ACH was set to an intermediate value (0.75) as no representative study or reference for infiltration in office buildings exist. The chosen value has been derived from the ASHRAE Handbook 2013 reference to residential buildings (American Society of Heating Refrigerating and Air-Conditioning Engineers, 2013), also assumed acceptable for office buildings (Beyer, 2016).

  In Versage (2015) this parameter is not fixed and its possible values range from 0.2 to 1.0. The assumed value in this work therefore lies slightly above the arithmetic mean value of Versage (2015).

  Consequently, the “*ZoneInfiltration:DesignFlowRate*” for all thermal zones is set to this value.

- Occupation:

  The occupation represents the density of occupation (people in the thermal zone) over time. It is often represented by hours of occupation per day (Versage, 2015), but *EP* may use more detailed schedules representing the differential occupation of an office for each hour during one year.

  The proposed model defines the hourly occupation densities for weekdays differently from weekends and holidays. For the detailed definitions, see “*Office Occupancy Schedule*” in the exemplary .idf in Appendix A.

- Lighting Power Density (LPD):

  The LPD defines the heat production in Watt per m^2 generated by artificial lighting.

  The value of 10.5 W/m^2 has been derived from the ASHRAE Handbook 2013 representing an enclosed office using the “Lighting Power Densities Using Space-by-Space Method” (American Society of Heating Refrigerating and Air-Conditioning Engineers, 2013).

- Occupation Density:

  The Occupation Density describes the density of persons per m^2 in the thermal zone. The set value was set to 1person per 11.6 m^2.

  To fix a value, the ASHRAE Handbook 2013 refers to this description as “50% laptop medium”, representing 1 workstation per 11.6 m^2, applying 50% laptop and 50% desktop use. Further 1 printer for 10 workstations, speakers and miscellaneous small equipment are included.

- Roof Exposure Type:

  Two different situations can be identified when dealing with this parameter’s definition. First, the top floor’s roof, which is always associated with the contact to the external condition, hereon considered Exposure Type: “External”. Second, the remaining floors and their respective roof components, which are basically inter-floor slabs and consequently are considered as Exposure Type “Adiabatic”.

- Floor Exposure Type:

  Congruently to the Roof Exposure Type, two situations are observed when dealing with the Floor Exposure. The lowest floor is associated with “External” Exposure, being in contact with the ground, while all remaining floors are part of the inter-floor slabs and are considered “Adiabatic”.

It must be observed that, except for the exposure types, all parameters have been expressed in area-normalized units (per m^2).

Special attention must be driven to the *Internal Thermal Mass*, for its total value is actually calculated as the sum of two distinct values and two distinct areas, these referring to (a*) Interior Floors* and (b) *Interior Walls*. The values for the mass are derived from the standard values specified above, but – while the interior floor area is directly dependent from the given footprint and *Number of Over Ground Floors* – the area of the *Interior Walls* belong to the indirectly presented input parameters. Due to its rare presence in *EADS*, a simplification step, which does not use the value related to the *Interior Walls* – calculating the *Internal Thermal Mass* exclusively based on the *Interior Floors* – has been included. This work assumes an *ODM* that includes detailed information regarding the project’s *Interior Walls*.

In a third and last step, the *Neighbourhood Obstruction Angle* (*NOA*) is eliminated from the list of parameters, as it is already considered for thermo-energetic simulations in *EP* through the *External Obstruction Volume*.

The resulting list of eight input parameters adopted in this work is presented below:

- (1) Wall Type
- (2) Window Type
- (3) Roof Type
- (4) *Window-To-Wall-Ratio* (*WWR*)
- (5) *Vertical Shading Angle* (*VSA*)
- (6) *Horizontal Shading Angle* (*HSA*)
- (7) Solar Orientation (*Azimuth*)
- (8) Ceiling Height

The following sub-section will detail the exemplary creation of three alternative values for each of the established input parameters above.

Creation of Alternative Value Options

A methodology to create alternative values is set forth departing from the need for contextualization by comparison and to offer a wider architectural design options.

The creation of a minimal number of alternative values for each input parameter is explained as to keep the resulting solution space as controllable as possible[6].

Seven parameters with three alternative values each and one parameter with four alternative values results on 8748 possible design solutions. Three values were chosen as to demonstrate the effects of alternative designs[7]. To allow to rotate, and hence

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[6] Each additional alternative value exponentially increases the possible combinations, with strong influence on the complexity and the time to be invested to simulate and evaluate the results.

[7] Starting from the intermediate value, making changes in either direction (augment or decrease) possible.

test, all four solar orientations, the parameter describing the project's solar orientation is allowed to assume four alternative values instead of three. It is important to highlight that the presented methodology easily allows to adopt any higher number of alternative values as to increase the design flexibility.

Two different types of input parameters are to be distinguished: (a) abstract inputs[8] and (b) numerical values. This work uses abstract inputs for the parameters (1) *Wall Type*, (2) *Window Type*, (3) *Roof Type*, while the remainder is expressed throughout numerical value.

The three choices, their origin and detailed information regarding the respective physical parameters, are specified below.

---

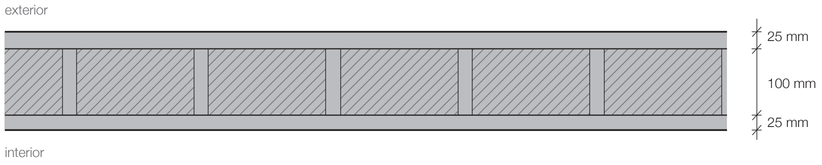
[8] The parameters (1), (2), and (3) permit the alteration of the composition of the respective architectural element. Therefore, the alternative values here are expressed in abstract form, in other words, the choices offered are no numerical values, but different Wall, Window and Roof constructions. All three groups of alternative values are chosen to represent a realistic spectrum of constructions inside the legal range of physical specifications. It is further goal to choose three values that represent equidistant values for the thermal resistance of the composition, as this represents the one of the most prominent influences on the overall thermal behaviour of the model. Note that the materials listed below are followed by the material name referring to the material used in EP; in some cases the material's thickness is not according to the description, in these cases, the original material from the data base (Beyer, 2015) is altered by modifying the thickness only; these materials have names starting with "LBP". It is important to highlight that choosing three pre-established construction types is only sound for certain applications, such as educational use of *FORwArDS*. The validation procedure presented in Chapter 4, will use the original values as defined in the *ODM* or the mean value of the thermal behaviour, obtained as described in

Model Simplification, and apply the two extreme alternative values described below to complete the three values for each parameter.

- Wall Type:

  The first *Wall Type*, denominated *Wall Type* 01, is chosen to represent a composition with a u-value close to the national legislation's superior limit of 3.0 W/(m^2.K) (Associação Brasileira de Normas Técnicas, 2003). Using table D.3 of the NBR 152200 (Associação Brasileira de Normas Técnicas, 2003), the closest value is achieved by a brick wall composed of 0.025 m exterior plaster (*LBP F07 25mm stucco*), 0.100 m of brick (*Brick – fired clay – 1120 kg/m3 – 102mm*), and 0.025 m interior plaster (LBP F07 25mm stucco), using 0.010 m of mortar between bricks[9], resulting in a total depth of 0.015 m. This composition has a u-value of 3.13 W/(m^2.K), a thermal capacity of 255 kJ/(m^2.K) and a thermal delay of 3.8 h. Figure 3-6 depicts the described component graphically.

construction type: exterior wall
name: Wall Type 01



layers:
15 mm exterior plaster; 140 mm insulation board; 240 mm lightweight concrete; 15 mm interior plaster

physical qualities:
u-value: 0.288 W/(m^2.K)

Figure 3-6: Wall Type 01.

The wall denominated *Wall Type* 02, with an intermediate u-value is, according to Table D.3 from the NBR 15220

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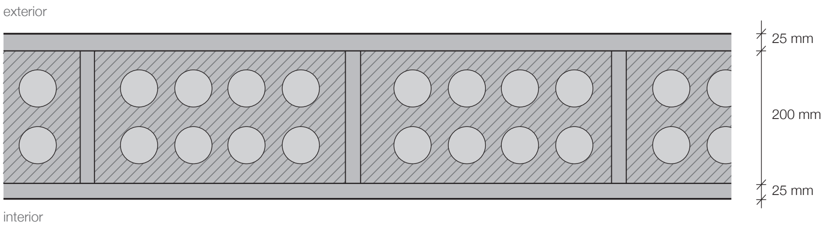
[9] This detail is not informed in the constructions of EP, but was used in order to calculate the u-value.

(Associação Brasileira de Normas Técnicas, 2003), composed as follows: 0.025 cm exterior plaster (*LBP F07 25mm stucco*), 0.200 m of hollow bricks with 8 circular holes (*LBP Brick – fired clay – 1120 kg/m3 – 200mm*), and 0.025 m interior plaster (*LBP F07 25mm stucco*), using 0.010 m of mortar between bricks[10] ; resulting in a total component depth of 0.250 m. This composition has a u-value of 1.61 W/(m^2.K), a thermal capacity of 232 kJ/(m^2.K) and a thermal delay of 5.9h. Figure 3-7 depicts the described component graphically.

construction type: exterior wall
name: Wall Type 02



layers:
25 mm exterior plaster; 200 mm hollow brick; 25 mm interior plaster

physical qualities:
u-value: 1.61 W/(m^2.K)
thermal capacity: 232 kJ/(m^2.K)

Figure 3-7: *Wall Type* 02.

The third wall composition, in order to be equidistant regarding its u-value, had to be defined outside the suggested compositions from the NBR 15220 (Associação Brasileira de Normas Técnicas, 2003), as no similar value is cited. A wall with a composition that resulted in the u-value of 0,09 W/(m^2.K) has been created. In more detail, this wall alternative is composed of a 0.100 m external

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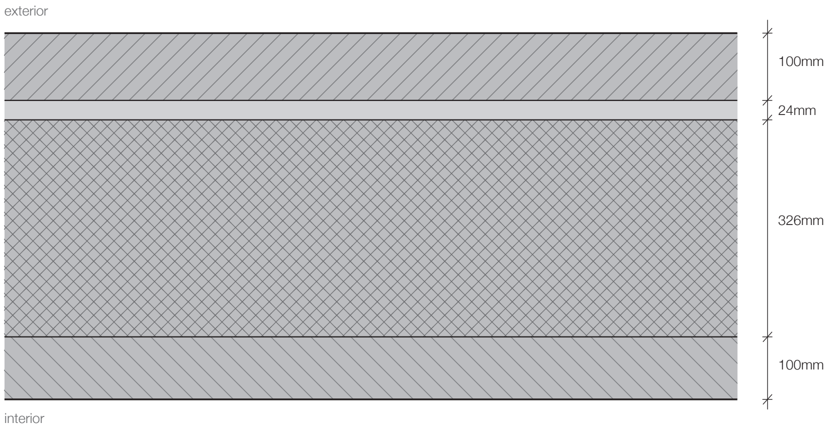
[10] This detail is not informed in the constructions of EP, but was used in order to calculate the u-value.

concrete (*M11 100mm lightweight concrete*), a 0.024 m air gap (*F04 Wall air space resistance*), 0.326 m XPS foam insulation (*LBP Insulation: Cellular polyurethane /polyisocyanuratei (CFC11 exp.) (unfaced))*, and 0.100 cm internal bricks (*M01 100mm brick*); resulting in a total depth of 0.550 m. This wall possesses a thermal capacity of 276 kJ/(m^2.K) and a thermal delay of 18.0h (U-wert.net UG, n.d.). Figure 3-8 depicts the described component graphically.

construction type: exterior wall
name: Wall Type 03



layers:
100mm external concrete; 24mm air gap; 326mm XPS foam insulation; 100mm internal brick

physical qualities:
u-value: 0.09W/m^2.K
thermal capacity: 276kJ/(m^2.K)

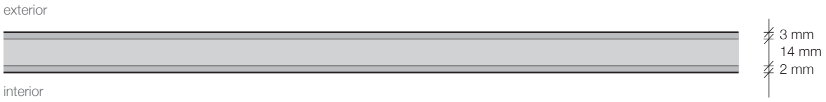
Figure 3-8: *Wall Type* 03.

- Window Type:

  As no Brazilian legislation directly regulates the thermal behaviour of glazing or windows, the three alternative components were arbitrarily chosen to represent three common solutions for Brazilian office buildings. It is worth notice that the following options relate exclusively to the glazing area[11].

  The first *Window Type*, *Window Type* 01, is an insulated double glazing, composed of an external 0.003 m simple transparent glazing (*CLEAR 3MM*), 0.014m air gap (*AIR 13MM*), and an internal 0.002 m simple transparent glazing (*CLEAR 2.5MM*), summing a total component depth of 0.020 m. This component possesses a u-value of 2.91 W/(m².K) (U-wert.net UG, n.d.). Figure 3-9 depicts the described component graphically.

construction type: window
name: Window Type 01



layers:
3 mm transparent glazing; 14 mm air gap; 2 mm transparent glazing

physical qualities:
u-value: 2.91 W/(m².K)

Figure 3-9: *Window Type* 01.

---

[11] The definition does not alter the framing or any further detail of the component “window”, all of them are considered not to be relevant in *EADS*.

Window Type 02 is a single transparent 0.006 m glazing (*CLEAR 6MM*), resulting in a u-value of 5.62 W/(m².K). Figure 3-10 depicts the described component graphically.

construction type: window
name: Window Type 02

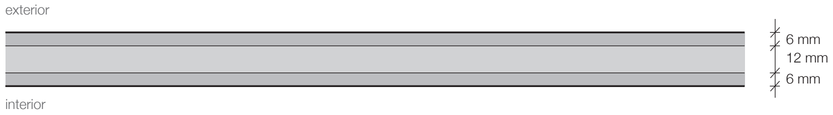
layers:
6 mm transparent glazing

physical qualities:
u-value: 5.62 W/(m².K)

Figure 3-10: *Window Type* 02.

Window Type 03, an insulated glazing, has a low-e coated glass on the exterior. The composition uses a 0.006 m transparent glazing (*CLEAR 6MM*), a 0.012 m air gap (*AIR 13MM*) and a low-e coated coloured (green) glazing of 0.006 m (*LoE TINT 6MM*) as external layer. This results in a total component depth of 0.042 m and a u-value of 2.60 W/(m².K) (cebrace, 2016). Figure 3-11 depicts the described component graphically.

construction type: window
name: Window Type 03



layers:
6 mm low-e glazing; 12 mm air gap; 6 mm transparent glazing

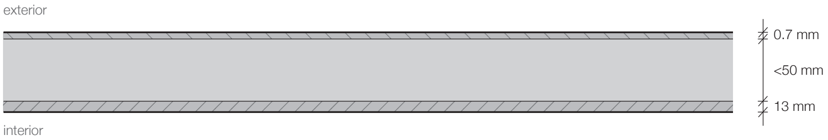
physical qualities:
u-value: 2.60 W/(m².K)

Figure 3-11: *Window Type* 03.

- Roof Type:

  Roof Type 01 represents a composition with a u-value closer to the Brazilian legislation's superior limits of 2.00 W/(m^2.K) for the u-value and 3.3h for the thermal delay (Associação Brasileira de Normas Técnicas, 2003). The nearest value was achieved by a roof composed of 0.007 m fiber cement tiles (*LBP Asbestos-cement board – 7.0mm*), an air gap of more than 0.05 m (*F05 Ceiling air space resistance*), and a wooden ceiling of 0.01 m (*G04 13mm wood*)[12]. This composition has a u-value of 2.00 W/(m^2.K), a thermal capacity of 25 kJ/(m^2.K) and a thermal delay of 1.3h. Figure 3-12 depicts the described component graphically.

construction type: roof
name: Roof Type 01



layers:
0.7 mm fiber cement tiles; >50 mm air gap; 13 mm wood

physical qualities:
u-value: 2.00 W/(m^2.K)

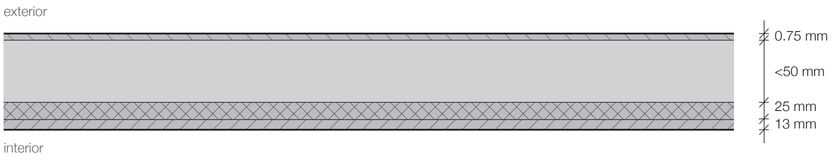
Figure 3-12: *Roof Type* 01.

---

[12] As a commonly used composition had been deployed, table D.3 of the NBR 152200 (Associação Brasileira de Normas Técnicas, 2003) has been consulted.

Roof Type 02 is meant to achieve a lower u-value. The NBR 15200 (Associação Brasileira de Normas Técnicas, 2003) offers various compositions with values near 1.00 W/(m^2.K) of which a roof composed of 0.075 m clay tiles (*Clay tile – hollow – 1 cell deep – 75mm*), an air gap of more than 0.050 m, 0.025 m glass fibre insulation (*LBP Insulation: Cellular glass – 20mm*), and a 0.010 m wooden ceiling (*G04 13mm wood*), is chosen. This composition results in a u-value of 0.95 W/(m^2.K), a thermal capacity of 33 kJ/(m^2.K) and a thermal delay of 2.3h. Figure 3-13 depicts the described component graphically.

construction type: roof
name: Roof Type 02



layers:
75 mm clay tiles; >50 mm air gap; 25 mm glass fiber insulation;
13 mm wood

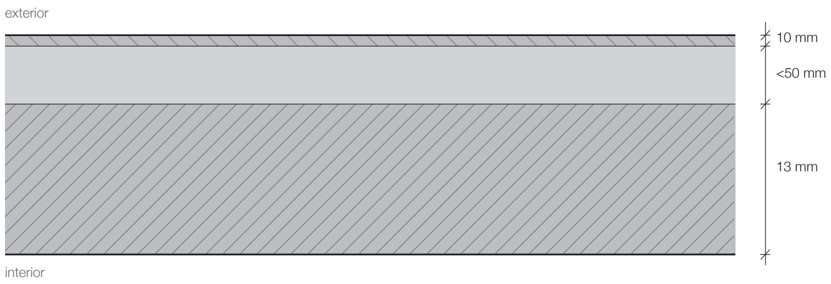
physical qualities:
u-value: 0.95 W/(m^2.K)

Figure 3-13: *Roof Type* 02

Roof Type 03 has a similar u-value of *Roof Type* 02, but drastically differs in its thermal capacity and delay. Table D.3 from the NBR 15220 offers a roof composed of 0.010 m cement tiles (*F14 Slate or tile*), an air gap of more than 0.050 m (*F05 Ceiling air space resistance*), and a 0.250 m concrete slab (*LBP M15 250mm heavyweight concrete*), resulting in a u-value of 1.03 W/(m^2.K), a thermal capacity of 561 kJ/(m^2.K) and a thermal delay of

13.4h (Associação Brasileira de Normas Técnicas, 2003)[13]. Figure 3-14 depicts the described component graphically.

construction type: roof
name: Roof Type 03



layers:
10 mm fiber cement tiles; >50 mm air gap; 250 mm heavyweight concrete

physical qualities:
u-value: 1.03 W/(m^2.K)

Figure 3-14: *Roof Type* 03.

The numerical values of parameters (4), (5), (6), (7), and (8) are the representation of the respective three alternative values used in this thesis. The following paragraphs describe the general methodology applied to create a set values, followed by the specification of these values.

With the parameter's base value as input, two basic steps can be identified: (a) the definition of an acceptable range and (b) the distribution of the remaining alternative values to guarantee an equidistant distribution in the beforehand defined range.

---

[13] It is worth to recall that the thermal delay is superior to the value allowed by the NBR 15220, but the different thermal characteristics are prioritized to offer a third variation inside the proposed framework.

The acceptable range is, in a first step, detailed for each of the eight input parameters below:

- Window-To-Wall-Ratio (WWR):

  The acceptable range for *WWR* is set from 0% to 95%, where 0% corresponds to a wall with no fenestration, while the upper limit of 95% is set to represent a glazed facade. The limit is reduced from the theoretical maximum of 100% firstly due to *EP*'s data structure, which defines a window as a sub-structure of the wall (and therefore every window must be nested inside a larger wall), further to guarantee the inclusion of inevitable opaque elements such as pillars and beams. The value of 95% is outside the range (0% – 80%) by Versage (2015) but is expected to adapt better to early stages of architectural design, when architects might not take constructional or structural issues into consideration.

- Vertical Shading Angle (VSA):

  The limit for *VSA* is chosen based on the theoretical minimum of 0°, representing no shading device, and 45°, the upper limit according to the Brazilian Energy Efficiency labelling (Eletrobrás/Procel; Procel Edifica/Electrobrás; CB3e, 2013). This work therefore limits the depth of the horizontal shading device by the height of the glazing it protects. To facilitate the architect's perception of the difference between the alternative values, the *VSA* will be reported in meters instead of degrees, *VSA*'s three options therefore vary according to the window geometry, but will always represent the corresponding values in degree.

- Horizontal Shading Angle (HSA):

  The limit for has been chosen based on the theoretical minimum of 0°(no shading device) and 45°, the upper limit according to the Brazilian Energy Efficiency labelling (Eletrobrás/Procel; Procel Edifica/Electrobrás; CB3e, 2013). It is worth noticing that *FORwArDS* always assumes two equal shading devices on each side of the glazing to be protected, thus limiting the depth of the horizontal shading devices by the width of the glazing[14].

- Solar Orientation (Azimuth):

  The Azimuth is considered to have no restriction, therefore allowing rotations from 0° (north stays north) and 359° clockwise (almost completing a full rotation) in steps of 1°.

  This work considers 0° as north and a cone of 90° as northwards. In more detail, these cones include the lower (or left-hand) degree while excluding the high (or right-hand) degree. The cone considered northwards therefore is from 325° to 44°. The corresponding cones apply for westwards, southwards, and eastwards.

- Ceiling Height:

  The range for the *Ceiling Height* is defined between the regulatory limit of 2.4 m (Município de Porto Alegre, 2001) and the upper value of 6.2 m from Versage (2015).

---

[14] To facilitate the architect's perception of the difference between the alternative values, the *HSA* will be reported in meters instead of degrees, its three options therefore vary according to the window geometry, but will always represent the corresponding values in degree.

The second step, the selection process of the alternative values, is explained using the *WWR* as example. It is meant to represent a generic and adaptable methodology to create any number of distributed alternative values inside a defined acceptable range. The methodology's main goals are to guarantee (a) equidistant intervals between the values, (b) a coverage of at least 50% of the acceptable range, and aims at generating (c) ate least one inferior and one superior alternative value with respect to the base value. The methodology was programmed in C programming language using *XCode* (Apple Inc., 2016), a partial code is presented in Figure 3-15. The entire code can be found in Appendix B.

```
// CALCULATE RANGE (r), dvinf, and dvsup
    r=(limsup-liminf);
    dvinf=(v-liminf);
    dvsup=(limsup-v);

// ALTERNATIVE VALUE CREATION
  // CASE 1 (r/3 fits)
    c1=(v-(r/3));
    c2=(v+(r/3));
    if ((c1>=liminf) && (c2<=limsup)){
        i=(r/3);
        valt1=(v-i);
        valt2=(v+i);
    }
  // CASE 2 (r/3 does not fit inferior
range, r/4 does fit inferior range, value
is in the inferior half)
    c1=(v-(r/4));
    c2=(v-(r/3));
    if
((c2<liminf)&&(c1>=liminf)&&(dvinf<dvsup)){
        i=(v-liminf);
        valt1=(v-i);
        valt2=(v+i);
    }
  // CASE 3 (r/3 does not fit superior
range, r/4 does fit superior range, value
is in the superior half)
    c1=(v+(r/4));
    c2=(v+(r/3));
    if
((c2>limsup)&&(c1<=limsup)&&(dvsup<dvinf)){
        i=(limsup-v);
        valt1=(v-i);
        valt2=(v+i);
    }
  // CASE 4 (r does not fit inferior range,
value is in the inferior half)
    c1=(v-(r/4));
    if ((c1<liminf)&&(dvinf<dvsup)){
        i=(r/3);
        valt1=(v+i);
        valt2=(v+(2*i));
    }
  // CASE 5 (r does not fit superior range,
value is in the superior)
    c1=(v+(r/4));
    if ((c1>limsup)&&(dvsup<dvinf)){
        i=(r/3);
        valt1=(v-i);
        valt2=(v-(2*i));
    }
```

Figure 3-15: Part of the code used to create two additional alternative values.

It is important to highlight, that an adaption to more additional alternative values is possible. To do so, additional lines for each additional alternative value would have to be added to the code's four if-conditions.

Using *WWR* as an example, the initial information is:

- Acceptable range: 0% to 80%

To demonstrate the methodology, three hypothetically possible base values (*v*) are assumed and the respective creation of two additional alternative values is specified. The three exemplary values assumed are: 40%, 21% and 79%.

For 40%, the steps in line 2 and 3 result in $\Delta liminf=40$ and $\Delta limsup=40$. With $r=80$, therefore $r/3=26{,}66$, the condition $40>26{,}66$ is true. Consequently, $i=26{,}66$ and the new alternative values are calculated as follows: $valt1=40-26{,}66=13{,}33$ and $valt2=40+26{,}66=66{,}66$.

To demonstrate the coverage, the covered range is calculated as follows:

$valt2-valt1=66{,}66-13{,}33=53{,}33$.

This represents 66,66% of the original range, while using equidistant intervals and creating both, a higher and a lower value, with respect to the base value. Figure 3-16 depicts this example.

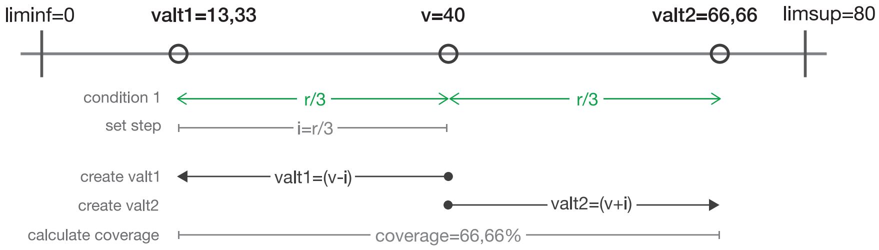


Figure 3-16: Exemplary alternative value creation using *WWR* with acceptable range from 0% to 80% and a base value of 40%.

In more detail, the top line represents the acceptable range the parameter, in the case of *WWR* used here as example from 0 to 80. The black circle in the centre, labelled v=40, is the base value. With these given information, the first condition is checked as shown in the second line; both conditions are fulfilled and therefore represented in green. This results in the definition of the step i. With this value defined the two alternative values can be defined, they are shown as black circles in the top line. The last line of Figure 3-16 demonstrate the achieved coverage, in this example 66,66%.

For 21%, lines 2 and 3 result in $\Delta liminf=21$ and $\Delta limsup=59$. With $r=80$, therefore $r/3=26{,}66$ and $r/4=20$, the condition $21>26{,}66$ is false, while the condition $21>20$ is true. Consequently, $i=\Delta\mathrm{liminf}=21$ and the new alternative values are calculated as follows: $valt1=21-21=0$ and $valt2=21+21=42$.

To check the coverage, the covered range is calculated as follows: $valt2-valt1=42-0=42$. This represents 52,50% of the original range, while using equidistant intervals and creating both, a higher and a lower value, with respect to the base value.

Figure 3-17 depicts this example.

Figure 3-17: Exemplary alternative value creation using *WWR* with acceptable range from 0% to 80% and a base value of 21%.

It is important to highlight that the inferior test of condition 1 failed (represented in red) and, consequently, the second condition has been checked in the following line of

Figure 3-17. An equivalent case would occur for base values in the same proximity to the superior limit.

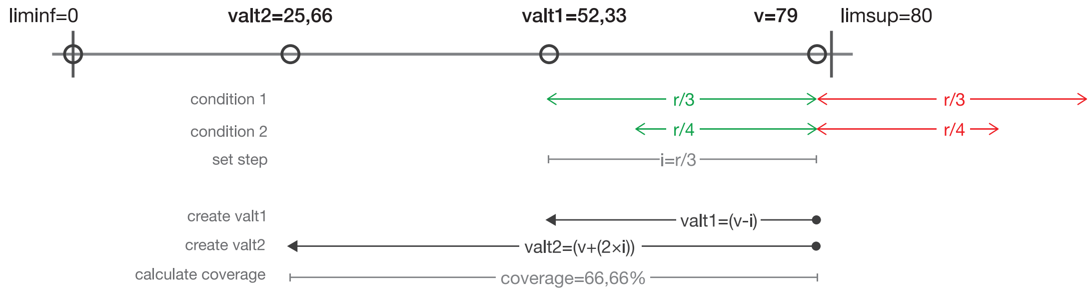
For 79%, the first step would result in $\Delta liminf=79$ and $\Delta limsup=1$. With $r=80$, therefore $r/3=26{,}67$ and $r/4=20$, both conditions $1>26{,}67$ and $1>20$ are false. Consequently, $i=26{,}67$ and the new alternative values are calculated as follows: $valt1=79-26{,}67=52{,}33$ and $valt2=79-26{,}67-26{,}67=25{,}66$.

To identify the coverage, the covered range is calculated as follows: *v-valt2*=79-25,67=53,33. This represents 66,66% of the original range, while using equidistant intervals. Due to the proximity of the base value to the upper limit, it is not possible to create an alternative value superior to the base value, instead two inferior values are created to guarantee better coverage. Figure 3-18 depicts this example graphically.

Figure 3-18: Exemplary alternative value creation using *WWR* with acceptable range from 0% to 80% and a base value of 79%

The example shown in Figure 3-18 demonstrates the situation in which both conditions fail for their superior test range.

An equivalent case would occur if the base value would be too close to the range’s inferior limit.



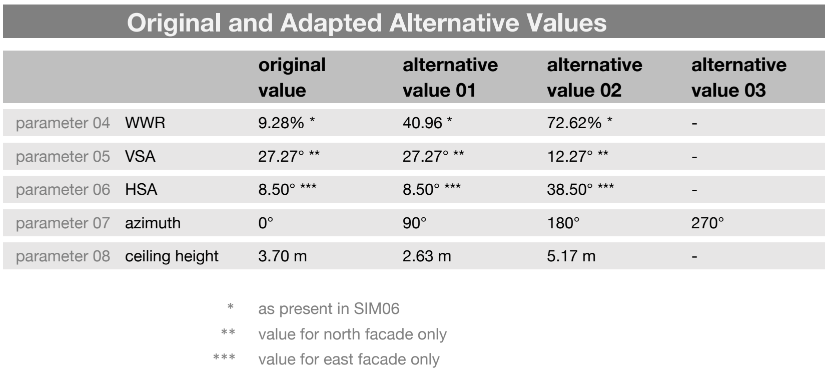
The presented examples demonstrate the best-case scenario with the example of 40% and a near worst case scenario, using 21%, with respect to coverage. Further, the last example shows how the proposed methodology deals with cases, where base values close to one of the range’s limits make the creation of a higher and lower alternative value unacceptable for the goal of coverage.

With the first two steps completed, an *ODM* with a reduced number of parameters has been defined and the necessary information for the third and last step are available.

Table 3-1 presents an overview of the alternative values created by the methodology described above for each of the 5 numerical parameters to be considered as inputs in the *FORwArDS*. Note that the solar orientation is creating 3 alternative values that are not created using the methodology described above but cover the 4 cardinal orientations.

Table 3-1: Overview of adapted alternative values for the considered parameters.

The following sub-section will specify the simplification steps taken, starting from the *ODM*, to generate multiple *SIMs* necessary to return simulation results for an integrated energy assessment during *EADS*.



Original and Adapted Alternative Values

		original value	alternative value 01	alternative value 02	alternative value 03
parameter 04	WWR	9.28% *	40.96 *	72.62% *	-
parameter 05	VSA	27.27° **	27.27° **	12.27° **	-
parameter 06	HSA	8.50° ***	8.50° ***	38.50° ***	-
parameter 07	azimuth	0°	90°	180°	270°
parameter 08	ceiling height	3.70 m	2.63 m	5.17 m	-

* as present in SIM06
** value for north facade only
*** value for east facade only

Model Simplification

The first two actions directly dealt with the input parameters, whereas the third action aims at the simplification of the digital model, which will be used as input for the *Assessment Model*. At this point it was necessary to define the simulation software, as each software has a specific input format. This work will exclusively use *EP* (National Laboratory of the U.S. Department of Energy, 2016a) and, consequently, all tasks related to the simplification of the underlying model converge to create an *.idf*-file, the input format used by *EP*. This input file contains numerous information that are not directly treated in this work, but briefly described in the sub-chapter 3.1.2.

The proposed six model simplification steps are modifications to the *ODM* that aim at reducing the complexity of the model – consequently augmenting the architect-friendliness and reducing the time for modelling – while maintaining an acceptable accuracy of the simulation results obtained. The modifications are mainly geometrical, but two steps (step 3 and 6) refer to modifications of numerical parameters, which do not have a geometrical representation. The remainder of this section will specify the six accumulative model simplification steps resumed in Table 3-2.

Table 3-2: Model simplification steps.

	Simplification Step:	Abreviation:
Step 1	Removal of External Objects	REO
Step 2	Simplified Constructions	SCo
Step 3	Zone Lumping	ZoL
Step 4	Internal Mass without Interior Walls	IMW
Step 5	Simplified Transparent Surfaces and Shading	TSS
Step 6	Zone Squaring	ZSQ

Note that the graphical representation is generated in *Trimble SketchUp* (Trimble Navigation Limited, 2016) using the *OpenStudio Legacy Plug-In* (National Laboratory of the U.S. Department of Energy, 2016b).

Below each step is detailed:

- Step 1: Removal of External Objects (REO)

  Even if the external conditions, such as the surrounding buildings, trees or other objects that may cast shadow on the project volume, are normally known from the beginning of the design process, this work has chosen to include this step into the sequence of simplifications in order to (a) compare the obtained results to those in Picco et al. (2014), who includes this step as well, and (b) to keep the obtained results as simplified as possible to avoid eventual interference from such objects on the overall result.

> "This step is not dictated by the unavailability of needed information, as the position of the building and its surroundings are one of the first information known, but by the observation that the modelling of external obstruction would be a too cumbersome and detailed work for an early-stage, and is in fact one of the most common simplifications applied in practice without noticing. Conversely, shadowing of fenestrations can be a specific design choice with significant impact on energy needs and requires to be modelled even if the exact dimensions of each shadowing element are probably not yet known."
> (Picco et al., 2014)

If necessary or desired, external objects could be easily integrated into the proposed modelling process, but their impact on the simulation time and accuracy is not estimated in this work.

An exemplary application of the removal is depicted in Figure 3-19.

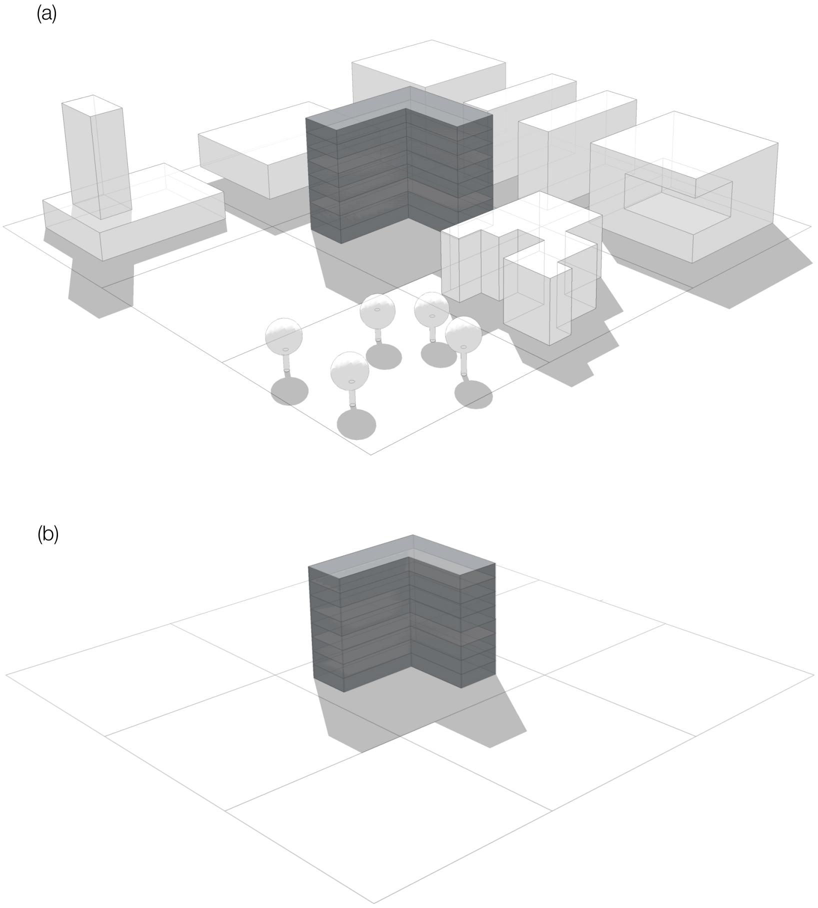


Figure 3-19: Exemplary application of *REO*: (a) before, (b) after

The model without external obstructions is assumed as base for the following simplification steps.

- Step 2: Simplified Constructions (SCo)

  The step of simplifying the constructions means to reduce all existing constructions into the following set of seven basic constructions:

  1. Exterior_Wall
  2. Exterior_Roof
  3. Exterior_Floor
  4. Window
  5. Shading
  6. Interior_Wall
  7. Interior_Floor

  Only the first five are needed to be provided as geometrical input, the last two are introduced using a numerical value inside the .idf input file representing the internal mass (see *Zone Lumping* for details).

  In order to simplify a model or project that contains more than one construction in the above-mentioned categories, for example two different exterior wall compositions, the following procedure is adapted in order to generate a single construction to be applied to all corresponding geometrical elements of the *SIM*:

  1. The U-value for all different constructions is calculated (U1, U2, ... , Uz);
  2. The corresponding area for these constructions is calculated (A1, A2, ..., Az);
  3. The area-weighted mean U-value is calculated according to the following equation:
  4. $U_{mean} = ((U_1/A_1) + (U_2/A_2) + \cdots + (U_z/A_z))/z$
  5. A construction with Umean is used in the SIM;
  6. The step is repeated for all seven constructions mentioned above.

It is important to remember that the simulations to be fed with the *SIM* are set to measure the differential energetic behaviour of the building, basically dependent on the thermo-energetic behaviour (need for air-conditioning) and natural lighting (need for artificial lighting). In this work, other important factors, such as internal mass, internal gains (both human and non-human) are assumed as constant.

It is important to point out that this simplification step does not have direct geometrical consequences, as constructions are represented as 2D planes. However, the reduction of constructions used in the simulation model represents an important step towards an adequate model for *EADS*, during which such detailed information rarely is available.

The model with only seven constructions is passed on to the next simplification step.

- Step 3: Zone Lumping (ZoL)

  In general terms, *ZoL* aims at the reduction of thermal zones in the model, creating one single thermal zone equal to the model's entire volume (Beyer, 2016).

  The values for internal mass and internal gains, such as equipment, artificial lighting, and people inside the building, are defined according to the project inputs and fixed parameters. In more detail, the internal mass is given as a single numerical input value calculated on the base of the internal slab area, the internal walls area and the respective materials chosen, while the internal gains are defined using the parameter of the area-predominant space type.

A visualization of the changes in the definition of thermal zones using this simplification step is depicted in Figure 3-20. In more detail, Figure 3-20(a) shows one of the eight floors with its six thermal zones, while Figure 3-20(b) shows the building using a single thermal zone for its entire volume.

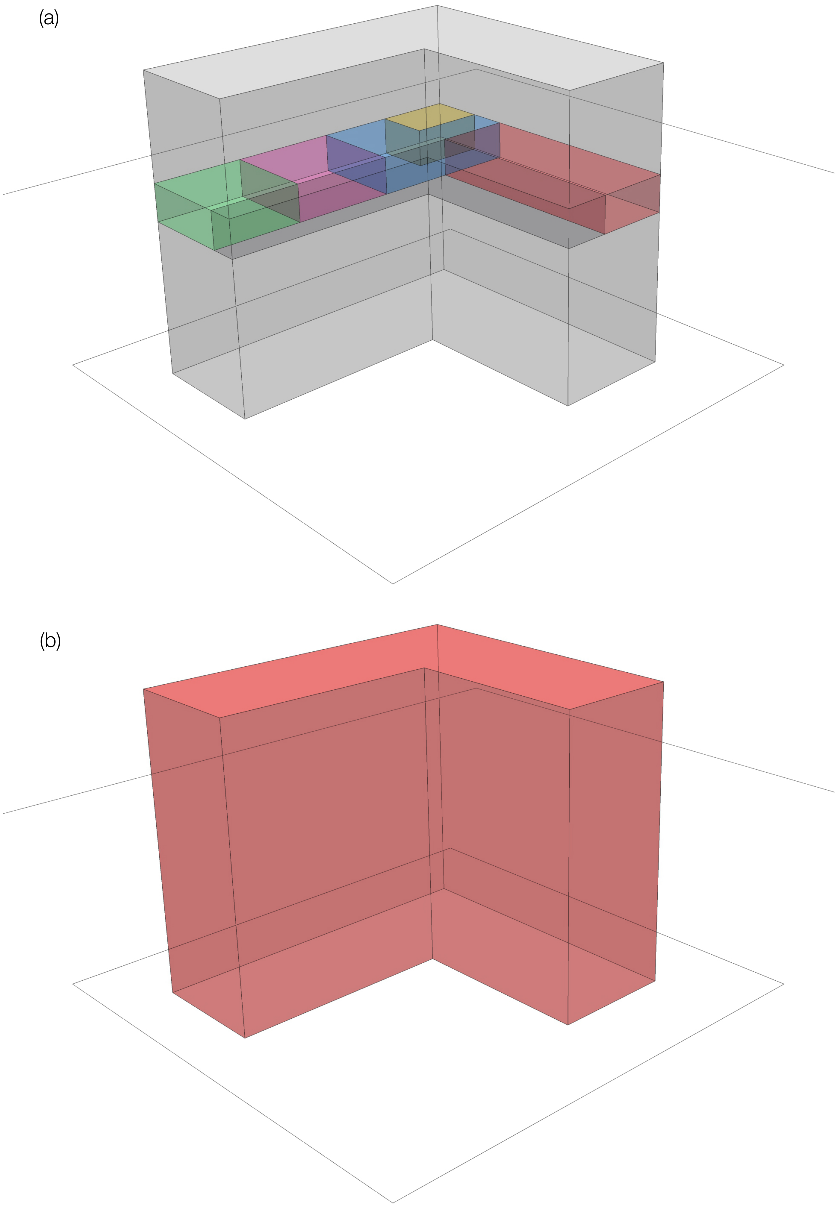


Figure 3-20: Exemplary application of *ZoL*: (a) before, (b) after

- Step 4: Internal Mass without Interior Walls (IMW)

  This simplification step is included to evaluate the possibility to generate *SIM*s with sufficient accuracy that do not have the necessity for the input of the area of interior walls.

  Step 4 uses less input information to calculate the internal mass, discarding any information with respect to the interior walls. The internal mass is therefore defined using the footprint's area, number of floors above ground and the fixed value for the mass of such interior floors.

  It is to be noted that this simplification performs geometric alterations only at the interior of the project.

- Step 5: Simplified Transparent Surfaces and Shading (TSS)

  This simplification step creates a single new window geometry with respective shading geometries for each facade element. In other words, for each rectangular plane created from each line element of the footprint's polygon.

The following steps are taken to create a new transparent surface geometry for each facade:

1. The average windows height (h_w) of the respective facade element is calculated;
2. The average windows width (w_w) of the respective facade element is calculated;
3. The total area of the facade element (Af) is calculated;
4. The *WWR* for the respective facade element is calculated;
5. The rectangle ($h_w \times w_w$) is denominated virtual rectangle and possesses the average proportion of the windows present in the respective facade, but an area that does not correspond to the total area of the original windows and, therefore, generates an incorrect *WWR* ($WWR_{vir} = (h_w \times w_w) / Af$);
6. The factor x describes the necessary scaling factor ($WWR_{vir} \times x = WWR$);
7. The factor x is calculated according to the following equation: $x = \sqrt{WWR/WWR_{vir}}$;
8. The new window dimensions (h_{w_new} , w_{w_new}) are calculated as follows: $h_{w\_new} = h_w \times x$, $w_{w\_new} = w_w \times x$
9. The new window geometry is centred on the facade element.

The corresponding shading geometry is generated for each new window.

With the horizontal and vertical shading angles of the original windows as inputs, the following steps are taken for each newly created window geometry:

1. The area-weighted mean values for *VSA* and *HSA* are calculated and used for the subsequent steps;
2. For the horizontal shading geometry, a single plane is created at the upper limit of the window geometry as this plane has the same width as the window;
3. The depth of the horizontal shading geometry is calculated to generate the *VSA*;
4. For the vertical shading geometries, two single planes are created at the left and right limit of the window geometry as these planes have the same height as the window;
5. The depth of the vertical shading geometries is calculated in order to generate the *HSA* as both planes are created with equal depths.

To graphically demonstrate the simplification, Figure 3-21 depicts the original situation, the created window geometry and finally the generated shading devices.

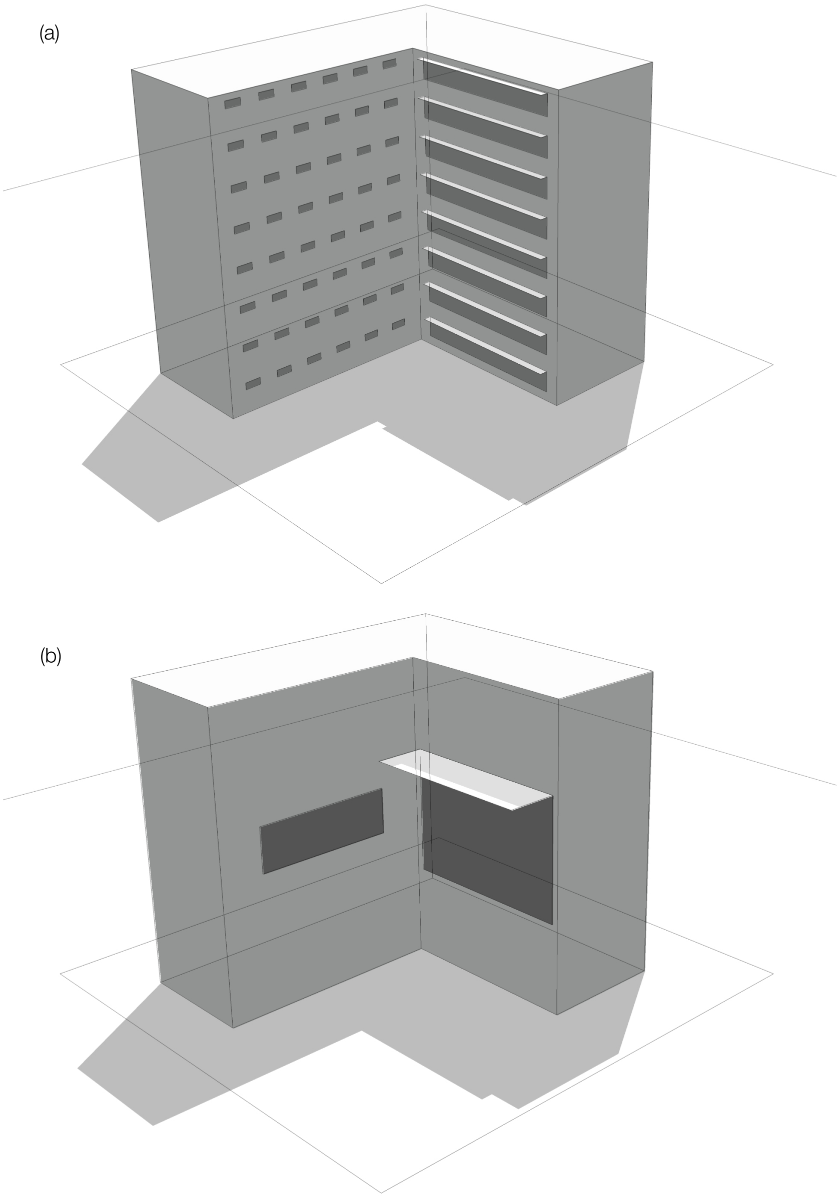


Figure 3-21: Exemplary application of *TSS*: (a) before, (b) new window and shading geometries.

Applying Step 5 to the model, one single window geometry per facade element is transferred to the next step.

- Step 6: Zone Squaring (ZSQ)

Zone Squaring is a procedure that is applied only to floor plans of non-rectangular shapes to transform the building's volume into a rectangular prism, therefore presenting four facades, one floor and one roof. A procedure to attend the same conditions as described in Picco et al. (2014) was elaborated. In more detail, the new floor plan needs to maintain the same proportions of the north-south and east-west facades and result in the same area as the original floor plan. To square a more complex floor plan, the steps of the following procedure are executed:

1. The sum of lengths of all (partial) south facades (lsf) is calculated;
2. The sum of lengths of all (partial) east facades (lef) is calculated;
3. The original area (A) is calculated;
4. The rectangle (lsf × lef) is denominated virtual rectangle and possesses the correct proportions, but an incorrect area (lsf × lef =Avir ≠ A);
5. The factor x describes the necessary scaling factor (Avir × x = A);
6. The factor x is calculated according to the following equation: $x = \sqrt{A/A_{\mathrm{vir}}}$;
7. The new facade lengths (lsf_new, lef_new) are calculated as follows: lsf_new = lsf × x, and lef_new = lef × x
8. The new footprint is oriented with its northern facade facing the weighted algorithmic average of the original footprint's facades facing northwards. This work considers the lengths of each facade section as weight for this calculation.

To create the final simplified model, it is necessary to re-simplify the transparent surfaces and shading with a similar procedure used in Step 5: all window elements from each solar orientation (north-, west-, south-, and eastwards) are grouped into one single window with respective shading and placed at the centre of the respective facade of the newly created rectangular prism.

An exemplary application of this simplification step is depicted in Figure 3-22.

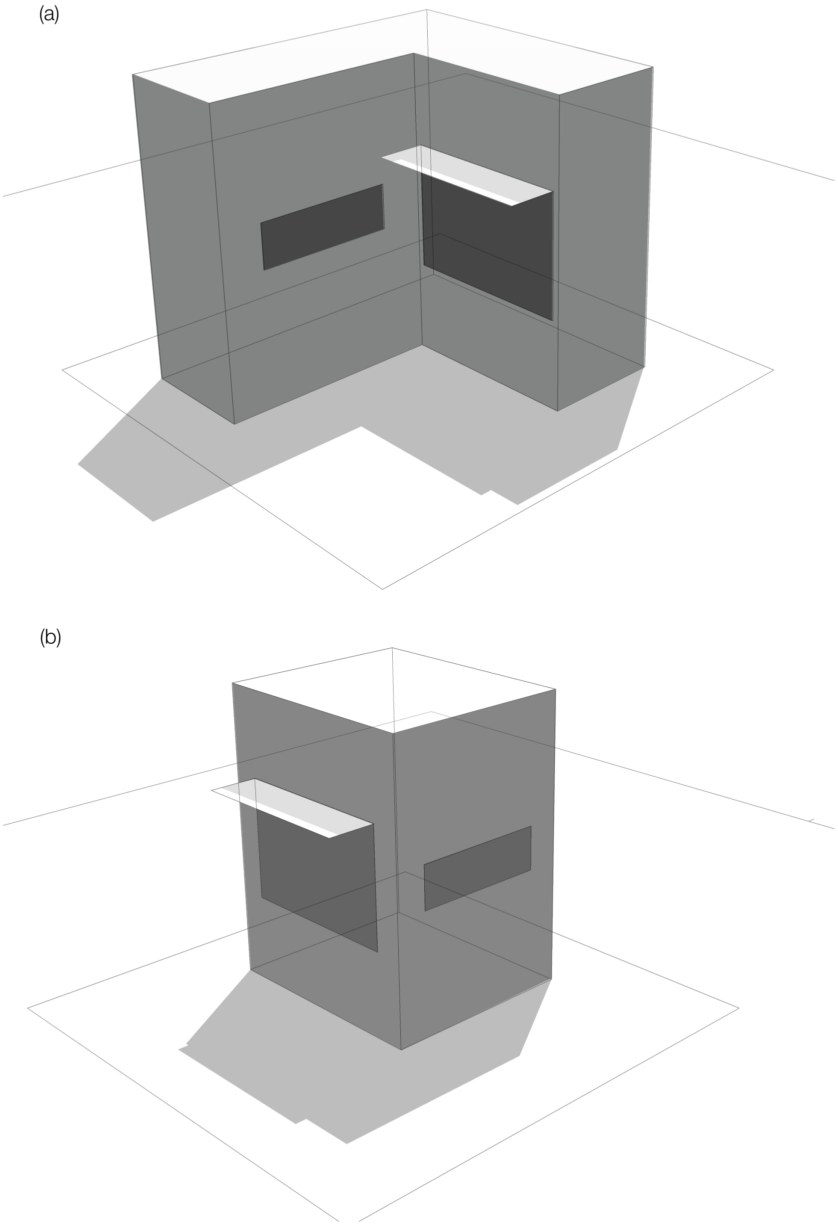


Figure 3-22: Exemplary application of *ZSQ*: (a) before, (b) after

The steps' order described process have been optimized for the validation. For such ends, it was important to create independent models after each step, allowing the validation of the methodology at each correspondent step (see sub-chapter 4.3 on the validation's setup).

The adapted order was derived from Picco et al. (2014). For optimized computerized / automated processes the order of steps should be *ZSQ*, *REO*, *SCo*, *ZoL TSS*, and finally *IMW*. Starting with *ZSQ* drastically reduces the data and complexity passed on to subsequent steps. It is important to highlight, that the *SIM* does not depend on the order of the execution of the described simplification steps; starting with a specific *ODM*, any order of the same steps will generate the same *SIM*.

With the reduced number of parameters defined, the alternative values generated, and the simplification steps specified, it is now possible to create the proposed exemplary *SIM*. The following two sub-sections do specify the remaining two components of *FORwArDS*: the assessment and the output models.

3.1.2. Assessment Model

The *Assessment Model* includes all steps taken starting from the input values' definition until the results of the digital assessment have been generated by the assessment tool, in this work's case: *EnergyPlus* (*EP*) (National Laboratory of the U.S. Department of Energy, 2016a). All the following descriptions are related to the chosen assessment tool, where, in more detail, the resulting input file (.idf) for *EP* is described.

To run simulations, the input file (.idf) for *EP* file includes the already mentioned parameters, further input information and defines the results requested as well as their output format.

Therefore, the following three components of the .idf are explained below: (a) the transformation of the input parameters from the anterior step into information inside the .idf format, (b) additional information stored inside the .idf, and (c) definitions of results and output format inside the .idf.

This chapter also contains a brief description of a developed C+ program that, starting from a comma-separated-value(.csv) list of input values (representing the input parameters), automatically creates .idf files. This program, the *Semi-Automatic .idf Creator* (*moSAIC*), makes the quick and correct generation of thousands of .idf files, possible. The developed C+ program also automatically generates all possible combinations for the parameters' given alternative values.

The following sub-sections describe the applied model to assess the *SIM*s whereas the *ODM* is assumed as given.

From input parameters to .idf

The following paragraphs describe the transformation of the above mentioned geometrical input, as well as the 8 numerical input parameters into part of the .idf file that will serve as inputs for the simulation during the assessment. These descriptions serve to make explicit numerical transformations and or adaptions, which were done due to non-equivalent definitions or other adaptions taken to guarantee the transition to an *EP*-readable input file. For more details, see the extract of an .idf example file in the Appendix A or the complete file found in the Digital Appendix (on CD).

The first input parameters are the geometric description of the building's footprint, the surrounding buildings, as well as the numerical value describing the floors above ground. In order to create the correct geometric description in the *EP*-readable format, two further tools were employed: Trimble SketchUp (*SU*) (Trimble Navigation Limited, 2016) and its free plug-in OpenStudio Legacy (*OSL*) (National Laboratory of the U.S. Department of Energy, 2016b). *SU* is used to model the footprint and the surrounding buildings, *OSL* is used to transform these geometrical information into a .idf file. As the .idf is a text based file, the sections that describe the geometry may easily be identified and copied in order as to serve as base for the creation of the .idf files to be simulated. *moSAIC* uses this base file and includes or substitutes the relevant information depending on the remaining 8 numerical parameter's values.

All geometrical descriptions follow a certain standard using three-dimensional coordinates to describe points, surfaces, or volumes. The right-hand rule is applied to define the order coordinate points that describe surfaces and their respective normal are listed in the text file. Figure 3-23 contains a schematic explanation. For further details, see the EnergyPlus Input Output reference (U.S. Department of Energy, 2016).

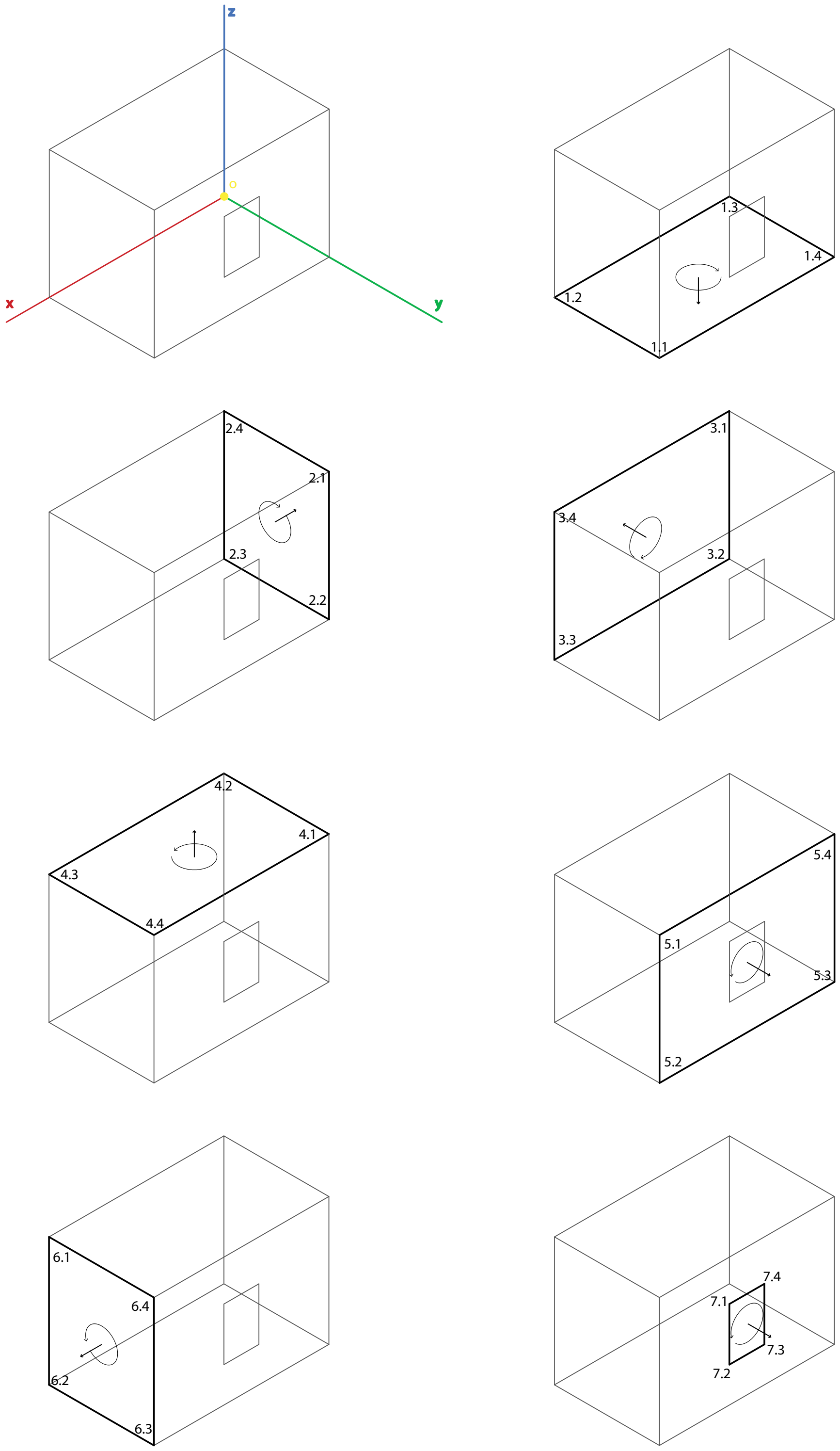


Figure 3-23: Right-hand rule in .idf geometric descriptions

Figure 3-23 demonstrates the order of the respective 4 points to define the 6 surfaces of a rectangular prism as well as 1 surface representing a window. *EP* does not differentiate the transparent surfaces by using the left-hand rule, but by using construction identifiers.

The first three parameters – *Wall Type*, *Window Type*, and *Roof Type* – are implemented as *constructions*.

All materials used have to be previously defined in the .idf. The list with materials, and their defined physical parameters, used in this work is based on the *EP* data base and a .idf file from a post-graduate course at the Federal University of Rio Grande do Sul by Prof. Dr. Paulo Otto Beyer (Beyer, 2015). The resulting 9 constructions were already chosen with materials from the *EP* data base that correspond to the materials described in the Brazilian legislation and, therefore, no adaptions had to be made. The necessary 9 constructions are inserted into the .idf's section denominated *Constructions*. *Wall Type* and *Roof Type* are inserted as "MATERIAL:REGULAR", while the *Window Type* constructions are declared as "MATERIAL:WINDOWGLASS". For detailed information regarding materials and constructions as declared in the .idf, see the exemplary .idf file in the Appendix A.

As *WWR*, *VSA*, and *HSA* are numerical values describing a geometry or geometries, which in turn depend on another geometry, the transition from the given input into the .idf necessarily includes the transformation of a numerical value into a geometrical information. These geometries are, in the case of *WWR*, the fenestration geometry for each wall of each thermal zone, the horizontal shading device for the *VSA*, and two vertical shading devices for the *HSA*. In all three cases, this work adapts generative rules already explained in sub-chapter 3.1.1. It is important to mention that other rules to generate these geometries could have been alternatively applied.

Feeding the explained generative rule above with the necessary geometrical input values, *moSAIC* is able to generate *EP*-readable coordinates representing the window and shading device geometries.

The *Azimuth* is defined as the input data describing the rotation in degrees from the original orientation as derived from the geometry of the *ODM*. This work adapted the *EP* standard used for the description of such rotation. In other words, rotations are described counter clockwise, where north is 0°, west 90°, south 180°, and east 270° (U.S. Department of Energy, 2016). The .idf's header defines the rotation adopted in the field denominated “North Axis {deg}”, as rotation point *EP* assumes 0,0,0. To rotate the building's model, *moSAIC* simply alters this field.

As the *Ceiling Height* defines the height of each of the earlier defined floors above ground, the models' thermal zone geometries are formed by multiplying the *Ceiling Height* with the number of floors. It is important to highlight that the idf's basic structure firstly defines the outer limits of a thermal zone and then lists each component (in case of this work: wall, window, roof, and floor) belonging to this zone. All entries are composed of three coordinates (X, Y, and Z) and further information such as materials and exposure type. For more details, please see the example .idf-file in Appendix A.

As mentioned, each component was associated with a material, as all *SIMs* are based on simplified constructions, all walls can be automatically associated with the material *External Wall*, windows with *Exterior Window*, roofs with *External Roof*, the floor with *Exterior Floor* as well as the corresponding internal geometries with the materials for *Internal Walls* (if applicable) and *Internal Floor* (if applicable).

Additional input information .idf

As the most important elements regarding the remaining information given in the .idf file, the following three topics will be briefly covered: (a) the Weather File, (b) the air conditioning type used for simulation, and (c) schedules.

The weather file is an external file containing the local weather information. The .idf needs to reference this file in order to base the simulations on the correct climatic conditions. This work uses the .epw weather file for Porto Alegre, generated by the LABEEE, Federal University of Santa Catarina (LabEEE, 2012).

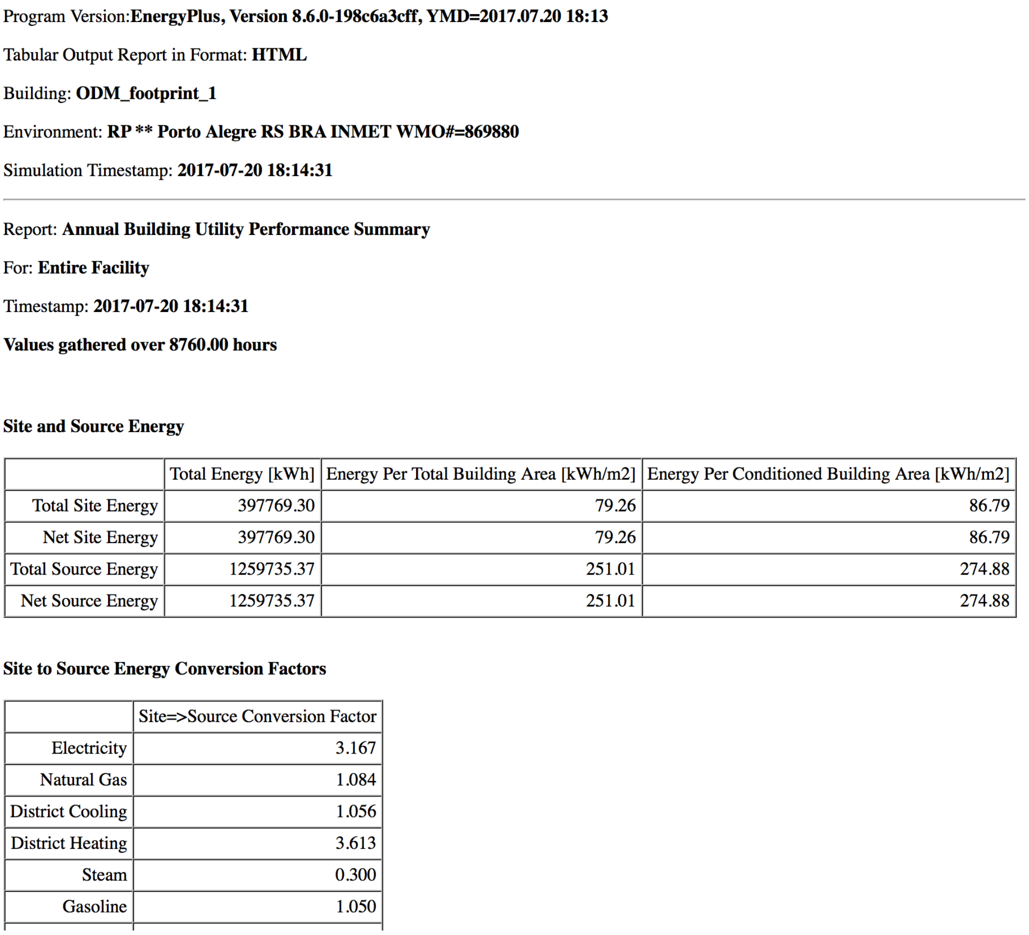
This work uses a *Packaged Terminal Heat Pump* (*PTHP*) as air conditioning system. This represents a commonly used system and, due to little necessary input regarding the system itself, is well adapted to be used in early simulations (Beyer, 2016). The temperature set points for the *HVAC* system are fixed to 22°C and 25°C, respectively. For more details about the setup of the *HVAC* system, see the example .idf in the Appendix A.

Schedules in *EP* describe the hourly application of a percentage of the maximum value for the respective parameter over time. For example, the occupational schedule informs the percentage of the maximum density of people in the thermal zone for each hour of the year. This makes a more realistic distribution of values possible. For instance, in non-commercial hours, the occupation of the building's thermal zones are extremely reduced whereas during the commercial hours will reach its maximum. This work applies such schedules to the following items: *Office Lights*, *Office Equipment*, *Office Occupancy*, among others. The schedules used in this work are derived from the .idf file created by Prof. Paulo Otto Beyer (Beyer, 2015). For more details on the schedules and their application throughout the .idf, please see the example .idf in Appendix A.

Output report and output format .idf

The desired form of the simulation's result has to be requested in the .idf. This work uses one single numerical value from the "All Summary" requested as output report. This report contains various information, but specifically contains the "Total Site Energy" in (kW.h)/m^2 used in this work. *EP* produces this report in several formats whereas this work uses a Microsoft Excel (Microsoft, 2016) Spreadsheet (.xls) for the elaboration of both the numerical validation and analysis as well as the creation of the output representation. The results represent the simulation of 8760 hours, a full year simulation with an hourly time step.

Figure 3-24 demonstrates a small section of the output report, the cell containing the "*Total Site Energy*" contains the value "79.26".



Program Version:**EnergyPlus, Version 8.6.0-198c6a3cff, YMD=2017.07.20 18:13**

Tabular Output Report in Format: **HTML**

Building: **ODM_footprint_1**

Environment: **RP ** Porto Alegre RS BRA INMET WMO#=869880**

Simulation Timestamp: **2017-07-20 18:14:31**

Report: **Annual Building Utility Performance Summary**

For: **Entire Facility**

Timestamp: **2017-07-20 18:14:31**

Values gathered over 8760.00 hours

Site and Source Energy

	Total Energy [kWh]	Energy Per Total Building Area [kWh/m2]	Energy Per Conditioned Building Area [kWh/m2]
Total Site Energy	397769.30	79.26	86.79
Net Site Energy	397769.30	79.26	86.79
Total Source Energy	1259735.37	251.01	274.88
Net Source Energy	1259735.37	251.01	274.88

Site to Source Energy Conversion Factors

	Site=>Source Conversion Factor
Electricity	3.167
Natural Gas	1.084
District Cooling	1.056
District Heating	3.613
Steam	0.300
Gasoline	1.050

Figure 3-24: Partial screenshot from an output report .html file

Semi-Automatic .idf Creator (*moSAIC*)

This sub-chapter describes the *Semi-Automatic .idf Creator's* (*moSAIC*) functionality proposed in this work. *moSAIC* has two different operational possibilities: (a) creation of multiple .idf from an input matrix, and (b) creation of multiple .idf from a .csv file. The difference between these two lies in the form that the parameters' values are given to form the desired number of .idf files. The output is always a set of .idf files sharing some parameters, but differing in the combination of values, which they relate to. *moSAIC* creates a unique combination of values for the variable parameters and includes these in a given .idf base containing all fixed parameters and information such as materials and/or constructions.

Using an input matrix, *moSAIC* receives all possible input parameter values in the following form: each line represents a parameter, while each column represents one value the corresponding parameter may assume. It is important to notice, that the number of columns, and therefore the number of values a parameter can assume, may vary from line to line. One line may have three columns (in other words this line's parameter may assume three different values) and another line may have four columns (this parameter may assume four different values).

Assuming an exemplary matrix of three lines, two of them with three and one with four columns, the total number of possible combinations is 36. *moSAIC* will then create 36 sets of parameter values, one for each possible combination from the input matrix and inserts the corresponding values or information into the base. idf. Finally, this results in 36 unique. idf files. This type of input allows for the quick creation of hundreds of .idf files and it is especially useful to test the susceptibility of simulations to changes in any of the input parameters.

The second input possibility arises from skipping the combinatorial steps and directly feeding *moSAIC* with a list of combinations. In this case, the input is given in a .csv file using the following rules: each line represents a file to be created (a given combination of input parameters), each parameter is separated from the following by a comma (",") and each line ends with a carriage return. Each line must contain the same number of inputs, representing the same number of parameters and the values must be given in the same order for each line.

Assuming that it is desired to create the same 36 .idf files as in the example above, 36 lines with three values would need to be manually prepared as input for *moSAIC*. As the creation of the .csv is manual, this type of input is more recommended for reduced numbers of combinations.

Figure 3-25 shows an extract from *moSAIC's* pseudo code, for more detailed information consult the complete pseudo code in Appendix C.

```
for i_1:=1 to n_column[1] {
        for i_2=1 to n_column[2] {
                for i_3:=1 to n_column[3] {
                        ...
                        for i_nlines:=1 to n_column[n_lines] {
                                combination[i_c]:= line1[i_1], line2[i_2], line3[i_3], ... , linen[i_nlines];
                                write file (COMBINATIONS.txt, combination[i_c]);
                        }
                }
        }
}
```

Figure 3-25: Extract from *moSAIC*'s pseudo code

3.1.3. Output Model

The third and last component of *FORwArDS* is its output model, the transformation of the numerical assessment result into a combination of graphical and numerical information to be presented back to the architect. This feedback must be integrated into the iconic model the architect works with to allow the prompt awareness of the impact of his design actions on the energy consumption. Three distinct steps may be identified for the creation of the proposed output model: (a) transforming the numerical result into an abstract rating, (b) representing this rating in graphical form, and (c) representing more than one possible combination in order to allow contextualization. All three steps are explained in more detail in the sub-sections below.

Transforming numerical results into abstract ratings

The transformation of *EP*'s numerical results into an abstract rating produces three advantages: (a) it expresses more clearly that the obtained simulation result is not a realistic estimate of the built project's energy consumption, (b) it reduces the value's expression complexity facilitating the comparison between different results and the contextualization, and (c) it facilitates the graphical representation by grouping various numerical results into one rating.

Certain precautions must be taken to fulfil these positive impacts. First, the transformation must be applicable to varying sets of simulation results, while maintaining the comparability between them. For example, if two different base-geometries are chosen, the value obtained as "Total Site Energy" is directly linked to the project's volume. In other words, when directly using this numerical result from *EP*'s output report, projects of varying area and/or floors above ground would not be comparable. Therefore, the first necessary step in the transformation described here would be to normalize the result using the total building area.

Applying Equation 3.2, the simulation results are linked to the floor area in m^2, resulting in the unit of kW.h/y.m^2.

$$TSE_{normalized\_area} = (TSE)/(A_{footprint} \times f) \tag{3.2}$$

where TSE3.1.33_area is the normalized Total Site Energy,
TSE is the Total Site Energy (as received from EP's output file),
Afootprint is the footprints total area, and
f is the number of floors above ground.

It is also possible to directly output the area-weighted value. In the proposed validation methodology, this value is directly taken from the .html output files.

With this numerical value at hand, a second normalization is applied in order to further simplify the numerical value, aiming at a rating scale from 1 to 100, 100 being the worst and 1 being the best result possible. This scale is used to represent energy use, seen as negative and therefore the highest value intuitively represents an undesired result, while low scores represent buildings with low energy consumption. To create this scale, the numbers that would represent the extremes must be defined. For the inferior limit, represented by the rating 1, this is a trivial task as the absolute minimum of the numerical result is 0; consequently, the numerical value 0 is represented by 100 in the rating. With respect to the worst numerical result to be expected the task is more complex. According to Ürge-Vorsatz (2012) the average energy end use per square meter in office buildings in Latin America is of about 70 (kW.h)/(y.m^2). Considering that Brazil has a high energy consumption when compared to its South American neighbours this work assumes an upper limit of 85 (kW.h)/(y.m^2) as sufficiently high to represent the worst case.

Graphical representation

The transformation of the obtained normalized value into a graphical representation makes its use inside the iconic model possible and therefore represents an important step for integrating *EA* into *EADS*. It is important to highlight that a high integration of the result's representation into the design model is desirable, especially when used for professional or educational purposes. This work suggests one form of representation, useful for educational purposes. For varying task or scopes of framework's use, further elaboration of the graphical representation might be necessary.

In this work, the numerical value is transformed into a stacked column graph. This bar has two characteristics: (a) height and (b) colour. The first one is the basic characteristic of any bar graph, the higher the value, higher the column (or the greater its Y axis value). The colour is an additional feature to ease the comparison during contextualization. This work separates the results into 3 groups whose corresponding bars will have distinct colours: from 1 to 24 the column is coloured green, from 25 to 74 the column is yellow and from 75 to 100 the column is orange.

Figure 3-26 demonstrates 5 exemplary representations.

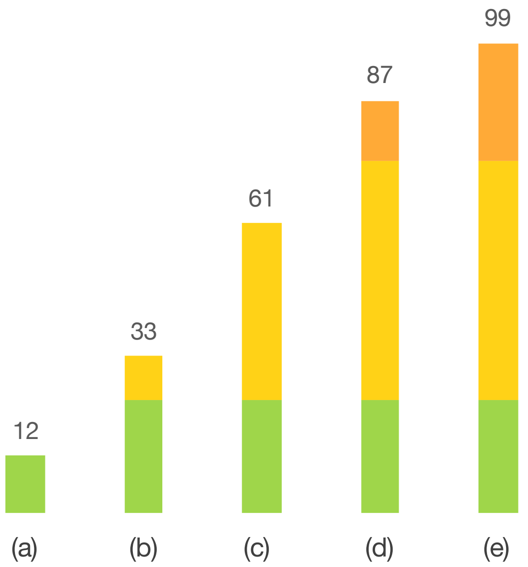


Figure 3-26: Representation of example values. (a) 12, (b) 33, (c) 61, (d) 87, and (e) 99.

If an exact identification of the numerical result is desired the numerical value can be plotted on top of each column.

Contextualization

At this point a single value has been transformed into a single column graph. To provide contextualization and hence improving the architect's decision-making process, this work proposes to present a group of column graphs as final output[15]. The output format and its role for contextualization are described below.

To demonstrate the potential energy savings, a set of results representing the complete solution space is generated. As the number of possible solutions highly depends on the number of alternative values used for each parameter, the results are arranged in decreasing order (left to right) of the numerical result, therefore placing the solution space's worst result on the left-hand side while the best result is plotted on the right-hand side[16]. The set of results is the base for contextualization, as it provides the architect the possibility to identify whether there is still potential for optimization and/or to compare two or more proposals to each other. To exemplify this action, the last three combinations of values for the applied parameters to be chosen by the architect are marked "1", "2", and "3" respectively. "1" being the last project, "3" the original one.

---

[15] Different applications, professional or research, would need different output representations: the described output should be understood as an alternative example as the output format is not the focus of this work.

[16] The plotted columns are not presented with any identification of the parameter value combination that generated the results.

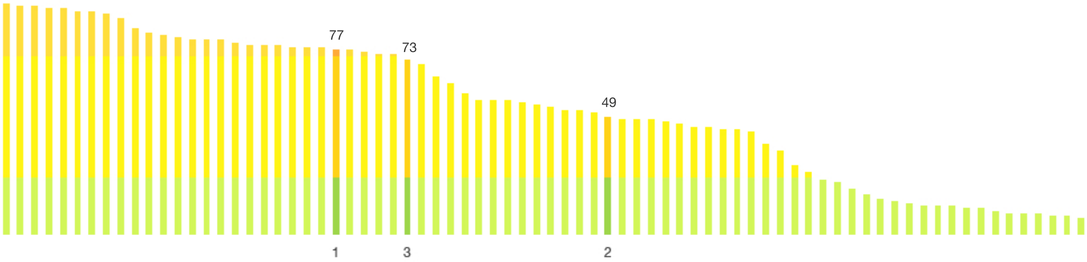


Figure 3-27: Exemplary set of columns with 3 last combinations marked.

It is possible to visualize certain clusters or “plains”, neighbouring results with minor changes: a total of 4 such clusters can be identified in this group of graphs. Assuming that “3” was the architect’s first combination, that “2” represents a reduction of the value of *WWR* and “1” a change to the *Wall Type*, the architect might now conclude that changes to the *WWR* had greater impact than those to the parameter *Wall Type*. He could further test this hypothesis, maintaining the *WWR* and changing other parameters. He could have then determined that smaller glazing areas would have a positive impact on the energy consumption of his project.

The output format allows the responsiveness of the energy consumption to parameter’s alterations. The comparison between the results of different attempts may well lead to a learning cycle and thus help to create a hands-on knowledge base regarding the correlation of changes to the project and the energy consumption. The same applies to the interconnections between parameters with respect to the optimization goal energy effectiveness. The above process may well lead to think about educational applications of *FORwArDS*, subject to be tackled further on this text.

The following sub-chapter outlines some of the possible applications of *FORwArDS*.

4. VALIDATION METHODOLOGY

This chapter presents the proposed validation methodology and its application to the framework proposed in chapter 3. It is worth stressing that the acceptable error margin may be extended during early stages, when compared to energy assessments with the complete information set at hand. In Picco et al. (2014) up to 20% of error for *SIMs* in early stages is proposed as limit whereas this work adapts this value as maximum.

It is worth noting that the numerical result for energy efficiency used as benchmark in this work's simulations is the annual total site energy [(kW.h)/(m^2.year)]. This value is used more as an abstract label or index than as an absolute value for prediction of a built reality. Due to the architect's lack of experience regarding the interpretation of this numerical value, supporting design decisions and assessing their respective consequences on the building's energy efficiency is possible through comparison of abstract labels only.

This work differentiates two different types of validation: *Direct Validation* (*DV*) and *Relative Validation (RV*), both explained in more detail in the sub-sections below.

4.1. Direct Validation

DV refers to the classical validation method using accuracy (in percent) as benchmark (Roache, 1998). It may be defined as the fraction of the result of a model to be validated and the target model. See Equation 3.3 for the mathematical description.

$$\%_{error} = (result_{vm})/(result_{tm}) \tag{3.3}$$

where $\%_{error}$ is the error in percentage obtained from the validation,
$result_{vm}$ is the result obtained from the model to be validated, and
$result_{tm}$ is the target model's result.

The accuracy of the results obtained with the model to be validated are compared with the output of a reliable target model. In the present work, the target model is always an *ODM* with identical input parameters.

Figure 4-1 shows a schematic illustration of the concept of *DV*, in more detail, part (a) demonstrates a successful validation of the results obtained throughout the model to be validated, its results are within the acceptable error margin; while part (b) of the same figure shows a failed validation, as the obtained result is not of acceptable accuracy when compared to the target model's output. At this point, it is important to remember that this work assumes 20% as the maximum acceptable error margin (Picco, 2016).

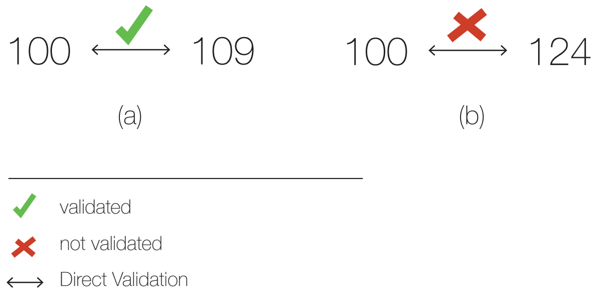


Figure 4-1: Schematic illustration of Direct Validation: (a) successful, (b) failed.

4.2. Relative Validation

RV refers to the proposed validation methodology, which also validates the accuracy (in percent) as benchmark, but refers to the relative changes in the outputs that occur due to equal changes to one input. In more detail, the original project and a single parameter change are simulated using a reliable model and the same original and change project are simulated in the model to be validated. *RV* than compares the difference between the original's result and the result from the modified model (using the reliable model) and the corresponding difference using the results obtained from the model to be validated. *RV* may be defined as the fraction of the difference of result deriving from two different sets of inputs of the model to be validated and the difference of the target model's results from the same set of inputs. See Equation 3.4 for the mathematical expression that describes the Error for *RV*.

$$\%_{error} = ((result_{vm1}) - (result_{vm2}))/((result_{tm1}) - (result_{tm2})) \tag{3.4}$$

where $\%_{error}$ is the error in percentage obtained from the validation,
$result_{vm1}$ is the result obtained from the model to be validated using the set of inputs 1,
$result_{vm2}$ is the result obtained from the model to be validated using the set of inputs 2,
$result_{tm1}$ is the target model's result using the set of inputs 1, and
$result_{tm2}$ is the target model's result using the set of inputs 2.

The accuracy of the results obtained with the model to be validated is compared with the target output of a reliable target model against which they are validated. Once again, the target model used in this work is the *ODM*.

In Figure 4-2 a schematic illustration of the concept of *RV* (a) demonstrates a successful *RV* as the results obtained regarding the impact of the changes in energy efficiency throughout the model to be validated are within the acceptable 20% error margin (note that *DV* fails); part (b) of the same figure shows an unsuccessful validation, as the obtained result do not have an acceptable accuracy when compared to the target model's output (note that the *DV* passes). In part (c) of an example of results that pass for the *DV* and *RV* is exposed.

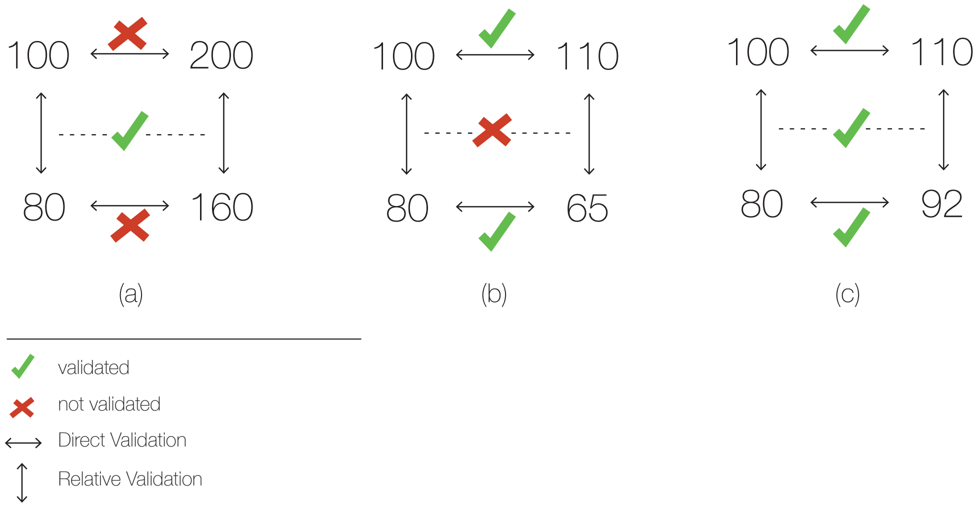


Figure 4-2: Schematic illustration of Indirect Validation:
(a) *DV* failed, *RV* successful; (b) *DV* successful, *RV* failed;
(c) *DV* and *RV* successful.

4.3. Validation Setup

This section describe (a) the case study used in this work and (b) the adopted procedures for the simulations using *EP*.

The validation experiments used different input models but identical assessment and output models. A total of six accumulative simplification steps were taken to create the final *SIM*. The *ODM* has been used as basis for the subsequent simplifications.

The 6 resulting *SIM*s, 1 for each simplification step are, hereby, denominated *SIM01*, *SIM02*, *SIM03*, *SIM04*, *SIM05*, and *SIM*, indicating which simplification step has been applied, while the model denominated *SIM* refers to the model resulting from the application of all 6 simplification steps.

Using the *ODM* as starting point, simplifications were performed and six *SIM*s were generated, resulting in a total of seven models. In order to perform *RV,* it was necessary to promote changes to single parameters in the *ODM,* as well as in the six *SIM*s. Testing two alternative values (original value derived from the *ODM* and two created alternative values) for seven of the eight parameters and four alternatives for the remaining, solar orientation, 175 models (including the *ODM*) are created.

Equation 3.5 presents the general combinational calculation as well as the specific calculation for this work.

$$\begin{aligned} n &= \left(NdM * \left((1 * P_1) + (2 * P_2) + \cdots + (n * P_x)\right)\right) \\ &= \left(7 * \left((1 * 0) + (2 * 0) + (3 * 7) + (4 * 1)\right)\right) \\ &= \left(7 * (25)\right) = 175 \end{aligned} \tag{3.5}$$

where n is the number of models to be created,
NdM is the Number of different Models,
P_x is the number of parameters with n alternative value options,
n is the number of alternative values
(including the original value).

This set of 175 models allows the input model's validation derived from one single *ODM*. In more detail, this set of models makes, besides 150 *DV*s, an additional 102 *RV*s possible. Each simplification step is validated regarding all possible changes to each parameter.

The simulation result for the assessment benchmark of *ODM* is assumed as the target value (100% accuracy) of all *Direct Validations*, while *RV*s compare the relative change in percent when applying a design alternative.

It is important to highlight that those models referring to the base value of a parameter, whether it is for the *ODM* or for any of the *SIM*s, are always identical. The number of different models created for each building of the case study is therefore reduced by 49, totalizing 126 models to be created.

All simulations were run on a MacBook Pro 2.5GHz Intel Core i7 with 16GB 1600MHz internal DDR3 memory.

4.3.1. Case Study and Deriving *ODM*s

The chosen case study is created to represent varying situations that correspond to important variations encountered by architects. In more detail, the case study is composed of three groups of information: (a) the external obstructions, (b) the building's *Footprint*, *Internal Walls* and *Number of Floors Above Ground*, and (c) the definition of the building's parameters, including the 8 parameters used in the *SIM* as well as further details regarding the building. Any given combination of these three components may generate an *ODM*. To reduce the solution space's complexity, this work will create two *ODM*s. To ease later comparisons and analysis, the two footprints have the same area and both buildings are ten floors tall. This leaves changes to the footprint's geometry, the building's *Internal Walls*, as well as changes to the parameters and other detailed descriptions possible. The following paragraphs describe the components for these *CS*01.

The building, denominated *CS*01, uses a L-shaped footprint placed in an urban context. Figure 4-3 shows two isometric views of the building and its assumed surroundings. Further, its ground floor possesses a differentiated interior layout. Ground and typical floor are presented in Figure 4-4 and Figure 4-5, respectively.

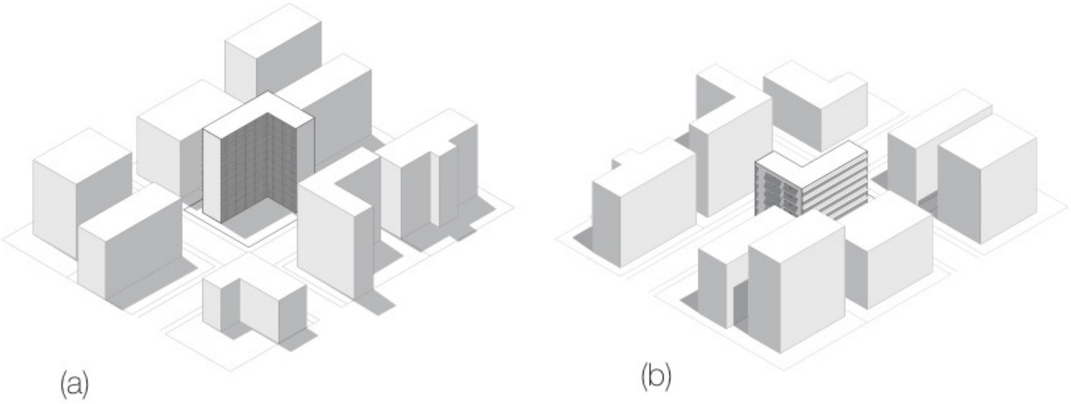


Figure 4-3: Isometric views of *CS*01 in urban context:
(a) from south-west, (b) from north-east.

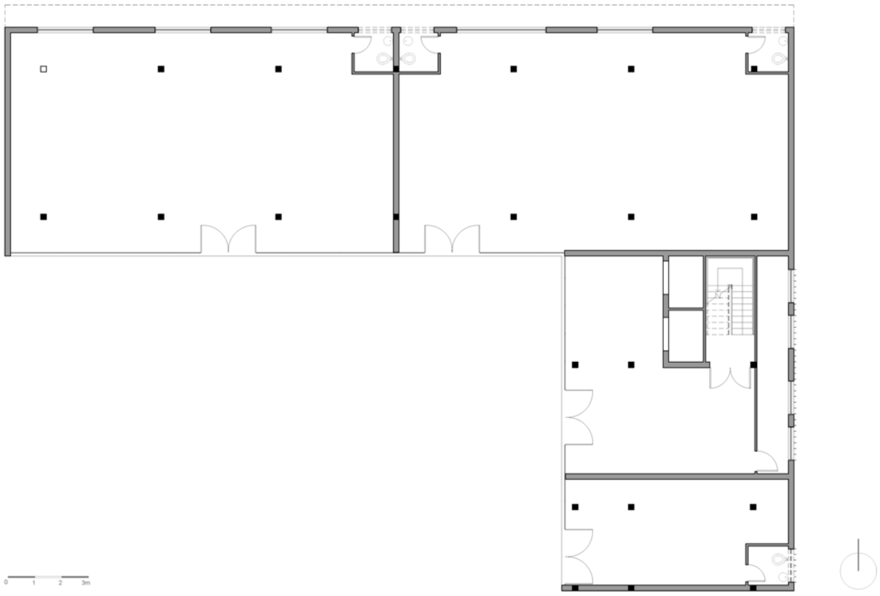


Figure 4-4: Footprint and interior layout of *CS*01: ground floor.

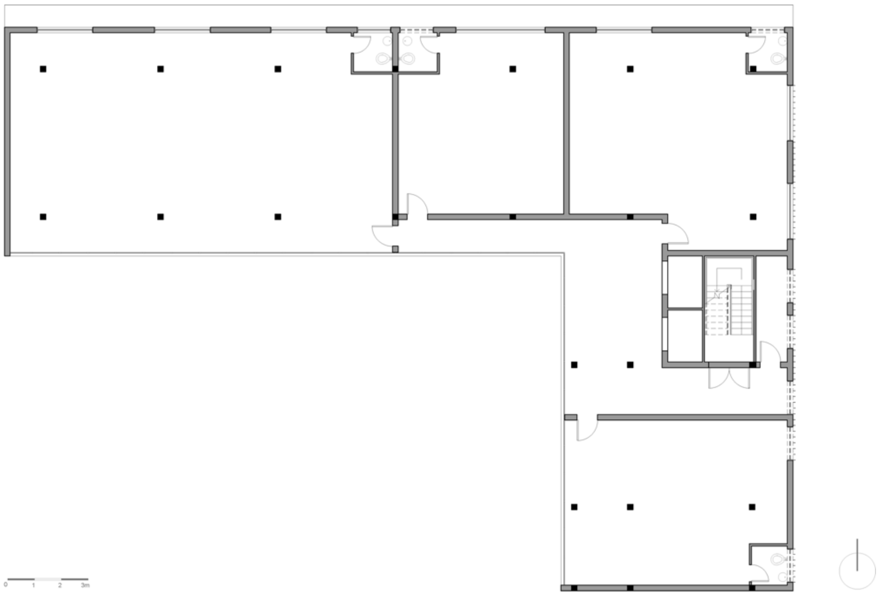
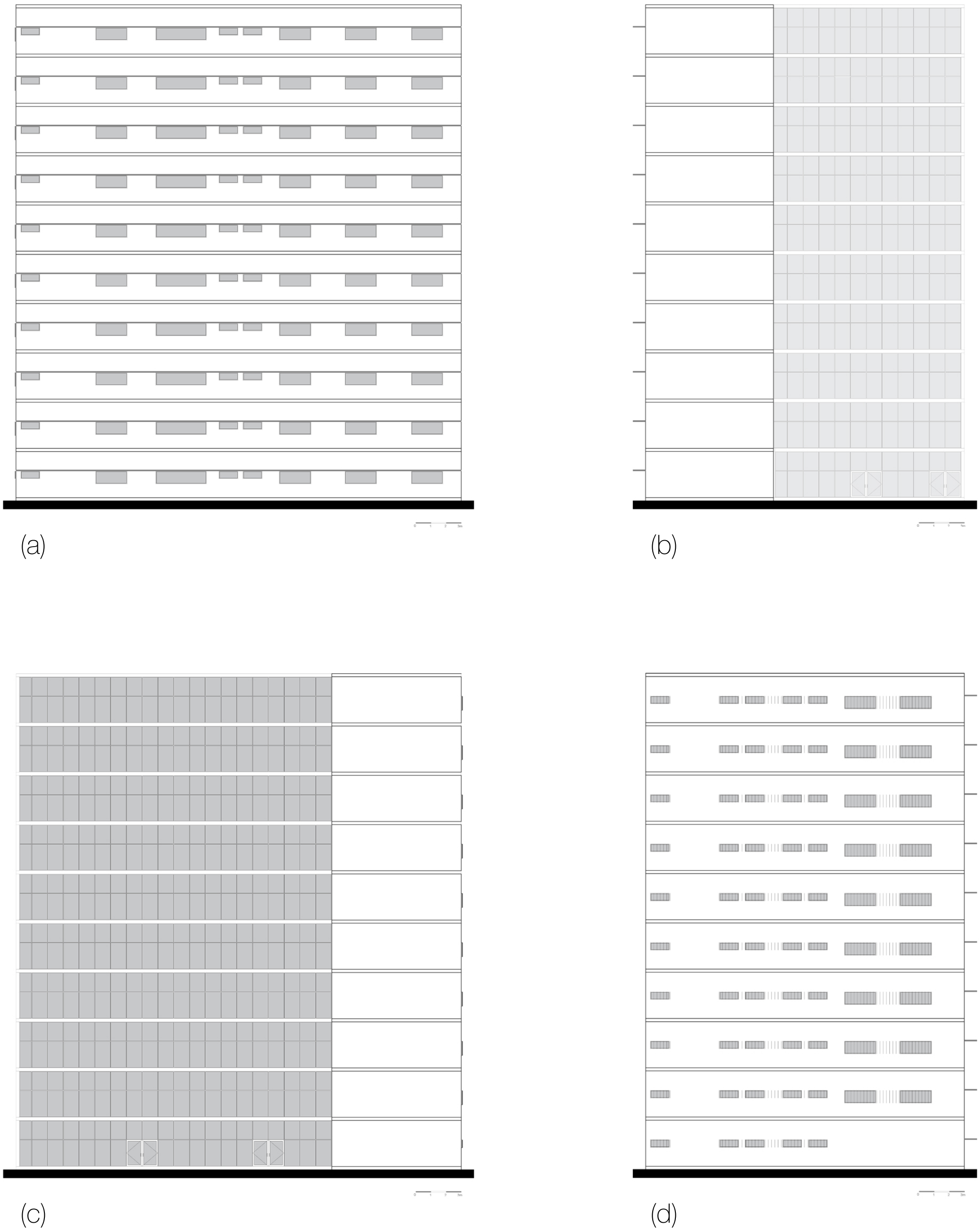


Figure 4-5: Footprint and interior layout of *CS*01: typical floor.

The assumed *ODM* includes the geometrical information regarding the glazed openings as well as the shading devices. Figure 4-6 shows the 4 facades.



(a) (b) (c) (d)

Figure 4-6: Facades of *CS*01: (a) north facade, (b) west facade, (c) south facade, (d) east facade.

As result of the geometrical information, adding further material and project choices, the eight parameters assume the following values:

- (1) *Wall Type*: *CS01* has been created using two different constructions in different parts of the exterior wall. The first is in the windowless facades, in the highly glazed west and south facades, as well as in the lower and upper parts of the north and east facade. The second exterior wall construction is used in the horizontal zone around the windows. They possess a u-value of 2.17 W/(m^2.K) and 0.57 W/(m^2.K), respectively. If weighted by their area this results in an average u-value of 1.59 W/(m^2.K) for the exterior wall of *CS01*.
- (2) *Window Type*: *CS01* uses the second glazing option from the ones described in the sub-section 3.1.1, a 6 mm single transparent glazing.
- (3) *Roof Type*: *CS01* is designed using the second roof alternative from the three described in the sub-section 3.1.1, an isolated multi-layer roof with an u-value of 0.95 W/(m^2.K).
- (4) Window-To-Wall-Ratio (*WWR*): This case study uses various different window options, ranging from totally opaque facade (*WWR*=0%) to almost complete glazed facades (*WWR*=91.09%). The building's weighted overall average for this value is 35.99%.
- (5) Vertical Shading Angle (*VSA*): With horizontal shadings applied only to the western facade, an overall *VSA* of 8.87° is calculated.
- (6) Horizontal Shading Angle (*HSA*): With vertical shading elements used only in the northern facade, the overall *HSA* is calculated to be of 22.59°. It is important to notice that the southern and eastern facade's glazing areas do receive shadowing from the building itself. For the calculation of the alternative values this fact is ignored and only the window's shading elements are considered. For the final simplification step though, when the buildings footprint (and therefore its auto-shading) is altered these values are considered to create a more precise model of the *ODM*'s shading situation.

- (7) Solar Orientation (Azimuth): The *ODM* is assumed to be oriented without any rotation, the original solar orientation is given by the geometry and the original parameter assumed therefore is 0.
- (8) *Ceiling Height*: The building's 10 floors have been designed with a ceiling height of 3,7 m.

As the *ODM* defines each ambient enclosed by internal walls as a separate thermal zone, the file uses *EP*s *ZoneList* function to group all thermal zones with identical parameters and hence reduce the modelling labour and time. It is to be noted that the bathrooms in this *CS* are handled as separate not conditioned thermal zones.

The parameters that are not part of the 8 input parameters described in Chapter 3 are implemented with the standard values described in 3.1 Specification. The resulting .idf file, describing the first *ODM* used as the base for the methodology's validation, includes further detailed information. To consult these details, please see Appendix A.

4.3.2. Simulation Proceedings

With the *ODM* as starting point the proceedings to create the necessary results for validation follows four basic steps: (a) generation of input files, (b) simulation setup, (c) simulation execution, (d) result elaboration. All 4 steps are described in more detail below.

4.3.3. Generation of Input Files

In order to begin the validation procedure, the *ODM* file is modelled using *Trimble SketchUp* (Trimble Navigation Limited, 2016) using the *OpenStudio Legacy Plug-In* (National Laboratory of the U.S. Department of Energy, 2016b) and the .idf Editor (United States Building Tecnology Office, 2016a). Next, the six simplification steps described in Chapter 3 were applied one by one to the *ODM*, generating an independent .idf for each accumulatively simplified model. This created additional six models for this case study, totalizing 7 models. In this work, the creation of these simplified models is elaborated manually using *Trimble SketchUp* (Trimble Navigation Limited, 2016) using the *OpenStudio Legacy Plug-In* (National Laboratory of the U.S. Department of Energy, 2016b) and the .idf Editor (United States Building Tecnology Office, 2016a). It is to be highlighted that this work did not develop automation to generate the simplification, although this is technically feasible. For more details see the example in 4.4 Validation Results.

With 7 models to start with, the next task consists in generating independent .idf files for the proposed parameter value changes. This work proposes two alternative values for parameters 1, 2, 3, 4, 5, 6, and 8, while suggesting to allow four (and therefore three alternative values) for the solar orientation described in parameter 7. Further it is important to notice that the geometric changes necessary to implement the alternative values of parameters 4, 5, 6, and 8 are implemented using some visual intelligence to produce architectural sound alternative projects. These models and their connection to the seven models representing the parameters' base values for *CS*01 are depicted in Figure 4-7.

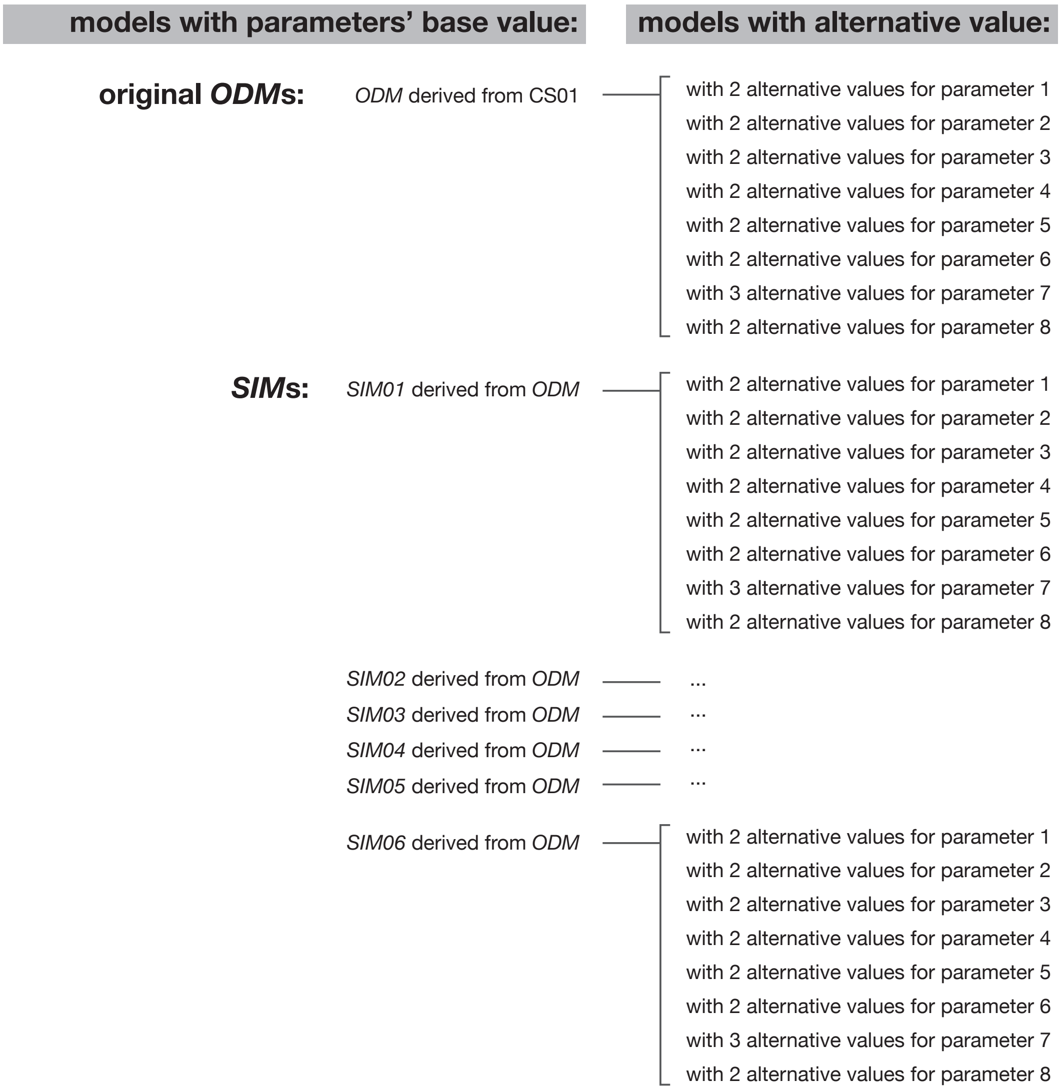


Figure 4-7: Overview of generated models for Validation for *CS*01.

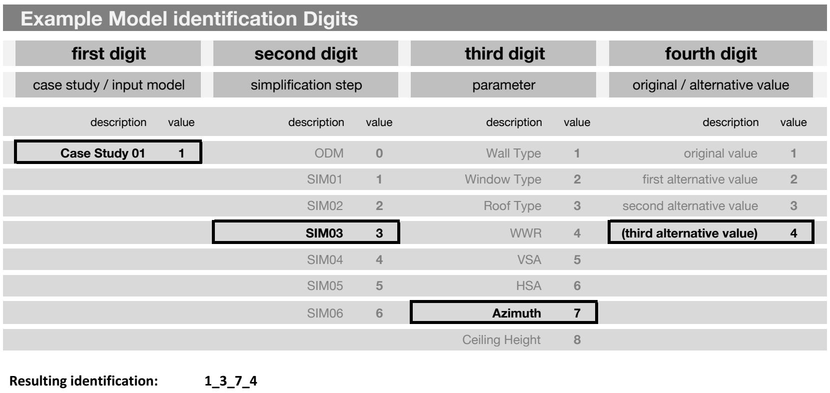
To keep track of the origin of each .idf file and correctly interpret the outcome, the file names are chosen to identify the originating *ODM* as well as the simplification step. The filename is composed of four digits, separated by underscores. The first digit refers to the case study, “1” for *CS*01. The second digit is “0” if the model is an *ODM* and identifies the simplification step (“1” for only the first step applied, “2” for the first two steps applied accumulatively and so on, finally “6” represents the complete simplification applying all six steps). The last two digits label the combination of the parameter, from “1” to “8”, and the alternative value, either “0”, if the original value is applied or either “1” or “2” (or eventually “3”) if an alternative value is applied. For example: “1_5_4_1.idf” is the file name of the input file containing the first alternative value for the fourth parameter (*WWR*) after applying 5 of the 6 simplification steps and starting from the building described in *CS01*. Table 4-1 presents an overview of the four digits, what they refer to and which values they may assume in this work.

Table 4-1: Overview model identification.

Overview Model identification Digits							
first digit		**second digit**		**third digit**		**fourth digit**	
case study / input model		simplification step		parameter		original / alternative value	
description	value	description	value	description	value	description	value
Case Study 01	**1**	ODM	**0**	Wall Type	**1**	original value	**1**
		SIM01	**1**	Window Type	**2**	first alternative value	**2**
		SIM02	**2**	Roof Type	**3**	second alternative value	**3**
		SIM03	**3**	WWR	**4**	(third alternative value)	**4**
		SIM04	**4**	VSA	**5**		
		SIM05	**5**	HSA	**6**		
		SIM06	**6**	Azimuth	**7**		
				Ceiling Height	**8**		

To exemplify the digits use, Table 4-2 presents an example. Note that any identification necessarily contains one value for each of the four digits.

Table 4-2: Example for model identification.



Example Model identification Digits

first digit		second digit		third digit		fourth digit	
case study / input model		simplification step		parameter		original / alternative value	
description	value	description	value	description	value	description	value
Case Study 01	**1**	ODM	0	Wall Type	1	original value	1
		SIM01	1	Window Type	2	first alternative value	2
		SIM02	2	Roof Type	3	second alternative value	3
		SIM03	**3**	WWR	4	**(third alternative value)**	**4**
		SIM04	4	VSA	5		
		SIM05	5	HSA	6		
		SIM06	6	**Azimuth**	**7**		
				Ceiling Height	8		

Resulting identification: 1_3_7_4

In more detail, the exemplified identification in Table 4-2 would refer to a model based on the input model provided in Case Study 01 with the accumulative simplification steps up to Step 03 included were applied. Further, the model described by this number contains a change to the parameter 7 (with respect to the original parameter values derived from the ODM), the solar orientation or azimuth. Precisely, the parameter assumes its third alternative value, in this case representing a 270° clockwise rotation.

This sub-section details some of the proceedings and steps taken in order to create the models for alternative values and simplifications steps based on the *ODM*. If not differently mentioned, the models are created following the rules and proceedings described in chapter 3.1.1.

It is important to remember that the case study used in this work contains a ground and a typical floor with differentiated characteristics regarding *WWR*, *VSA* and *HSA*.

The following procedures to create certain models are worth noting throughout all simplification steps:

- Alternative values 1 and 2 regarding *WWR*: as the *WWR* has been calculated – using the rules described in chapter 3.1.1 – for each solar orientation group of facade elements (south-facing, east-facing, etc.) separately, the overall building *WWR* does not represent the distribution criteria for the alternative value (but rather each facade element does follow the criteria).
- Alternative value 1 regarding *WWR*: with the need to drastically increase the window area while trying to maintain the architectural identity of the *ODM* as far as possible the following strategies have been applied: (a) first increase width, increase height only if necessary, (b) use same facade element to create orientation's *WWR*, use other elements of same orientation only if necessary.
- Alternative values 1 and 2 regarding *Ceiling Height*: as the simple alteration of the floor's ceiling height would cause a change to the *WWR* (augmenting the wall area, while leaving the windows' area unaltered), it is necessary to augment each facade element's window area to maintain the *WWR*. If necessary, the shading geometries were adjusted to maintain *VSA* and *HSA* correspondingly.

Regarding *SIM02*, simplifying the materials applied to the model, the following must be noted:

- Base value of *Exterior Wall*: As the alternative values 1 and 2 regarding exterior walls already have been applied to all such constructions, the simplification takes place only in the original material model (1_1_1_1).

With respect to *SIM03*, creating a model with a single thermal zone, the following must be stated:

- As the prior step has already simplified the *ODM*'s interior walls to a single construction, this simplified construction is used as the base for the calculation of the internal mass.

In the models of *SIM06*, the final simplification step creating a rectangular prismatic building volume, the following noteworthy proceedings have become necessary to create the models:

- Base value and alternative values 1 and 2 regarding *HSA*: while auto-shading (by the buildings volume) has not been regarded in the previous calculations regarding *HSA* – as the volume still existed and its casted shadows were therefore automatically acknowledged by *EP* – the windows of the affected facades have been designed with vertical shading elements inlcuding the shading angles created by auto-shading based on the *ODM*'s building geometry.

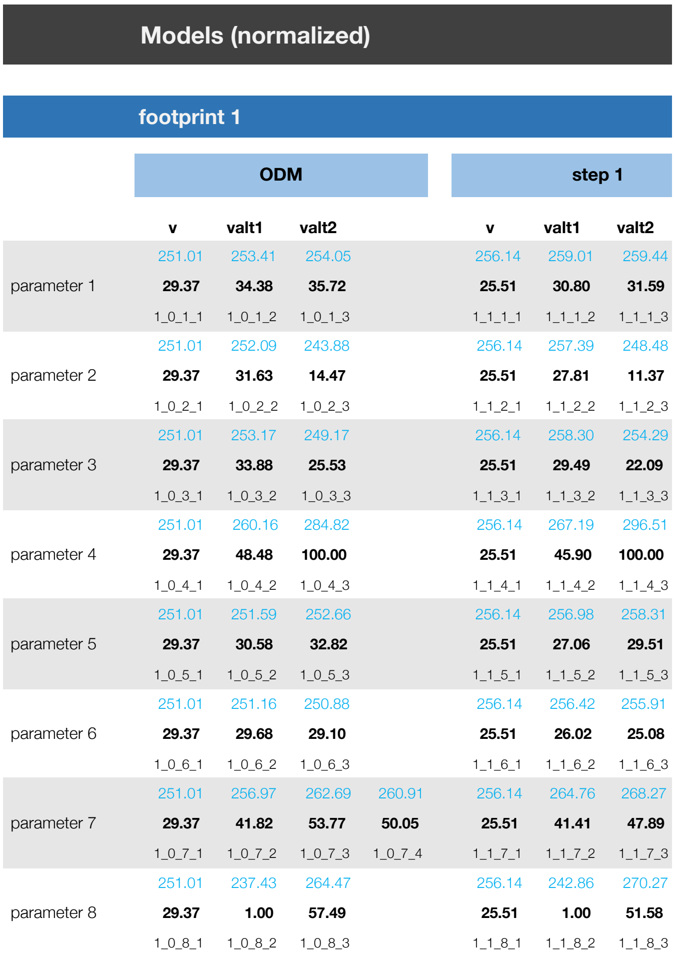
4.3.4. Simulation Setup and Execution

With all .idf files created it is now possible to set up the simulations. In certain cases the software *EP* Launch (United States Building Tecnology Office, 2016b) was used to run more than one simulation in an automated sequence. The software is used to setup the input files that will be run with *EP* and the weather file. It is important to remember that important simulation options, such as the type of output and output file format are part of the information saved in each of the .idf files and were laid out in chapter 3. For details read the exemplary .idf in Appendix A.

The total runtime for all .idf files was of 10h:04m:49s and all output files were generated without errors.

4.3.5. Result Elaboration

Using the 175 .html files generated using the same denomination as the .idf files, the results are transformed into the desired numerical output format. To do so – differently from the procedure described in chapter 3.1.3. – the *ODM*'s and each simplification steps’ results were normalized between 1 and 100. This leads to each of the seven groups of 25 simulation results containing a result “1” (representing the lowest value) and a “100” (representing the highest value). This work used Microsoft Excel 15.19.1 (Microsoft, 2016) to collect the single numerical value used for the output and to transform it into an abstract and normalized value. A prepared spreadsheet executed the numerical operations for the input values. Finally, using a specially adapted spreadsheet for this set of simulations and obeying the correct order of the results, the spreadsheet automatically generated the outputs representing (a) *DV* and (b) *RV*. An exemplary portion of the spreadsheet is shown in Figure 4-8.



Models (normalized)

footprint 1

	ODM				step 1		
	v	**valt1**	**valt2**		**v**	**valt1**	**valt2**
parameter 1	251.01	253.41	254.05		256.14	259.01	259.44
	29.37	**34.38**	**35.72**		**25.51**	**30.80**	**31.59**
	1_0_1_1	1_0_1_2	1_0_1_3		1_1_1_1	1_1_1_2	1_1_1_3
parameter 2	251.01	252.09	243.88		256.14	257.39	248.48
	29.37	**31.63**	**14.47**		**25.51**	**27.81**	**11.37**
	1_0_2_1	1_0_2_2	1_0_2_3		1_1_2_1	1_1_2_2	1_1_2_3
parameter 3	251.01	253.17	249.17		256.14	258.30	254.29
	29.37	**33.88**	**25.53**		**25.51**	**29.49**	**22.09**
	1_0_3_1	1_0_3_2	1_0_3_3		1_1_3_1	1_1_3_2	1_1_3_3
parameter 4	251.01	260.16	284.82		256.14	267.19	296.51
	29.37	**48.48**	**100.00**		**25.51**	**45.90**	**100.00**
	1_0_4_1	1_0_4_2	1_0_4_3		1_1_4_1	1_1_4_2	1_1_4_3
parameter 5	251.01	251.59	252.66		256.14	256.98	258.31
	29.37	**30.58**	**32.82**		**25.51**	**27.06**	**29.51**
	1_0_5_1	1_0_5_2	1_0_5_3		1_1_5_1	1_1_5_2	1_1_5_3
parameter 6	251.01	251.16	250.88		256.14	256.42	255.91
	29.37	**29.68**	**29.10**		**25.51**	**26.02**	**25.08**
	1_0_6_1	1_0_6_2	1_0_6_3		1_1_6_1	1_1_6_2	1_1_6_3
parameter 7	251.01	256.97	262.69	260.91	256.14	264.76	268.27
	29.37	**41.82**	**53.77**	**50.05**	**25.51**	**41.41**	**47.89**
	1_0_7_1	1_0_7_2	1_0_7_3	1_0_7_4	1_1_7_1	1_1_7_2	1_1_7_3
parameter 8	251.01	237.43	264.47		256.14	242.86	270.27
	29.37	**1.00**	**57.49**		**25.51**	**1.00**	**51.58**
	1_0_8_1	1_0_8_2	1_0_8_3		1_1_8_1	1_1_8_2	1_1_8_3

Figure 4-8: Partial view of the Microsoft Excel spreadsheet used for result elaboration.

4.4. Validation Results

For the *ODMs* and all *SIMs* eight (identical) models using the base values of each parameter and 17 models using the alternative values for each parameter were created.

For the *DV* the comparison of the abstract and normalized values obtained from the models referring to the six *SIMs* and the equivalent model from the set deriving from the *ODM* is performed. For example, the six models for the second alternative value of the *WWR* are compared to the model using the same alternative value for this parameter in the *ODM* are compared and if a difference of more than 20% is observed the validation is assumed as failed. All possible *DV*s are presented in the sub-section 4.4.1.

In order to perform *RV* an additional step is taken: the difference between the abstract and normalized values for each of the 17 possible parameter alternative values of each *SIM* and the *ODM* with respect to the corresponding parameter's base value of the same *SIM* or *ODM* is calculated. For example, the difference between the first alternative value for the *WWR* of *SIM03* and the base value for the *WWR* of *SIM03* is computed, as is the difference between the first alternative value for the *WWR* of the *ODM* and the base value for *WWR* of the *ODM*. This generates a total of 17 differences for each model, a total of 119 for the case study. By comparing the 17 differences from the *ODM* to the corresponding respective differences from each of the six *SIM*s, 102 *RV*s are possible; their results are reported in sub-section 4.4.2.

The conclusions drawn from these results can be found in chapter 5.

4.4.1. Direct Validation

The *DV*'s results are reported to demonstrate the accuracy of the results and make further conclusions possible.

Table 4-3, Table 4-3, Table 4-5, Table 4-6, Table 4-7, Table 4-8, Table 4-9, and Table 4-10 demonstrate the *DV* results for the eight parameters considered in this work respectively. It must be stated that in order to maintain the basic idea of *DV* the values used for comparison are the absolute values obtained for the

Total Site Energy per m^2, no further normalization has been applied.

Table 4-3: Direct Validation results regarding parameter 1 (*Wall Type*)

Direct Validation

footprint 1

		no.	ODM		SIMs		difference	Direct Validation
			name	result	name	result		
			[ ]	[kWh/m²]	[ ]	[kWh/m²]	[%]	
Wall Type	**ODM vs. SIMs with orig. value**	1	1_0_1_1	**79.26**	1_1_1_1	**80.88**	**2.00**	✓
		2	1_0_1_1	**79.26**	1_2_1_1	**80.75**	**1.85**	✓
		3	1_0_1_1	**79.26**	1_3_1_1	**267.10**	**70.33**	✗
		4	1_0_1_1	**79.26**	1_4_1_1	**243.28**	**67.42**	✗
		5	1_0_1_1	**79.26**	1_5_1_1	**255.23**	**68.95**	✗
		6	1_0_1_1	**79.26**	1_6_1_1	**245.69**	**67.74**	✗
	ODM vs. SIMs with alt. Value 01	7	1_0_1_2	**80.01**	1_1_1_2	**81.78**	**2.16**	✓
		8	1_0_1_2	**80.01**	1_2_1_2	**81.71**	**2.08**	✓
		9	1_0_1_2	**80.01**	1_3_1_2	**280.03**	**71.43**	✗
		10	1_0_1_2	**80.01**	1_4_1_2	**258.45**	**69.04**	✗
		11	1_0_1_2	**80.01**	1_5_1_2	**267.49**	**70.09**	✗
		12	1_0_1_2	**80.01**	1_6_1_2	**253.63**	**68.45**	✗
	ODM vs. SIMs with alt. value 02	13	1_0_1_3	**80.22**	1_1_1_3	**81.92**	**2.08**	✓
		14	1_0_1_3	**80.22**	1_2_1_3	**81.82**	**1.96**	✓
		15	1_0_1_3	**80.22**	1_3_1_3	**259.62**	**69.10**	✗
		16	1_0_1_3	**80.22**	1_4_1_3	**242.30**	**66.89**	✗
		17	1_0_1_3	**80.22**	1_5_1_3	**250.42**	**67.97**	✗
		18	1_0_1_3	**80.22**	1_6_1_3	**243.35**	**67.04**	✗

Table 4-3 presents the *DV* for the original value as well as the alternative values of the parameter *Wall Type*. The comparisons are sorted primarily in groups, differing in the value the parameter assumes. In more detail, the first group (lines 1 to 6) refer to the original value, while the second (lines 7 to 12) and third group (lines 13 to 18) apply the first and second alternative value to the *ODM* and the *SIMs* respectively. The first line of each group (lines 1, 7 and 13) represent the comparison of the *ODM* with the first simplification step, the second line compares the *ODM* with *SIM02* and so on. Finally, the last line of each group shows the comparison of the ODM with the most simplified *SIM06*. The absolute numerical value for the *ODM* and the two alternative values are reported in the columns denominated “ODM”, the columns of “SIMs” refer to the corresponding models from the simplification steps. For example, the first row shows the result of the *ODM* (79.26) and of the simplified model without external obstructions (80.88). Further right, the absolute difference (2.00) between the two models is reported. The column “Direct Validation” contains a check mark to emphasize that the difference lies below the threshold of 20% adopted in this work. A yellow exclamation would mark lines with differences above 20% but below 33% and a red “x” is exhibited in lines whose difference between the results of *ODM* and *SIM* is above 33%. All following tables regarding the validation use these symbols applying the same rules.

For the parameter *Wall Type* 6 of the total 18 *DV* pairs are validated, this represents 33.3%.

Table 4-4: Direct Validation results regarding parameter 2 (*Window Type*)

Direct Validation

footprint 1

			ODM		SIMs		difference	Direct Validation
		no.	name	result	name	result		
			[]	[kWh/m²]	[]	[kWh/m²]	[%]	
Window Type	**ODM vs. SIMs with orig. value**	1	1_0_2_1	**79.26**	1_1_2_1	**80.88**	**2.0**	✓
		2	1_0_2_1	**79.26**	1_2_2_1	**80.75**	**1.8**	✓
		3	1_0_2_1	**79.26**	1_3_2_1	**267.10**	**70.3**	✗
		4	1_0_2_1	**79.26**	1_4_2_1	**243.28**	**67.4**	✗
		5	1_0_2_1	**79.26**	1_5_2_1	**255.23**	**68.9**	✗
		6	1_0_2_1	**79.26**	1_6_2_1	**245.69**	**67.7**	✗
	ODM vs. SIMs with alt. Value 01	7	1_0_2_2	**79.60**	1_1_2_2	**81.27**	**2.1**	✓
		8	1_0_2_2	**79.60**	1_2_2_2	**81.17**	**1.9**	✓
		9	1_0_2_2	**79.60**	1_3_2_2	**270.11**	**70.5**	✗
		10	1_0_2_2	**79.60**	1_4_2_2	**249.35**	**68.1**	✗
		11	1_0_2_2	**79.60**	1_5_2_2	**257.43**	**69.1**	✗
		12	1_0_2_2	**79.60**	1_6_2_2	**248.16**	**67.9**	✗
	ODM vs. SIMs with alt. value 02	13	1_0_2_3	**77.01**	1_1_2_3	**78.46**	**1.8**	✓
		14	1_0_2_3	**77.01**	1_2_2_3	**78.16**	**1.5**	✓
		15	1_0_2_3	**77.01**	1_3_2_3	**236.28**	**67.4**	✗
		16	1_0_2_3	**77.01**	1_4_2_3	**224.80**	**65.7**	✗
		17	1_0_2_3	**77.01**	1_5_2_3	**238.04**	**67.6**	✗
		18	1_0_2_3	**77.01**	1_6_2_3	**227.54**	**66.2**	✗

Table 4-4 shows the *DV* results with respect to the parameter *Window Type*. 6 of the total 18 *DV* pairs are validated, this represents 33.3%.

Table 4-5: Direct Validation results regarding parameter 3 (*Roof Type*)

Direct Validation

footprint 1

			ODM		SIMs		difference	Direct Validation
		no.	name	result	name	result		
			[ ]	[kWh/m²]	[ ]	[kWh/m²]	[%]	
Roof Type	**ODM vs. SIMs with orig. value**	1	1_0_3_1	**79.26**	1_1_3_1	**80.88**	**2.0**	✓
		2	1_0_3_1	**79.26**	1_2_3_1	**80.75**	**1.8**	✓
		3	1_0_3_1	**79.26**	1_3_3_1	**267.10**	**70.3**	✗
		4	1_0_3_1	**79.26**	1_4_3_1	**243.28**	**67.4**	✗
		5	1_0_3_1	**79.26**	1_5_3_1	**255.23**	**68.9**	✗
		6	1_0_3_1	**79.26**	1_6_3_1	**245.69**	**67.7**	✗
	ODM vs. SIMs with alt. Value 01	7	1_0_3_2	**79.94**	1_1_3_2	**81.56**	**2.0**	✓
		8	1_0_3_2	**79.94**	1_2_3_2	**81.43**	**1.8**	✓
		9	1_0_3_2	**79.94**	1_3_3_2	**274.46**	**70.9**	✗
		10	1_0_3_2	**79.94**	1_4_3_2	**253.41**	**68.5**	✗
		11	1_0_3_2	**79.94**	1_5_3_2	**261.58**	**69.4**	✗
		12	1_0_3_2	**79.94**	1_6_3_2	**252.34**	**68.3**	✗
	ODM vs. SIMs with alt. value 02	13	1_0_3_3	**78.68**	1_1_3_3	**80.29**	**2.0**	✓
		14	1_0_3_3	**78.68**	1_2_3_3	**80.14**	**1.8**	✓
		15	1_0_3_3	**78.68**	1_3_3_3	**268.63**	**70.7**	✗
		16	1_0_3_3	**78.68**	1_4_3_3	**247.78**	**68.2**	✗
		17	1_0_3_3	**78.68**	1_5_3_3	**255.84**	**69.2**	✗
		18	1_0_3_3	**78.68**	1_6_3_3	**245.97**	**68.0**	✗

Table 4-5 depicts the results with respect to the *DV* of the parameter *Roof Type*. 6 of the total 18 *DV* pairs are validated, representing 33.3%.

Table 4-6: Direct Validation results regarding parameter 4 (*WWR*)

Direct Validation

footprint 1

			ODM		SIMs		difference	Direct Validation
		no.	name [ ]	result [kWh/m²]	name [ ]	result [kWh/m²]	[%]	
Window to Wall Ration (WWR)	ODM vs. SIMs with orig. value	1	1_0_4_1	79.26	1_1_4_1	80.88	2.0	✓
		2	1_0_4_1	79.26	1_2_4_1	80.75	1.8	✓
		3	1_0_4_1	79.26	1_3_4_1	267.10	70.3	✗
		4	1_0_4_1	79.26	1_4_4_1	243.28	67.4	✗
		5	1_0_4_1	79.26	1_5_4_1	255.23	68.9	✗
		6	1_0_4_1	79.26	1_6_4_1	245.69	67.7	✗
	ODM vs. SIMs with alt. Value 01	7	1_0_4_2	82.15	1_1_4_2	84.37	2.6	✓
		8	1_0_4_2	82.15	1_2_4_2	83.66	1.8	✓
		9	1_0_4_2	82.15	1_3_4_2	262.84	68.7	✗
		10	1_0_4_2	82.15	1_4_4_2	242.36	66.1	✗
		11	1_0_4_2	82.15	1_5_4_2	268.85	69.4	✗
		12	1_0_4_2	82.15	1_6_4_2	259.01	68.3	✗
	ODM vs. SIMs with alt. value 02	13	1_0_4_3	89.93	1_1_4_3	93.62	3.9	✓
		14	1_0_4_3	89.93	1_2_4_3	93.35	3.7	✓
		15	1_0_4_3	89.93	1_3_4_3	328.87	72.7	✗
		16	1_0_4_3	89.93	1_4_4_3	294.97	69.5	✗
		17	1_0_4_3	89.93	1_5_4_3	324.65	72.3	✗
		18	1_0_4_3	89.93	1_6_4_3	314.97	71.4	✗

Table 4-6 presents the results with respect to the *WWR*. 6 of the total 18 *DV* pairs are validated, this represents 33.3%

Table 4-7: Direct Validation results regarding parameter 5 (*VSA*)

Direct Validation								
footprint 1								
			ODM		SIMs		difference	Direct Validation
		no.	name	result	name	result		
			[ ]	[kWh/m^2]	[ ]	[kWh/m^2]	[%]	
Vertical Shading Angle (VSA)	**ODM vs. SIMs with orig. value**	1	1_0_5_1	**79.26**	1_1_5_1	**80.88**	**2.0**	✓
		2	1_0_5_1	**79.26**	1_2_5_1	**80.75**	**1.8**	✓
		3	1_0_5_1	**79.26**	1_3_5_1	**267.10**	**70.3**	✗
		4	1_0_5_1	**79.26**	1_4_5_1	**243.28**	**67.4**	✗
		5	1_0_5_1	**79.26**	1_5_5_1	**255.23**	**68.9**	✗
		6	1_0_5_1	**79.26**	1_6_5_1	**245.69**	**67.7**	✗
	ODM vs. SIMs with alt. Value 01	7	1_0_5_2	**79.44**	1_1_5_2	**81.14**	**2.1**	✓
		8	1_0_5_2	**79.44**	1_2_5_2	**81.00**	**1.9**	✓
		9	1_0_5_2	**79.44**	1_3_5_2	**267.05**	**70.3**	✗
		10	1_0_5_2	**79.44**	1_4_5_2	**246.93**	**67.8**	✗
		11	1_0_5_2	**79.44**	1_5_5_2	**255.41**	**68.9**	✗
		12	1_0_5_2	**79.44**	1_6_5_2	**246.46**	**67.8**	✗
	ODM vs. SIMs with alt. value 02	13	1_0_5_3	**79.78**	1_1_5_3	**81.56**	**2.2**	✓
		14	1_0_5_3	**79.78**	1_2_5_3	**81.42**	**2.0**	✓
		15	1_0_5_3	**79.78**	1_3_5_3	**268.37**	**70.3**	✗
		16	1_0_5_3	**79.78**	1_4_5_3	**248.09**	**67.8**	✗
		17	1_0_5_3	**79.78**	1_5_5_3	**255.04**	**68.7**	✗
		18	1_0_5_3	**79.78**	1_6_5_3	**245.11**	**67.5**	✗

Table 4-7 displays the *DV* results with respect to the parameter *VSA*. 6 of the total 18 *DV* pairs are validated, which represents 33.3%.

Table 4-8: Direct Validation results regarding parameter 6 (*HSA*)

Direct Validation

footprint 1

			ODM		**SIMs**		**difference**	**Direct Validation**
		no.	name	result	name	result		
			[]	[kWh/m^2]	[]	[kWh/m^2]	[%]	
Horizontal Shading Angle (HSA)	**ODM vs. SIMs with orig. value**	1	1_0_6_1	**79.26**	1_1_6_1	**80.88**	**2.00**	✓
		2	1_0_6_1	**79.26**	1_2_6_1	**80.75**	**1.85**	✓
		3	1_0_6_1	**79.26**	1_3_6_1	**267.10**	**70.33**	✗
		4	1_0_6_1	**79.26**	1_4_6_1	**243.28**	**67.42**	✗
		5	1_0_6_1	**79.26**	1_5_6_1	**255.23**	**68.95**	✗
		6	1_0_6_1	**79.26**	1_6_6_1	**778.09**	**89.81**	✗
	ODM vs. SIMs with alt. Value 01	7	1_0_6_2	**79.31**	1_1_6_2	**80.97**	**2.1**	✓
		8	1_0_6_2	**79.31**	1_2_6_2	**80.84**	**1.9**	✓
		9	1_0_6_2	**79.31**	1_3_6_2	**267.60**	**70.4**	✗
		10	1_0_6_2	**79.31**	1_4_6_2	**247.38**	**67.9**	✗
		11	1_0_6_2	**79.31**	1_5_6_2	**255.37**	**68.9**	✗
		12	1_0_6_2	**79.31**	1_6_6_2	**246.54**	**67.8**	✗
	ODM vs. SIMs with alt. value 02	13	1_0_6_3	**79.22**	1_1_6_3	**80.81**	**2.0**	✓
		14	1_0_6_3	**79.22**	1_2_6_3	**80.68**	**1.8**	✓
		15	1_0_6_3	**79.22**	1_3_6_3	**266.72**	**70.3**	✗
		16	1_0_6_3	**79.22**	1_4_6_3	**246.58**	**67.9**	✗
		17	1_0_6_3	**79.22**	1_5_6_3	**254.92**	**68.9**	✗
		18	1_0_6_3	**79.22**	1_6_6_3	**247.87**	**68.0**	✗

Table 4-8 illustrates the results with respect to the parameter *HSA*. 6 of the total 18 *DV* pairs are validated, this represents 33.3%.

Table 4-9: Direct Validation results regarding parameter 7 (Azimuth)

Direct Validation								
footprint 1								
			ODM		SIMs		difference	Direct Validation
		no.	name [ ]	result [kWh/m^2]	name [ ]	result [kWh/m^2]	[%]	
Azimuth	ODM vs. SIMs with orig. value	1	1_0_7_1	**79.26**	1_1_7_1	**80.88**	**2.0**	✓
		2	1_0_7_1	**79.26**	1_2_7_1	**80.75**	**1.8**	✓
		3	1_0_7_1	**79.26**	1_3_7_1	**267.10**	**70.3**	✗
		4	1_0_7_1	**79.26**	1_4_7_1	**243.28**	**67.4**	✗
		5	1_0_7_1	**79.26**	1_5_7_1	**255.23**	**68.9**	✗
		6	1_0_7_1	**79.26**	1_6_7_1	**245.69**	**67.7**	✗
	ODM vs. SIMs with alt. Value 01	7	1_0_7_2	**81.14**	1_1_7_2	**83.60**	**2.9**	✓
		8	1_0_7_2	**81.14**	1_2_7_2	**83.65**	**3.0**	✓
		9	1_0_7_2	**81.14**	1_3_7_2	**286.34**	**71.7**	✗
		10	1_0_7_2	**81.14**	1_4_7_2	**263.96**	**69.3**	✗
		11	1_0_7_2	**81.14**	1_5_7_2	**273.21**	**70.3**	✗
		12	1_0_7_2	**81.14**	1_6_7_2	**260.16**	**68.8**	✗
	ODM vs. SIMs with alt. value 02	13	1_0_7_3	**82.95**	1_1_7_3	**84.71**	**2.1**	✓
		14	1_0_7_3	**82.95**	1_2_7_3	**84.90**	**2.3**	✓
		15	1_0_7_3	**82.95**	1_3_7_3	**273.34**	**69.7**	✗
		16	1_0_7_3	**82.95**	1_4_7_3	**273.34**	**69.7**	✗
		17	1_0_7_3	**82.95**	1_5_7_3	**259.82**	**68.1**	✗
		18	1_0_7_3	**82.95**	1_6_7_3	**252.27**	**67.1**	✗
	ODM vs. SIMs with alt. value 03	19	1_0_7_4	**82.38**	1_1_7_4	**84.45**	**2.5**	✓
		20	1_0_7_4	**82.38**	1_2_7_4	**84.44**	**2.4**	✓
		21	1_0_7_4	**82.38**	1_3_7_4	**281.66**	**70.8**	✗
		22	1_0_7_4	**82.38**	1_4_7_4	**281.66**	**70.8**	✗
		23	1_0_7_4	**82.38**	1_5_7_4	**268.62**	**69.3**	✗
		24	1_0_7_4	**82.38**	1_6_7_4	**258.41**	**68.1**	✗

Table 4-9 shows the *DV* results with respect to the parameter *Azimuth*. Different from the other 7 parameters, 3 alternative values were applied here. 8 of the total 24 *DV* pairs are validated, this represents 33.0%.

Table 4-10: Direct Validation results regarding parameter 8 (*Ceiling Height*)

Direct Validation								
		footprint 1						
			ODM		SIMs		difference	Direct Validation
		no.	name	result	name	result		
			[ ]	[kWh/m²]	[ ]	[kWh/m²]	[%]	
Ceiling Height	ODM vs. SIMs with orig. value	1	1_0_8_1	**79.26**	1_1_8_1	**80.88**	**2.0**	✓
		2	1_0_8_1	**79.26**	1_2_8_1	**80.75**	**1.8**	✓
		3	1_0_8_1	**79.26**	1_3_8_1	**267.10**	**70.3**	✗
		4	1_0_8_1	**79.26**	1_4_8_1	**243.28**	**67.4**	✗
		5	1_0_8_1	**79.26**	1_5_8_1	**255.23**	**68.9**	✗
		6	1_0_8_1	**79.26**	1_6_8_1	**245.69**	**67.7**	✗
	ODM vs. SIMs with alt. Value 01	7	1_0_8_2	**74.97**	1_1_8_2	**76.68**	**2.2**	✓
		8	1_0_8_2	**74.97**	1_2_8_2	**76.71**	**2.3**	✓
		9	1_0_8_2	**74.97**	1_3_8_2	**209.71**	**64.3**	✗
		10	1_0_8_2	**74.97**	1_4_8_2	**199.78**	**62.5**	✗
		11	1_0_8_2	**74.97**	1_5_8_2	**205.27**	**63.5**	✗
		12	1_0_8_2	**74.97**	1_6_8_2	**186.40**	**59.8**	✗
	ODM vs. SIMs with alt. value 02	13	1_0_8_3	**83.51**	1_1_8_3	**85.34**	**2.1**	✓
		14	1_0_8_3	**83.51**	1_2_8_3	**85.09**	**1.9**	✓
		15	1_0_8_3	**83.51**	1_3_8_3	**321.94**	**74.1**	✗
		16	1_0_8_3	**83.51**	1_4_8_3	**290.20**	**71.2**	✗
		17	1_0_8_3	**83.51**	1_5_8_3	**302.48**	**72.4**	✗
		18	1_0_8_3	**83.51**	1_6_8_3	**269.99**	**69.1**	✗

Table 4-10 demonstrates the results with respect to the parameter *Ceiling Height*. 6 of the total 18 *DV* pairs are validated, this represents 33.3%.

Overall it can be stated that 50 of 150, representing 33.3%, of the *DV*s result in differences below 20% and consequently would be acceptable. The remaining 100 validations fail, no case of nearly validated results (20% to 33%) is observed with respect to this work's *CS*. In more detail, all results for the first two simplification steps are validated, while all steps from the third onwards result in a drastic increase of inaccuracy (from about 1.8% for the second step to about 70.3% for the third).

4.4.2. Relative Validation

The results regarding *RV* are reported to demonstrate how the proposed validation methodology is employed to the *CS* presented in this work when applying the described simplifications steps inside the proposed framework. Following the methodology, the proposed *CS* allows creating a total of 102 result pairs for validation.

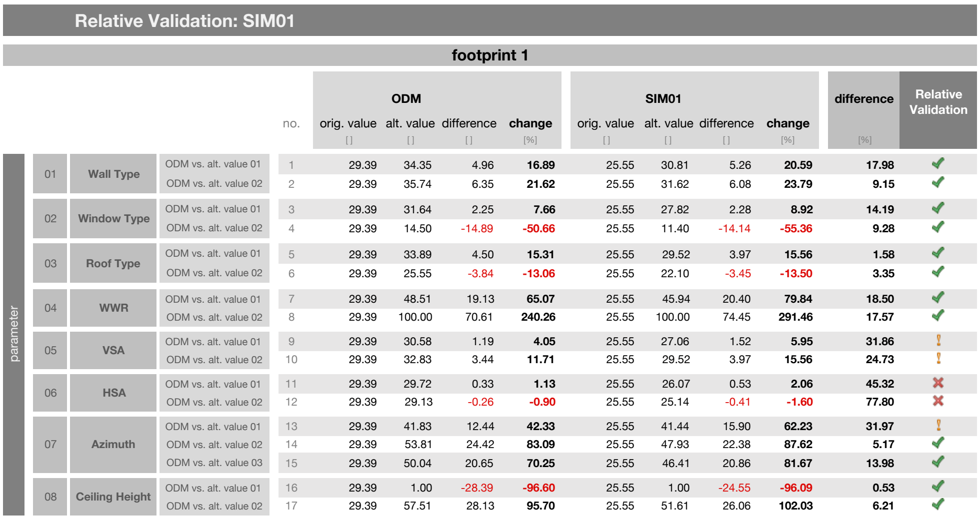
Table 4-11,

Table 4-12, Table 4-13, Table 4-14, Table 4-15, and Table 4-16 present the *RV* results for the six simplification steps adopted during this work respectively. All results now refer to the normalized value obtained throughout the steps detailed in the framework's description.

Table 4-11: Relative Validation results regarding *SIM*01

In

Table 4-11 it is possible to observe the normalized values for the *ODM*, the resulting difference and the change in percentage as well as the respective values for the *SIM0*, applying the removal of external obstructions. In more detail, the results are grouped in with respect to the parameter that is altered. With exception of lines 13 to 15, which report the validation of the consequences of the three possible value alternatives for the solar orientation, the seven remaining groups are composed of two lines, which report the validation for the changes from the original to the two available alternative values for the respective seven parameters. Finally, in the last two columns on the right-hand side, the difference between the observed change in the



Relative Validation: SIM01

footprint 1

parameter				no.	ODM orig. value []	ODM alt. value []	ODM difference []	ODM **change** [%]	SIM01 orig. value []	SIM01 alt. value []	SIM01 difference []	SIM01 **change** [%]	**difference** [%]	**Relative Validation**
parameter	01	**Wall Type**	ODM vs. alt. value 01	1	29.39	34.35	4.96	**16.89**	25.55	30.81	5.26	**20.59**	**17.98**	✓
			ODM vs. alt. value 02	2	29.39	35.74	6.35	**21.62**	25.55	31.62	6.08	**23.79**	**9.15**	✓
	02	**Window Type**	ODM vs. alt. value 01	3	29.39	31.64	2.25	**7.66**	25.55	27.82	2.28	**8.92**	**14.19**	✓
			ODM vs. alt. value 02	4	29.39	14.50	-14.89	**-50.66**	25.55	11.40	-14.14	**-55.36**	**9.28**	✓
	03	**Roof Type**	ODM vs. alt. value 01	5	29.39	33.89	4.50	**15.31**	25.55	29.52	3.97	**15.56**	**1.58**	✓
			ODM vs. alt. value 02	6	29.39	25.55	-3.84	**-13.06**	25.55	22.10	-3.45	**-13.50**	**3.35**	✓
	04	**WWR**	ODM vs. alt. value 01	7	29.39	48.51	19.13	**65.07**	25.55	45.94	20.40	**79.84**	**18.50**	✓
			ODM vs. alt. value 02	8	29.39	100.00	70.61	**240.26**	25.55	100.00	74.45	**291.46**	**17.57**	✓
	05	**VSA**	ODM vs. alt. value 01	9	29.39	30.58	1.19	**4.05**	25.55	27.06	1.52	**5.95**	**31.86**	!
			ODM vs. alt. value 02	10	29.39	32.83	3.44	**11.71**	25.55	29.52	3.97	**15.56**	**24.73**	!
	06	**HSA**	ODM vs. alt. value 01	11	29.39	29.72	0.33	**1.13**	25.55	26.07	0.53	**2.06**	**45.32**	✗
			ODM vs. alt. value 02	12	29.39	29.13	-0.26	**-0.90**	25.55	25.14	-0.41	**-1.60**	**77.80**	✗
	07	**Azimuth**	ODM vs. alt. value 01	13	29.39	41.83	12.44	**42.33**	25.55	41.44	15.90	**62.23**	**31.97**	!
			ODM vs. alt. value 02	14	29.39	53.81	24.42	**83.09**	25.55	47.93	22.38	**87.62**	**5.17**	✓
			ODM vs. alt. value 03	15	29.39	50.04	20.65	**70.25**	25.55	46.41	20.86	**81.67**	**13.98**	✓
	08	**Ceiling Height**	ODM vs. alt. value 01	16	29.39	1.00	-28.39	**-96.60**	25.55	1.00	-24.55	**-96.09**	**0.53**	✓
			ODM vs. alt. value 02	17	29.39	57.51	28.13	**95.70**	25.55	51.61	26.06	**102.03**	**6.21**	✓

ODM and the observed change in the SIM as well as the symbolic representation of the *RV*'s success are presented.

Exemplarily line 10 shows the change of the *VSA*'s base value in the *ODM* (11.74%) and the corresponding change when looking at the *SIM01* (15.70%). The difference between these two values is of 25.24%, outside of the acceptable range of 20%, but still below 33%. Consequently, the last column depicts a yellow exclamation mark.

12 of the 17 *RV*s are positive, while three are nearly positive and two fail with more than 33% difference. This represents 70.6%, 17.6%, and 11.8%, respectively.

Table 4-12: Relative Validation results regarding *SIM*02

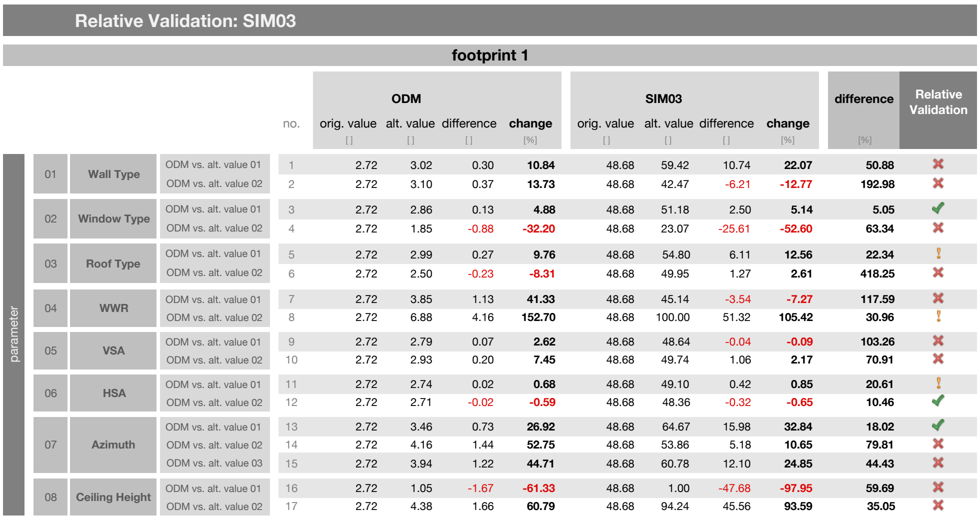
Relative Validation: SIM02

footprint 1

					ODM				**SIM02**				**difference**	**Relative Validation**
				no.	orig. value []	alt. value []	difference []	**change** [%]	orig. value []	alt. value []	difference []	**change** [%]	[%]	
parameter	01	**Wall Type**	ODM vs. alt. value 01	1	29.39	34.35	4.96	**16.89**	25.04	30.75	5.71	**22.81**	**25.97**	!
			ODM vs. alt. value 02	2	29.39	35.74	6.35	**21.62**	25.04	31.40	6.37	**25.43**	**14.99**	✓
	02	**Window Type**	ODM vs. alt. value 01	3	29.39	31.64	2.25	**7.66**	25.04	27.53	2.50	**9.98**	**23.30**	!
			ODM vs. alt. value 02	4	29.39	14.50	-14.89	**-50.66**	25.04	9.63	-15.41	**-61.55**	**21.49**	!
	03	**Roof Type**	ODM vs. alt. value 01	5	29.39	33.89	4.50	**15.31**	25.04	29.08	4.05	**16.16**	**5.25**	✓
			ODM vs. alt. value 02	6	29.39	25.55	-3.84	**-13.06**	25.04	21.41	-3.63	**-14.50**	**11.00**	✓
	04	**WWR**	ODM vs. alt. value 01	7	29.39	48.51	19.13	**65.07**	25.04	42.35	17.31	**69.15**	**5.90**	✓
			ODM vs. alt. value 02	8	29.39	100.00	70.61	**240.26**	25.04	100.00	74.96	**299.42**	**19.76**	✓
	05	**VSA**	ODM vs. alt. value 01	9	29.39	30.58	1.19	**4.05**	25.04	26.52	1.49	**5.94**	**31.78**	!
			ODM vs. alt. value 02	10	29.39	32.83	3.44	**11.71**	25.04	29.02	3.99	**15.92**	**26.46**	!
	06	**HSA**	ODM vs. alt. value 01	11	29.39	29.72	0.33	**1.13**	25.04	25.57	0.54	**2.14**	**47.36**	✗
			ODM vs. alt. value 02	12	29.39	29.13	-0.26	**-0.90**	25.04	24.62	-0.42	**-1.66**	**84.69**	✗
	07	**Azimuth**	ODM vs. alt. value 01	13	29.39	41.83	12.44	**42.33**	25.04	42.29	17.25	**68.92**	**38.57**	✗
			ODM vs. alt. value 02	14	29.39	53.81	24.42	**83.09**	25.04	49.73	24.69	**98.62**	**15.75**	✓
			ODM vs. alt. value 03	15	29.39	50.04	20.65	**70.25**	25.04	46.99	21.95	**87.69**	**19.88**	✓
	08	**Ceiling Height**	ODM vs. alt. value 01	16	29.39	1.00	-28.39	**-96.60**	25.04	1.00	-24.04	**-96.01**	**0.62**	✓
			ODM vs. alt. value 02	17	29.39	57.51	28.13	**95.70**	25.04	50.86	25.82	**103.13**	**7.21**	✓

Table 4-12 shows the results for the second simplification step, which simplifies the number of constructions represented in the model. Nine, representing 52.9% are validated, while five (29.4%) are critical and three (17.6%) fail *RV*.

Table 4-13: Relative Validation results regarding *SIM*03



Relative Validation: SIM03

footprint 1

parameter			no.	**ODM**				**SIM03**				**difference**	**Relative Validation**
				orig. value []	alt. value []	difference []	**change** [%]	orig. value []	alt. value []	difference []	**change** [%]	[%]	
01	**Wall Type**	ODM vs. alt. value 01	1	2.72	3.02	0.30	**10.84**	48.68	59.42	10.74	**22.07**	**50.88**	✗
		ODM vs. alt. value 02	2	2.72	3.10	0.37	**13.73**	48.68	42.47	-6.21	**-12.77**	**192.98**	✗
02	**Window Type**	ODM vs. alt. value 01	3	2.72	2.86	0.13	**4.88**	48.68	51.18	2.50	**5.14**	**5.05**	✓
		ODM vs. alt. value 02	4	2.72	1.85	-0.88	**-32.20**	48.68	23.07	-25.61	**-52.60**	**63.34**	✗
03	**Roof Type**	ODM vs. alt. value 01	5	2.72	2.99	0.27	**9.76**	48.68	54.80	6.11	**12.56**	**22.34**	!
		ODM vs. alt. value 02	6	2.72	2.50	-0.23	**-8.31**	48.68	49.95	1.27	**2.61**	**418.25**	✗
04	**WWR**	ODM vs. alt. value 01	7	2.72	3.85	1.13	**41.33**	48.68	45.14	-3.54	**-7.27**	**117.59**	✗
		ODM vs. alt. value 02	8	2.72	6.88	4.16	**152.70**	48.68	100.00	51.32	**105.42**	**30.96**	!
05	**VSA**	ODM vs. alt. value 01	9	2.72	2.79	0.07	**2.62**	48.68	48.64	-0.04	**-0.09**	**103.26**	✗
		ODM vs. alt. value 02	10	2.72	2.93	0.20	**7.45**	48.68	49.74	1.06	**2.17**	**70.91**	✗
06	**HSA**	ODM vs. alt. value 01	11	2.72	2.74	0.02	**0.68**	48.68	49.10	0.42	**0.85**	**20.61**	!
		ODM vs. alt. value 02	12	2.72	2.71	-0.02	**-0.59**	48.68	48.36	-0.32	**-0.65**	**10.46**	✓
07	**Azimuth**	ODM vs. alt. value 01	13	2.72	3.46	0.73	**26.92**	48.68	64.67	15.98	**32.84**	**18.02**	✓
		ODM vs. alt. value 02	14	2.72	4.16	1.44	**52.75**	48.68	53.86	5.18	**10.65**	**79.81**	✗
		ODM vs. alt. value 03	15	2.72	3.94	1.22	**44.71**	48.68	60.78	12.10	**24.85**	**44.43**	✗
08	**Ceiling Height**	ODM vs. alt. value 01	16	2.72	1.05	-1.67	**-61.33**	48.68	1.00	-47.68	**-97.95**	**59.69**	✗
		ODM vs. alt. value 02	17	2.72	4.38	1.66	**60.79**	48.68	94.24	45.56	**93.59**	**35.05**	✗

Table 4-13 depicts for the zone lumping step. In this case, just three, representing 17.6%, of the total of 17 pairs are validated, while three (17.6%) are categorized as critical and 11 (64.7%) fail *RV*. This simplification therefore represents the first step that has less than 70% of its results validated. The third and all further simplification steps do present validation rates of less than 30%.

Table 4-14: Relative Validation results regarding *SIM*04

Relative Validation: SIM04

footprint 1

					ODM				**SIM04**				**difference**	**Relative Validation**
				no.	orig. value []	alt. value []	difference []	**change** [%]	orig. value []	alt. value []	difference []	**change** [%]	[%]	
parameter	01	**Wall Type**	ODM vs. alt. value 01	1	2.72	3.02	0.30	**10.84**	46.24	62.02	15.78	**34.12**	**68.23**	✗
			ODM vs. alt. value 02	2	2.72	3.10	0.37	**13.73**	46.24	45.22	-1.02	**-2.20**	**116.05**	✗
	02	**Window Type**	ODM vs. alt. value 01	3	2.72	2.86	0.13	**4.88**	46.24	52.55	6.31	**13.65**	**64.27**	✗
			ODM vs. alt. value 02	4	2.72	1.85	-0.88	**-32.20**	46.24	27.02	-19.22	**-41.56**	**29.07**	!
	03	**Roof Type**	ODM vs. alt. value 01	5	2.72	2.99	0.27	**9.76**	46.24	56.78	10.54	**22.78**	**57.18**	✗
			ODM vs. alt. value 02	6	2.72	2.50	-0.23	**-8.31**	46.24	50.92	4.68	**10.12**	**182.11**	✗
	04	**WWR**	ODM vs. alt. value 01	7	2.72	3.85	1.13	**41.33**	46.24	45.28	-0.96	**-2.07**	**105.01**	✗
			ODM vs. alt. value 02	8	2.72	6.88	4.16	**152.70**	46.24	100.00	53.76	**116.26**	**23.87**	!
	05	**VSA**	ODM vs. alt. value 01	9	2.72	2.79	0.07	**2.62**	46.24	50.04	3.80	**8.21**	**68.09**	✗
			ODM vs. alt. value 02	10	2.72	2.93	0.20	**7.45**	46.24	51.24	5.00	**10.82**	**31.12**	!
	06	**HSA**	ODM vs. alt. value 01	11	2.72	2.74	0.02	**0.68**	46.24	50.51	4.26	**9.22**	**92.65**	✗
			ODM vs. alt. value 02	12	2.72	2.71	-0.02	**-0.59**	46.24	49.67	3.43	**7.42**	**107.91**	✗
	07	**Azimuth**	ODM vs. alt. value 01	13	2.72	3.46	0.73	**26.92**	46.24	67.75	21.51	**46.51**	**42.13**	✗
			ODM vs. alt. value 02	14	2.72	4.16	1.44	**52.75**	46.24	77.50	31.26	**67.61**	**21.97**	!
			ODM vs. alt. value 03	15	2.72	3.94	1.22	**44.71**	46.24	86.16	39.92	**86.32**	**48.20**	✗
	08	**Ceiling Height**	ODM vs. alt. value 01	16	2.72	1.05	-1.67	**-61.33**	46.24	1.00	-45.24	**-97.84**	**59.52**	✗
			ODM vs. alt. value 02	17	2.72	4.38	1.66	**60.79**	46.24	95.04	48.80	**105.53**	**42.39**	✗

Table 4-14 shows the results for the fourth simplification step, which calculates the internal mass values without using any internal walls. Here, zero of the 17 pairs are validated. Further, four pairs (23.5%) are categorized as critical while 13 (76.5%) fail *RV*.

Table 4-15: Relative Validation results regarding *SIM*05

Relative Validation: SIM05														
					footprint 1									
					ODM				**SIM05**				**difference**	**Relative Validation**
				no.	orig. value []	alt. value []	difference []	**change** [%]	orig. value []	alt. value []	difference []	**change** [%]	[%]	
parameter	01	**Wall Type**	ODM vs. alt. value 01	1	2.72	3.02	0.30	**10.84**	42.43	52.60	10.17	**23.96**	**54.76**	✗
			ODM vs. alt. value 02	2	2.72	3.10	0.37	**13.73**	42.43	38.44	-3.99	**-9.40**	**168.47**	✗
	02	**Window Type**	ODM vs. alt. value 01	3	2.72	2.86	0.13	**4.88**	42.43	44.26	1.82	**4.30**	**11.85**	✓
			ODM vs. alt. value 02	4	2.72	1.85	-0.88	**-32.20**	42.43	28.18	-14.26	**-33.60**	**4.33**	✓
	03	**Roof Type**	ODM vs. alt. value 01	5	2.72	2.99	0.27	**9.76**	42.43	47.70	5.27	**12.41**	**21.39**	!
			ODM vs. alt. value 02	6	2.72	2.50	-0.23	**-8.31**	42.43	42.94	0.51	**1.19**	**797.05**	✗
	04	**WWR**	ODM vs. alt. value 01	7	2.72	3.85	1.13	**41.33**	42.43	53.73	11.29	**26.62**	**35.59**	✗
			ODM vs. alt. value 02	8	2.72	6.88	4.16	**152.70**	42.43	100.00	57.57	**135.68**	**11.15**	✓
	05	**VSA**	ODM vs. alt. value 01	9	2.72	2.79	0.07	**2.62**	42.43	42.58	0.15	**0.35**	**86.57**	✗
			ODM vs. alt. value 02	10	2.72	2.93	0.20	**7.45**	42.43	42.27	-0.16	**-0.37**	**104.98**	✗
	06	**HSA**	ODM vs. alt. value 01	11	2.72	2.74	0.02	**0.68**	42.43	42.55	0.12	**0.27**	**59.61**	✗
			ODM vs. alt. value 02	12	2.72	2.71	-0.02	**-0.59**	42.43	42.17	-0.26	**-0.61**	**3.19**	✓
	07	**Azimuth**	ODM vs. alt. value 01	13	2.72	3.46	0.73	**26.92**	42.43	57.34	14.91	**35.14**	**23.40**	!
			ODM vs. alt. value 02	14	2.72	4.16	1.44	**52.75**	42.43	46.24	3.81	**8.97**	**82.99**	✗
			ODM vs. alt. value 03	15	2.72	3.94	1.22	**44.71**	42.43	53.54	11.10	**26.17**	**41.47**	✗
	08	**Ceiling Height**	ODM vs. alt. value 01	16	2.72	1.05	-1.67	**-61.33**	42.43	1.00	-41.43	**-97.64**	**59.20**	✗
			ODM vs. alt. value 02	17	2.72	4.38	1.66	**60.79**	42.43	81.61	39.18	**92.35**	**34.17**	✗

Table 4-15 depicts the *RV* for the fourth step, simplifying the model with respect to its transparent surfaces. Four are validated, this represents 23.5%, two pairs (11.8%) are critical, while 11 (64.7%) fail.

Table 4-16: Relative Validation results regarding *SIM*06

Relative Validation: SIM06														
					footprint 1									
					ODM				**SIM06**				**difference**	**Relative Validation**
				no.	orig. value	alt. value	difference	**change**	orig. value	alt. value	difference	**change**		
					[ ]	[ ]	[ ]	[%]	[ ]	[ ]	[ ]	[%]	[%]	
parameter	01	**Wall Type**	ODM vs. alt. value 01	1	2.72	3.02	0.30	**10.84**	46.65	52.77	6.11	**13.10**	**17.29**	✓
			ODM vs. alt. value 02	2	2.72	3.10	0.37	**13.73**	46.65	44.85	-1.80	**-3.86**	**128.13**	✗
	02	**Window Type**	ODM vs. alt. value 01	3	2.72	2.86	0.13	**4.88**	46.65	48.56	1.90	**4.08**	**16.42**	✓
			ODM vs. alt. value 02	4	2.72	1.85	-0.88	**-32.20**	46.65	32.68	-13.98	**-29.96**	**7.50**	✓
	03	**Roof Type**	ODM vs. alt. value 01	5	2.72	2.99	0.27	**9.76**	46.65	51.77	5.12	**10.98**	**11.12**	✓
			ODM vs. alt. value 02	6	2.72	2.50	-0.23	**-8.31**	46.65	46.87	0.22	**0.46**	**1898.24**	✗
	04	**WWR**	ODM vs. alt. value 01	7	2.72	3.85	1.13	**41.33**	46.65	56.91	10.26	**21.98**	**46.80**	✗
			ODM vs. alt. value 02	8	2.72	6.88	4.16	**152.70**	46.65	100.00	53.35	**114.34**	**25.12**	!
	05	**VSA**	ODM vs. alt. value 01	9	2.72	2.79	0.07	**2.62**	46.65	47.25	0.59	**1.27**	**51.49**	✗
			ODM vs. alt. value 02	10	2.72	2.93	0.20	**7.45**	46.65	46.21	-0.45	**-0.96**	**112.85**	✗
	06	**HSA**	ODM vs. alt. value 01	11	2.72	2.74	0.02	**0.68**	46.65	47.31	0.65	**1.40**	**51.71**	✗
			ODM vs. alt. value 02	12	2.72	2.71	-0.02	**-0.59**	46.65	48.33	1.68	**3.60**	**116.32**	✗
	07	**Azimuth**	ODM vs. alt. value 01	13	2.72	3.46	0.73	**26.92**	46.65	57.80	11.14	**23.88**	**11.28**	✓
			ODM vs. alt. value 02	14	2.72	4.16	1.44	**52.75**	46.65	51.72	5.07	**10.86**	**79.41**	✗
			ODM vs. alt. value 03	15	2.72	3.94	1.22	**44.71**	46.65	56.45	9.79	**20.99**	**53.05**	✗
	08	**Ceiling Height**	ODM vs. alt. value 01	16	2.72	1.05	-1.67	**-61.33**	46.65	1.00	-45.65	**-97.86**	**59.55**	✗
			ODM vs. alt. value 02	17	2.72	4.38	1.66	**60.79**	46.65	65.37	18.71	**40.11**	**34.03**	✗

In the most simplified model, five of the 17 *RVs* are positive, while one is nearly positive and 11 fail with more than 33% difference. This represents 29.4%, 5.9%, and 64.7%, respectively. The details are presented in Table 4-16.

It can be observed that 32 of the total of 102 *RVs* are below the allowed error margin of 20%, another 18 present a margin below 33%, while the remaining 52 results' validation fails. The conclusions regarding these results are drawn in Chapter 5.

5. CONCLUSIONS

The following sub-items discuss the framework's and validation's procedures strengths and weaknesses from the results obtained and described in chapter 4. Further, considering the work's restrictions and limitations, a set of possible applications and future works is outlined.

5.1. Considerations regarding the Validation Results

It must be highlighted that this work uses a single case study to illustrate a possible pathway towards a simplified model. Being a single case, its results are still not conclusive regarding its results' validation neither sufficiently robust to afford the great variety of cases concerning restrictions related to geographical position (and therefore climatic situation), building type and external obstructions. As an example, the case study presented in Beyer (2016) has applied the creation of a single thermal zone basically without any significant change to the numerical outcome. In other words, the simplification step that presents the most significant degradation of accuracy in this work's case study would even obtain *Direct Validation* using the *ODM* used in Beyer (2016).

While the first two simplification steps still present a considerably high percentage of validated and critical results (88.2% and 82.4% respectively), the validation results from the third simplification step on do present a lack of accuracy exhibiting more than 70% of the results as not validated. The simplification method used as an example in this work, in its settings and under the given circumstances (office buildings in Porto Alegre, Brazil, specific *ODM* qualities), could not be considered as validated if applying 20% as acceptable margin.

Two separate facts are most likely to be the main causes for this degradation: Firstly, with the reduction to a single thermal zone, the buildings floor area is reduced by a tenth (as it had ten floors originally and only one single floor after the simplification). As the already area-normalized output result is used in this work, the representativity of this result is doubtful. Secondly, the internal gains are defined as values per m^2 and with the reduction of the floor area, the simulated gains also reduce by a tenth.

Both problems can be resolved, the first by applying the calculation of Equation 3.2 instead of using the normalized output value, the second by multiplying the values used for internal gains by the number of original floors in order to compensate for the reduced floor area.

It is important to understand each simplification step's impact on the accuracy and validation outcome. This work evaluates the accuracy using two distinct measures: (a) the accuracy degradation and (b) the negative *RV* percentage. The accuracy degradation is measured by the mean value of the step's 17 differences; higher values present less accurate and, therefore, worse results. It is important to understand that each step's result is relative to the original model's outcome and not to the previous step. The negative *RV* percentage is the sum of percentages of critical and failed *RV*.

Figure 5-1 presents both values for each of the six simplification steps.

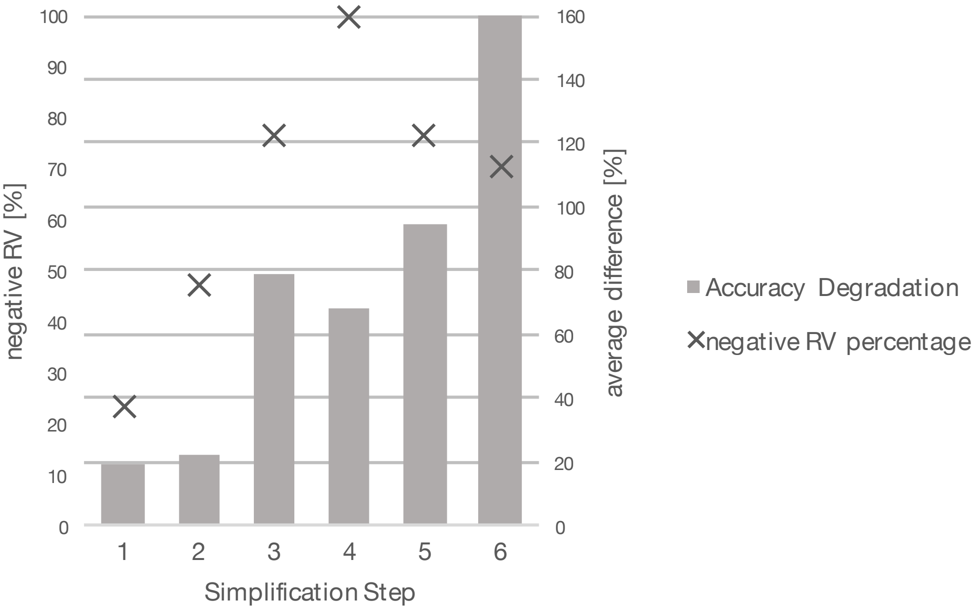


Figure 5-1: Accuracy degradation with respect to *ODM* for each simplification step applied.

From

Figure 5-1 it is possible to conclude that the worst accuracy degradation takes place when applying Zone Squaring, where only the elimination of external obstructions and the material simplification result in degradation with average differences of less than 60% for this work's 17 validation results. Further, it can be noted that there is no direct or linear correlation between the accuracy and the percentage of negative (or positive) *RV* results. Finally,

Figure 5-1 also shows that the worst validation result is obtained in an intermediate step, the final simplified model represents the third-best (or third-worst) validation result, but – with 160% average difference and over 70% of failed RV– is still clearly flawed for the defined task.

Figure 5-2 illustrate an analysis on whether the exemplary simplification steps mounted into the framework are creating a *SIM* still able to present a correct indication whether the executed change of the parameter's value has resulted in an improvement (reduction of energy need) or deterioration (augment of energy need) of the buildings energy performance prediction. This graph presents the percentage of correct indications of directions (improvement or deterioration) of the energy performance. Different from the proposed validation, this measurement has a binary output and represents the most abstract form of validation, but, in some cases, may already be sufficient to aid a decision process. Figure 5-2 presents this measurement for each simplification step and an overall result for all 107 *RV* pairs.

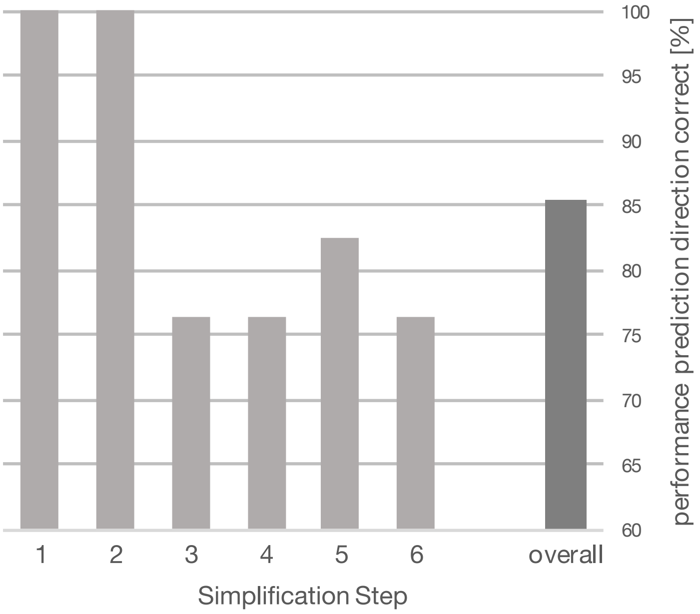


Figure 5-2: Performance prediction direction accuracy

All 34 of the two first simplification steps' validation results correctly predict the energy performance change's direction. Even those ten simplified models (four from the first and six from the second step), that had been categorized as not validated, are able to indicate the correct performance direction. Further, the overall prediction percentage of 85% is rather satisfying.

5.2. Overall Considerations

Aiming at the creation of a framework that supports the generation and test of *SIM*s to integrate energy assessment into *EADS*, the reduction of *the Input Model*'s complexity has been identified as one of the most important issues. When looking at this work's specific objectives the following overall considerations can now be outlined.

The proposed framework presents a detailed description of the procedure to reduce the number of parameters to be taken into consideration, as well as a potentially automatable methodology to create alternative values for the considered parameters; these are important steps towards an architect-friendly *EA* during *EADS*. Applying exemplary simplification steps and using a suggested *assessment* and *output model*, a complete framework had been developed and presented.

The proposed validation methodology can identify whether a suggested *SIM* fulfils the architect's need for accuracy. It may be applied to input models created within *FORwArDS*, but also to methodologies of model simplification from the existent literature and/or future tools.

It has been argued that the existent computational simulation tools for building's energy performance assessment are impacting the architect's accessibility at the early stages of design. The steps laid out in all sub-components of the proposed framework, but specially the creation of a *SIM*, are fully compatible with automation; a correctly created software tool, based on the descriptions given in Chapter 3, would able to create the simplified model from any given iconic (therefore merely geometrical) model (see the sub-section 5.1.2).

The need to report the assessment results back in an adequate manner using the iconic model architects are used to employ during early design stages is stated as the third challenge to overcome for assessment integration. The development of such output is considered out of scope for this work and does highly depend on the situation and circumstances a developed tool would be used for. This work delivers a graphical output example, but a higher degree of integration may arise from developing the output embedded in the iconic representation of the building, for example colouring the faces or volumes according to the results.

When creating a design decision support, the need to contextualize the created assessment result is of the outmost importance. Architects need to understand, if the intended design change is resulting in positive or negative energy consequences, when compared to earlier or alternative design proposals. Comparison already implies the need of at least two results, hence two models. Using the developed methodology to generate alternative value options for parameters used in the input model and *moSAIC* to quickly create *EP* simulation files, this work is providing a functional support for the creation of design decision tools, while maintaining the architects focus on the iconic model.

The lack of integrated tools with enough architect-friendliness is reflected in the rare application of tools in the architectural practices (and schools) around the world. A framework for the development of possible tools and a methodology to validate the reliability of the consequent results have been presented in this work. This represents an important theoretical step towards conceiving buildings thinking about their energy use from the beginning of the design process on. With the identification of the Input Model as interface between user and simulation, between iconic and mathematical model, the need to discuss the creation of tools that obey the needs of the architectural users of developed tools has become necessary, many tools have been developed, but little attention had been directed to the architects' cognitive point of view. This work tackled this existent gap, but there is still a long way to go to optimize the design process using what this work denominated *Certaindipity*.

The development of a validation procedure that tests obtained results of early performance assessment to be used as design support for architects could be seen as one of this work's main contributions. The need to create tools that are reliable or to be able to compare existing tools using a specific benchmark is very important to create better tools, allow the architect to choose the correct tool for his needs and to augment the confidence architects may invest in tools they are using during *EADS*.

5.3. Possible Applications

The embedded adaptability of framework is one of its most important aspects. Most of its already specified steps may be adapted to better fit specific means and goals. This applies to all three components, but specially to those not yet detailed in this work, namely Assessment and *Output Model*.

In this context, this sub-chapter describes examples of the framework's possible applications, highlighting the necessary adjustments with respect to the specifications already made. Three main application areas are identified: (a) educational use, (b) professional use, and (c) scientific use. The following sub-chapters will describe one example for each.

5.3.1. Educational Use

In architectural education projects rarely get to the last stages of executable design drawings where extensive details and building information are available. Educational processes focus on themes to facilitate the student's learning and knowledge fixation processes. *FORwArDS* is fitted to this stage of professional development as it already uses a reduced number of parameters. These can be further adjusted to different discipline objectives and goals.

In the architectural education application of *FORwArDS*, attention has to be directed to the balance between the artistic freedom and abstraction. A playful adaption of an exemplary project throughout the assessment with *FORwArDS* may be useful to create a hands-on experience to test energy impacts after parameter changes on the students' projects.

With the previously described contextualization, throughout confronting the energy assessment's changes, the student could create an awareness or knowledge base for the sensibility of the input parameters with respect to the final project's energy consumption. The *Output Model* would need to be adjusted to fit all assessed changes into one single visualization in order to allow the contextualization of all proposed combinations over the time of the application of *FORwArDS*.

To sum up, the focus of educational applications will lie on the contextualization of changes, either to form awareness of each parameters sensibility, the importance of a set of specific parameters or, in more general terms, to create an awareness for the challenge of energy efficient buildings.

5.3.2. Professional Use

The professional use would aim at reaching a (predefined) energy efficiency goal as fast as possible. Major changes to the framework settings described above would have to: (a) automatically augment the number of explored alternatives in order to expand offered solutions possibly interesting the architect, and (b) alter the output representing the assessment results to facilitate the architects weighting of different alternatives. Possibly an additional step would represent a set of parameter alternative value combinations that satisfy the energy efficiency goal, leaving the choice of the formal (architectural) aspect between those pre-selected by the framework to the architect.

Basically, the professional use is much closer to an optimization process with indicates the best results for the assessment benchmark. *FORwArDS* is adaptable and the integration of a selection mechanism is feasible.

5.3.3. Scientific Use

The proposed framework may be adopted to support extensive research work, *FORwArDS* and the results must be based on an extremely high number of cases.

In this context, the framework would basically be used for its feature of *moSAIC*, enabling the quick creation of a great number of simulation results within a controlled parameter value range. Augmenting, for example, the number of alternative values from 3 (or 4) to 10 for each parameter would create a set of 100.000.000 combinations that could be analysed with statistical tools and would guarantee a sufficient sample set.

In scientific work, the generation of a substantial but reliable set of simulation is necessary to generate conclusive studies about sensitivity and co-relations between parameters. Due to today's computational power and the reduced necessity for real-time responses, the scientific application may dispense the application of simplification steps to enhance the result's reliability. *FORwArDS* permits to create such controlled sets with minor adjustments to the framework setting described above.

5.4. Future Works

From the general conclusions and from the results obtained throughout the exemplary application of the proposed validation procedure, it may follow that future developments of both the framework and the validation methodology are necessary. The following sub-items will describe six main lines of further development of the proposed framework and validation methodology: (a) automation (b) implementation, (c) extended evaluation, (d) extended data analysis, (e) adjustments to the framework, especially to the simplification steps, and (f) adjustments to the validation methodology.

With the description of a framework for a specific building type and a defined region and therefore climate, the re-elaboration of the validation for other combinations could also be a valid complement to the results described here and would allow interesting comparisons and conclusions.

5.4.1. Automation

This line of future work focuses on transforming the described manual procedure into an automated process. This step includes the automated reading of all graphical inputs as given by the architect in the iconic model, the automated transformation of all data into a *SIM* and into a machine-readable format (in this case an .idf-archive) and the automated generation of the output, including the automatic creation of an output for the validation of obtained results.

5.4.2. Implementation

The implementation is somehow bound to the automation but aims at the creation of a software tool that implements the framework and generates a *Graphical User Interface* that allows the architect to model the geometrical inputs and inform the numerical or abstract ones. The automated process would generate the output to be represented using the tool's graphic interface.

5.4.3. Extended Data Analysis

The extended analysis of data makes the creation of a greater and more complete solution space necessary. In other words, this future work would start with the creation of a great number of possible solutions, thus including steps like augmenting the number of alternative values for some or all parameters used in *FORwArDS* and, using *moSAIC*, the creation of all possible combinations of these parameter options.

Different type of scenarios may be tested, everything from detailing a single parameter to thoroughly analyse its importance on the overall outcome (in other words the energy efficiency's sensibility to this parameter) or the equally distributed increase of alternatives throughout the parameters in order to generally analyse whether the created solution space is valuable.

Statistical analysis would be the most indicated manner to generate conclusions from such big sets of output data. A great variety of methodologies and directions of investigation are potentially viable.

5.4.4. Extended Evaluation

This future work includes two directions: (a) the evaluation of the methodologies sensibility and accuracy in additional diverse architectural cases and (b) the evaluation of other integration criteria.

A case study providing further geometrical and architectural changes, such as different footprints, different external obstructions, as well as more alternative values for each of the 8 parameters, would enable a more complete evaluation of the methodology's sensibility and accuracy.

Extended evaluation would increase the complexity of the evaluation regarding the time criteria. This evaluation should necessarily include an experiment with architects, ideally comparing the time spent for modelling and simulation with and without the use of the framework. This evaluation depends on the availability of an automated *FORwArDS* tool-like.

5.4.5. Adjustments to the framework

For framework adjustments (ultimately aiming to reach the validation criteria) it would be necessary to run a specific extended data analysis. This analysis could help to better understand which of the simplification steps had generated the *Relative Validation's* lack of accuracy. Further, it would be necessary to create a wider range of case studies extending the conclusions and checking whether the same behaviour would occur when the original model's characteristics (different footprints, different external obstructions, etc.) are altered.

5.4.6. Adjustments to the validation methodology

With the previous elaboration of extended evaluation, it would also be possible to adjust the validation methodology. While the main concept of Relative Validation would probably remain unaltered, the exact sequence, including the normalization procedure, may proof inadequate or unprecise for a different setting (climate, building type, parameters) or even for other examples of the parameters exemplified in this work (different footprint geometries, window geometries or detail levels of the Original Detailed Model). Specific tests using extended data and extended evaluation results would enable the necessary adjustments.

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APPENDIX

This work's analogue appendix contains the following: an exemplary .idf file, the code for the automatic creation of alternative values, and the pseudo code for the *Semi-Automatic IDF Creator* (*moSAIC*). Further, a Digital Appendix with the following contents can be found on the enclosed DVD: a digital version of this work's text, all simulation files (input and output), the *Microsoft Excel* table used to generate the results, and, finally, the code for the automatic generation of alternative values as well as the pseudo code for the *Semi-Automatic IDF Creator* (*moSAIC*).

APPENDIX A

Appendix A presents the extract of an exemplary .idf input file, representing the *ODM* used in this work's case study. For the complete .idf as well as all other input files consult the Digital Appendix enclosed DVD.

```
!-Generator IDFEditor 1.49
!-Option SortedOrder

!-NOTE: All comments with '!-' are ignored
by   the   IDFEditor   and   are   generated
automatically.
!-      Use '!' comments if they need to be
retained when using the IDFEditor.


!-    ===========   ALL  OBJECTS  IN  CLASS:
VERSION ===========

Version,
    8.7;                            !- Version
Identifier


!-    ===========   ALL  OBJECTS  IN  CLASS:
SIMULATIONCONTROL ===========

SimulationControl,
    Yes,                           !- Do  Zone
Sizing Calculation
    Yes,                         !- Do System
Sizing Calculation
    No,                           !- Do Plant
Sizing Calculation
    Yes,                               !-  Run
Simulation for Sizing Periods
    Yes;                               !-  Run
Simulation for Weather File Run Periods


!-    ===========   ALL  OBJECTS  IN  CLASS:
BUILDING ===========

Building,
    ODM_footprint_1,         !- Name
    90,                 !- North Axis {deg}
    ,                        !- Terrain
    ,                              !-  Loads
Convergence Tolerance Value
    ,                        !- Temperature
Convergence Tolerance Value {deltaC}
    ,                              !-  Solar
Distribution
    ,                            !- Maximum
Number of Warmup Days
```

```
    ;                            !- Minimum
Number of Warmup Days
!-    ===========   ALL  OBJECTS  IN  CLASS:
SHADOWCALCULATION ===========

ShadowCalculation,
    AverageOverDaysInFrequency,          !-
Calculation Method
    20,                      !- Calculation
Frequency
    15000;                       !- Maximum
Figures in Shadow Overlap Calculations


!-    ===========   ALL  OBJECTS  IN  CLASS:
SURFACECONVECTIONALGORITHM:INSIDE
===========

SurfaceConvectionAlgorithm:Inside,
    TARP;                    !- Algorithm


!-    ===========   ALL  OBJECTS  IN  CLASS:
SURFACECONVECTIONALGORITHM:OUTSIDE
===========

SurfaceConvectionAlgorithm:Outside,
    DOE-2;                   !- Algorithm


!-    ===========   ALL  OBJECTS  IN  CLASS:
HEATBALANCEALGORITHM ===========

HeatBalanceAlgorithm,
    ConductionTransferFunction,          !-
Algorithm
    200,                         !- Surface
Temperature Upper Limit {C}
    0.1,                         !- Minimum
Surface    Convection    Heat    Transfer
Coefficient Value {W/m2-K}
    1000;                        !- Maximum
Surface    Convection    Heat    Transfer
Coefficient Value {W/m2-K}


!-    ===========   ALL  OBJECTS  IN  CLASS:
TIMESTEP ===========

Timestep,
    6;                         !- Number of
Timesteps per Hour


!-    ===========   ALL  OBJECTS  IN  CLASS:
CONVERGENCELIMITS ===========

ConvergenceLimits,
    1,                           !- Minimum
System Timestep {minutes}
    20,                          !- Maximum
HVAC Iterations
    2,                           !- Minimum
Plant Iterations
    8;                           !- Maximum
Plant Iterations
```

```
!-    ===========   ALL  OBJECTS  IN  CLASS:
SITE:LOCATION ===========

Site:Location,
    Porto  Alegre  Aero  BRA  WMO=839710,   !-
Name
    -30,                        !- Latitude
{deg}
    -51.18,                    !- Longitude
{deg}
    -3,                        !- Time Zone
{hr}
    3;                         !- Elevation
{m}


!-    ===========   ALL  OBJECTS  IN  CLASS:
SIZINGPERIOD:DESIGNDAY ===========

SizingPeriod:DesignDay,
    Porto  Alegre  Aero  Ann  Clg  .4%  Condns
DB=>MWB,  !- Name
    1,                       !- Month
    21,                           !- Day of
Month
    SummerDesignDay,         !- Day Type
    34.7,                         !- Maximum
Dry-Bulb Temperature {C}
    9.7,                      !- Daily Dry-
Bulb Temperature Range {deltaC}
    DefaultMultipliers,         !-  Dry-Bulb
Temperature Range Modifier Type
    ,                           !- Dry-Bulb
Temperature  Range  Modifier  Day  Schedule
Name
    Wetbulb,                    !- Humidity
Condition Type
    24.6,                     !- Wetbulb or
DewPoint at Maximum Dry-Bulb {C}
    ,                           !- Humidity
Condition Day Schedule Name
    ,                           !- Humidity
Ratio       at       Maximum       Dry-Bulb
{kgWater/kgDryAir}
    ,                        !- Enthalpy at
Maximum Dry-Bulb {J/kg}
    ,                         !- Daily Wet-
Bulb Temperature Range {deltaC}
    101289,                   !- Barometric
Pressure {Pa}
    3.5,                      !- Wind Speed
{m/s}
    300,                             !-  Wind
Direction {deg}
    No,                              !-  Rain
Indicator
    No,                              !-  Snow
Indicator
    No,                         !- Daylight
Saving Time Indicator
    ASHRAETau,               !- Solar Model
Indicator
    ,                         !- Beam Solar
Day Schedule Name
    ,                             !- Diffuse
Solar Day Schedule Name
```

```
    0.4,                         !- ASHRAE
Clear Sky Optical Depth for Beam Irradiance
(taub) {dimensionless}
    2.589;                       !- ASHRAE
Clear  Sky  Optical  Depth  for  Diffuse
Irradiance (taud) {dimensionless}

SizingPeriod:DesignDay,
    Porto Alegre Aero Ann Htg 99.6% Condns
DB,  !- Name
    7,                      !- Month
    21,                          !- Day of
Month
    WinterDesignDay,        !- Day Type
    3.9,                        !- Maximum
Dry-Bulb Temperature {C}
    0,                        !- Daily Dry-
Bulb Temperature Range {deltaC}
    DefaultMultipliers,        !- Dry-Bulb
Temperature Range Modifier Type
    ,                          !- Dry-Bulb
Temperature  Range  Modifier  Day  Schedule
Name
    Wetbulb,                   !- Humidity
Condition Type
    3.9,                      !- Wetbulb or
DewPoint at Maximum Dry-Bulb {C}
    ,                          !- Humidity
Condition Day Schedule Name
    ,                          !- Humidity
Ratio      at      Maximum      Dry-Bulb
{kgWater/kgDryAir}
    ,                       !- Enthalpy at
Maximum Dry-Bulb {J/kg}
    ,                         !- Daily Wet-
Bulb Temperature Range {deltaC}
    101289,                   !- Barometric
Pressure {Pa}
    1,                        !- Wind Speed
{m/s}
    300,                             !- Wind
Direction {deg}
    No,                              !- Rain
Indicator
    No,                              !- Snow
Indicator
    No,                        !- Daylight
Saving Time Indicator
    ASHRAEClearSky,         !- Solar Model
Indicator
    ,                         !- Beam Solar
Day Schedule Name
    ,                            !- Diffuse
Solar Day Schedule Name
    ,                             !- ASHRAE
Clear Sky Optical Depth for Beam Irradiance
(taub) {dimensionless}
    ,                             !- ASHRAE
Clear  Sky  Optical  Depth  for  Diffuse
Irradiance (taud) {dimensionless}
    0;                                !- Sky
Clearness


!-    ===========   ALL  OBJECTS  IN  CLASS:
RUNPERIOD ===========
```

```
RunPeriod,
    rp,                      !- Name
    1,                       !- Begin Month
    1,                         !- Begin Day
of Month
    12,                      !- End Month
    31,                       !- End Day of
Month
    Friday,                  !- Day of Week
for Start Day
    No,                      !- Use Weather
File Holidays and Special Days
    No,                      !- Use Weather
File Daylight Saving Period
    No,                            !- Apply
Weekend Holiday Rule
    No,                      !- Use Weather
File Rain Indicators
    No,                      !- Use Weather
File Snow Indicators
    1;                         !- Number of
Times Runperiod to be Repeated


!-    ===========   ALL  OBJECTS  IN  CLASS:
RUNPERIODCONTROL:SPECIALDAYS ===========

RunPeriodControl:SpecialDays,
    sd1,                     !- Name
    1/1,                     !- Start Date
    1,                          !- Duration
{days}
    Holiday;                 !- Special Day
Type

RunPeriodControl:SpecialDays,
    sd2,                     !- Name
    2/17,                    !- Start Date
    1,                          !- Duration
{days}
    Holiday;                 !- Special Day
Type

RunPeriodControl:SpecialDays,
    sd3,                     !- Name
    4/3,                     !- Start Date
    1,                          !- Duration
{days}
    Holiday;                 !- Special Day
Type

RunPeriodControl:SpecialDays,
    sd4,                     !- Name
    4/21,                    !- Start Date
    1,                          !- Duration
{days}
    Holiday;                 !- Special Day
Type

RunPeriodControl:SpecialDays,
    sd5,                     !- Name
    5/1,                     !- Start Date
    1,                          !- Duration
{days}
    Holiday;                 !- Special Day
Type
```

```
RunPeriodControl:SpecialDays,
    sd6,                     !- Name
    9/7,                     !- Start Date
    1,                          !- Duration
{days}
    Holiday;                 !- Special Day
Type

RunPeriodControl:SpecialDays,
    sd7,                     !- Name
    10/12,                   !- Start Date
    1,                          !- Duration
{days}
    Holiday;                 !- Special Day
Type

RunPeriodControl:SpecialDays,
    sd8,                     !- Name
    11/2,                    !- Start Date
    1,                          !- Duration
{days}
    Holiday;                 !- Special Day
Type

RunPeriodControl:SpecialDays,
    sd9,                     !- Name
    11/15,                   !- Start Date
    1,                          !- Duration
{days}
    Holiday;                 !- Special Day
Type

RunPeriodControl:SpecialDays,
    sd10,                    !- Name
    12/25,                   !- Start Date
    1,                          !- Duration
{days}
    Holiday;                 !- Special Day
Type

RunPeriodControl:SpecialDays,
    sd11,                    !- Name
    9/20,                    !- Start Date
    1,                          !- Duration
{days}
    Holiday;                 !- Special Day
Type

RunPeriodControl:SpecialDays,
    sd12,                    !- Name
    2/2,                     !- Start Date
    1,                          !- Duration
{days}
    Holiday;                 !- Special Day
Type


!-    ===========   ALL  OBJECTS  IN  CLASS:
RUNPERIODCONTROL:DAYLIGHTSAVINGTIME
===========
RunPeriodControl:DaylightSavingTime,
    3rd Sunday in October,   !- Start Date
    3rd Sunday in February;  !- End Date
```

```
!-    ===========   ALL  OBJECTS  IN  CLASS:
SITE:GROUNDTEMPERATURE:BUILDINGSURFACE
===========

Site:GroundTemperature:BuildingSurface,
    22.71,                       !- January
Ground Temperature {C}
    24.27,                      !- February
Ground Temperature {C}
    24.65,                         !- March
Ground Temperature {C}
    24.23,                         !- April
Ground Temperature {C}
    22.00,                    !- May Ground
Temperature {C}
    19.56,                   !- June Ground
Temperature {C}
    17.30,                   !- July Ground
Temperature {C}
    15.69,                        !- August
Ground Temperature {C}
    15.27,                     !- September
Ground Temperature {C}
    16.11,                       !- October
Ground Temperature {C}
    18.02,                      !- November
Ground Temperature {C}
    20.39;                      !- December
Ground Temperature {C}


!-    ===========   ALL  OBJECTS  IN  CLASS:
SITE:GROUNDREFLECTANCE ===========

Site:GroundReflectance,
    0.2,                         !- January
Ground Reflectance {dimensionless}
    0.2,                        !- February
Ground Reflectance {dimensionless}
    0.2,                           !- March
Ground Reflectance {dimensionless}
    0.2,                           !- April
Ground Reflectance {dimensionless}
    0.2,                      !- May Ground
Reflectance {dimensionless}
    0.2,                     !- June Ground
Reflectance {dimensionless}
    0.2,                     !- July Ground
Reflectance {dimensionless}
    0.2,                          !- August
Ground Reflectance {dimensionless}
    0.2,                       !- September
Ground Reflectance {dimensionless}
    0.2,                         !- October
Ground Reflectance {dimensionless}
    0.2,                        !- November
Ground Reflectance {dimensionless}
    0.2;                        !- December
Ground Reflectance {dimensionless}


!-    ===========   ALL  OBJECTS  IN  CLASS:
SCHEDULETYPELIMITS ===========

ScheduleTypeLimits,
    ActivityLevel,           !- Name
```

```
    0,                       !- Lower Limit
Value
    ,                        !- Upper Limit
Value
    Continuous,                  !- Numeric
Type
    activitylevel;           !- Unit Type

ScheduleTypeLimits,
    Control Type,            !- Name
    0,                       !- Lower Limit
Value
    4,                       !- Upper Limit
Value
    DISCRETE;                    !- Numeric
Type

ScheduleTypeLimits,
    Fraction,                !- Name
    0,                       !- Lower Limit
Value
    1,                       !- Upper Limit
Value
    CONTINUOUS;                  !- Numeric
Type

ScheduleTypeLimits,
    Humidity,                !- Name
    10,                      !- Lower Limit
Value
    90,                      !- Upper Limit
Value
    CONTINUOUS;                  !- Numeric
Type

ScheduleTypeLimits,
    On/Off,                  !- Name
    0,                       !- Lower Limit
Value
    1,                       !- Upper Limit
Value
    DISCRETE,                    !- Numeric
Type
    availability;            !- Unit Type

ScheduleTypeLimits,
    Temperature,             !- Name
    -60,                     !- Lower Limit
Value
    200,                     !- Upper Limit
Value
    CONTINUOUS,                  !- Numeric
Type
    temperature;             !- Unit Type

ScheduleTypeLimits,
    Any Number;              !- Name


!-    ===========   ALL  OBJECTS  IN  CLASS:
SCHEDULE:COMPACT ===========

Schedule:Compact,
    Store Lights Schedule,   !- Name
    Fraction,                   !- Schedule
Type Limits Name
    Through: 12/31,          !- Field 1
```

```
    For: Weekdays,           !- Field 2
    Until: 05:00,            !- Field 3
    0.05,                    !- Field 4
    Until: 07:00,            !- Field 5
    0.1,                     !- Field 6
    Until: 08:00,            !- Field 7
    0.3,                     !- Field 8
    Until: 17:00,            !- Field 9
    0.9,                     !- Field 10
    Until: 18:00,            !- Field 11
    0.5,                     !- Field 12
    Until: 20:00,            !- Field 13
    0.3,                     !- Field 14
    Until: 22:00,            !- Field 15
    0.2,                     !- Field 16
    Until: 23:00,            !- Field 17
    0.1,                     !- Field 18
    Until: 24:00,            !- Field 19
    0.05,                    !- Field 20
    For: SummerDesignDay,    !- Field 21
    Until: 24:00,            !- Field 22
    1.0,                     !- Field 23
    For: Saturday,           !- Field 24
    Until: 06:00,            !- Field 25
    0.05,                    !- Field 26
    Until: 08:00,            !- Field 27
    0.1,                     !- Field 28
    Until: 12:00,            !- Field 29
    0.3,                     !- Field 30
    Until: 17:00,            !- Field 31
    0.15,                    !- Field 32
    Until: 24:00,            !- Field 33
    0.05,                    !- Field 34
    For: WinterDesignDay,    !- Field 35
    Until: 24:00,            !- Field 36
    0.0,                     !- Field 37
    For: Sunday Holidays AllOtherDays,   !-
Field 38
    Until: 24:00,            !- Field 39
    0.05;                    !- Field 40

Schedule:Compact,
    Store Equipment Schedule,!- Name
    Fraction,                   !- Schedule
Type Limits Name
    Through: 12/31,          !- Field 1
    For: Weekdays,           !- Field 2
    Until: 08:00,            !- Field 3
    .15,                     !- Field 4
    Until: 12:00,            !- Field 5
    0.90,                    !- Field 6
    Until: 13:00,            !- Field 7
    0.80,                    !- Field 8
    Until: 17:00,            !- Field 9
    0.90,                    !- Field 10
    Until: 18:00,            !- Field 11
    0.50,                    !- Field 12
    Until: 24:00,            !- Field 13
    .15,                     !- Field 14
    For: SummerDesignDay,    !- Field 15
    Until: 24:00,            !- Field 16
    1.0,                     !- Field 17
    For: Saturday,           !- Field 18
    Until: 08:00,            !- Field 19
    .15,                     !- Field 20
    Until: 12:00,            !- Field 21
    .5,                      !- Field 22
```

```
    Until: 13:00,           !- Field 23
    .4,                     !- Field 24
    Until: 17:00,           !- Field 25
    .25,                    !- Field 26
    Until: 24:00,           !- Field 27
    .15,                    !- Field 28
    For: WinterDesignDay,   !- Field 29
    Until: 24:00,           !- Field 30
    0.0,                    !- Field 31
    For: Sunday Holidays AllOtherDays,  !-
Field 32
    Until: 24:00,           !- Field 33
    0.30;                   !- Field 34

Schedule:Compact,
    Store Occupancy Schedule,!- Name
    Fraction,                   !- Schedule
Type Limits Name
    Through: 12/31,         !- Field 1
    For: Weekdays,          !- Field 2
    Until: 06:00,           !- Field 3
    0.0,                    !- Field 4
    Until: 07:00,           !- Field 5
    0,                      !- Field 6
    Until: 08:00,           !- Field 7
    .1,                     !- Field 8
    Until: 10:00,           !- Field 9
    .2,                     !- Field 10
    Until: 12:00,           !- Field 11
    0.5,                    !- Field 12
    Until: 15:00,           !- Field 13
    .7,                     !- Field 14
    Until: 16:00,           !- Field 15
    .8,                     !- Field 16
    Until: 17:00,           !- Field 17
    .7,                     !- Field 18
    Until: 19:00,           !- Field 19
    .5,                     !- Field 20
    Until: 21:00,           !- Field 21
    .3,                     !- Field 22
    Until: 24:00,           !- Field 23
    0,                      !- Field 24
    For: SummerDesignDay,   !- Field 25
    Until: 24:00,           !- Field 26
    0,                      !- Field 27
    For: Saturday,          !- Field 28
    Until: 07:00,           !- Field 29
    0.0,                    !- Field 30
    Until: 08:00,           !- Field 31
    .1,                     !- Field 32
    Until: 09:00,           !- Field 33
    .2,                     !- Field 34
    Until: 10:00,           !- Field 35
    .5,                     !- Field 36
    Until: 11:00,           !- Field 37
    .6,                     !- Field 38
    Until: 17:00,           !- Field 39
    .8,                     !- Field 40
    Until: 18:00,           !- Field 41
    .6,                     !- Field 42
    Until: 21:00,           !- Field 43
    .2,                     !- Field 44
    Until: 22:00,           !- Field 45
    .1,                     !- Field 46
    Until: 24:00,           !- Field 47
    0,                      !- Field 48
    For: WinterDesignDay,   !- Field 49
```

```
    Until: 24:00,            !- Field 50
    0,                       !- Field 51
    For: Sunday Holidays AllOtherDays,   !-
Field 52
    Until: 06:00,            !- Field 53
    0,                       !- Field 54
    Until: 18:00,            !- Field 55
    0,                       !- Field 56
    Until: 24:00,            !- Field 57
    0;                       !- Field 58

Schedule:Compact,
    Always 374,              !- Name
    Any Number,                 !- Schedule
Type Limits Name
    Through: 12/31,          !- Field 1
    For: AllDays,            !- Field 2
    Until: 24:00,            !- Field 3
    374;                     !- Field 4

Schedule:Compact,
    Always Off,              !- Name
    On/Off,                     !- Schedule
Type Limits Name
    Through: 12/31,          !- Field 1
    For: AllDays,            !- Field 2
    Until: 24:00,            !- Field 3
    0.0;                     !- Field 4

Schedule:Compact,
    Always On,               !- Name
    On/Off,                     !- Schedule
Type Limits Name
    Through: 12/31,          !- Field 1
    For: AllDays,            !- Field 2
    Until: 24:00,            !- Field 3
    1.0;                     !- Field 4

Schedule:Compact,
    Cooling Setpoint Schedule,  !- Name
    Temperature,                !- Schedule
Type Limits Name
    Through: 12/31,          !- Field 1
    For:  Weekdays  SummerDesignDay,     !-
Field 2
    Until: 06:00,            !- Field 3
    30.0,                    !- Field 4
    Until: 22:00,            !- Field 5
    24.0,                    !- Field 6
    Until: 24:00,            !- Field 7
    30.0,                    !- Field 8
    For: Saturday,           !- Field 9
    Until: 06:00,            !- Field 10
    30.0,                    !- Field 11
    Until: 18:00,            !- Field 12
    24.0,                    !- Field 13
    Until: 24:00,            !- Field 14
    30.0,                    !- Field 15
    For WinterDesignDay,     !- Field 16
    Until: 24:00,            !- Field 17
    30.0,                    !- Field 18
    For: Sunday Holidays AllOtherDays,   !-
Field 19
    Until: 24:00,            !- Field 20
    30.0;                    !- Field 21

Schedule:Compact,
```

```
    Heating Setpoint Schedule,  !- Name
    Temperature,                !- Schedule
Type Limits Name
    Through: 12/31,          !- Field 1
    For: Weekdays,           !- Field 2
    Until: 05:00,            !- Field 3
    15.6,                    !- Field 4
    Until: 19:00,            !- Field 5
    21.0,                    !- Field 6
    Until: 24:00,            !- Field 7
    15.6,                    !- Field 8
    For SummerDesignDay,     !- Field 9
    Until: 24:00,            !- Field 10
    15.6,                    !- Field 11
    For: Saturday,           !- Field 12
    Until: 06:00,            !- Field 13
    15.6,                    !- Field 14
    Until: 17:00,            !- Field 15
    21.0,                    !- Field 16
    Until: 24:00,            !- Field 17
    15.6,                    !- Field 18
    For: WinterDesignDay,    !- Field 19
    Until: 24:00,            !- Field 20
    21.0,                    !- Field 21
    For: Sunday Holidays AllOtherDays,  !-
Field 22
    Until: 24:00,            !- Field 23
    15.6;                    !- Field 24

Schedule:Compact,
    Hours of Operation Schedule,  !- Name
    On/Off,                     !- Schedule
Type Limits Name
    Through: 12/31,          !- Field 1
    For:  Weekdays  SummerDesignDay,     !-
Field 2
    Until: 08:00,            !- Field 3
    0.0,                     !- Field 4
    Until: 18:00,            !- Field 5
    1.0,                     !- Field 6
    Until: 24:00,            !- Field 7
    0.0,                     !- Field 8
    For:  Saturday  WinterDesignDay,     !-
Field 9
    Until: 08:00,            !- Field 10
    0.0,                     !- Field 11
    Until: 12:00,            !- Field 12
    1.0,                     !- Field 13
    Until: 24:00,            !- Field 14
    0.0,                     !- Field 15
    For: Sunday Holidays AllOtherDays,  !-
Field 16
    Until: 24:00,            !- Field 17
    0.0;                     !- Field 18

Schedule:Compact,
    Infiltration Half On Schedule,  !- Name
    Fraction,                   !- Schedule
Type Limits Name
    Through: 12/31,          !- Field 1
    For:  Weekdays  SummerDesignDay,     !-
Field 2
    Until: 06:00,            !- Field 3
    1.0,                     !- Field 4
    Until: 22:00,            !- Field 5
    0.5,                     !- Field 6
    Until: 24:00,            !- Field 7
```

```
    1.0,                    !- Field 8
    For:  Saturday  WinterDesignDay,    !-
Field 9
    Until: 06:00,           !- Field 10
    1.0,                    !- Field 11
    Until: 18:00,           !- Field 12
    0.5,                    !- Field 13
    Until: 24:00,           !- Field 14
    1.0,                    !- Field 15
    For: Sunday Holidays AllOtherDays,  !-
Field 16
    Until: 24:00,           !- Field 17
    1.0;                    !- Field 18

Schedule:Compact,
    Infiltration Quarter On Schedule,  !-
Name
    Fraction,                  !- Schedule
Type Limits Name
    Through: 12/31,         !- Field 1
    For:  Weekdays  SummerDesignDay,    !-
Field 2
    Until: 06:00,           !- Field 3
    1.0,                    !- Field 4
    Until: 22:00,           !- Field 5
    0.25,                   !- Field 6
    Until: 24:00,           !- Field 7
    1.0,                    !- Field 8
    For:  Saturday  WinterDesignDay,    !-
Field 9
    Until: 06:00,           !- Field 10
    1.0,                    !- Field 11
    Until: 18:00,           !- Field 12
    0.25,                   !- Field 13
    Until: 24:00,           !- Field 14
    1.0,                    !- Field 15
    For: Sunday Holidays AllOtherDays,  !-
Field 16
    Until: 24:00,           !- Field 17
    1.0;                    !- Field 18

Schedule:Compact,
    Infiltration Schedule,  !- Name
    Fraction,                  !- Schedule
Type Limits Name
    Through: 12/31,         !- Field 1
    For:  Weekdays  SummerDesignDay,    !-
Field 2
    Until: 06:00,           !- Field 3
    1.0,                    !- Field 4
    Until: 22:00,           !- Field 5
    0.0,                    !- Field 6
    Until: 24:00,           !- Field 7
    1.0,                    !- Field 8
    For:  Saturday  WinterDesignDay,    !-
Field 9
    Until: 06:00,           !- Field 10
    1.0,                    !- Field 11
    Until: 18:00,           !- Field 12
    0.0,                    !- Field 13
    Until: 24:00,           !- Field 14
    1.0,                    !- Field 15
    For: Sunday Holidays AllOtherDays,  !-
Field 16
    Until: 24:00,           !- Field 17
    1.0;                    !- Field 18
```

```
Schedule:Compact,
    Office Activity Schedule,!- Name
    ActivityLevel,              !- Schedule
Type Limits Name
    Through: 12/31,          !- Field 1
    For: AllDays,            !- Field 2
    Until: 24:00,            !- Field 3
    120.;                    !- Field 4

Schedule:Compact,
    Office Clothing Schedule,!- Name
    Any Number,                 !- Schedule
Type Limits Name
    Through: 04/30,          !- Field 1
    For: AllDays,            !- Field 2
    Until: 24:00,            !- Field 3
    1.0,                     !- Field 4
    Through: 09/30,          !- Field 5
    For: AllDays,            !- Field 6
    Until: 24:00,            !- Field 7
    0.5,                     !- Field 8
    Through: 12/31,          !- Field 9
    For: AllDays,            !- Field 10
    Until: 24:00,            !- Field 11
    1.0;                     !- Field 12

Schedule:Compact,
    Office Equipment Schedule,  !- Name
    Fraction,                   !- Schedule
Type Limits Name
    Through: 12/31,          !- Field 1
    For: Weekdays,           !- Field 2
    Until: 08:00,            !- Field 3
    .15,                     !- Field 4
    Until: 12:00,            !- Field 5
    0.90,                    !- Field 6
    Until: 13:00,            !- Field 7
    0.80,                    !- Field 8
    Until: 17:00,            !- Field 9
    0.90,                    !- Field 10
    Until: 18:00,            !- Field 11
    0.50,                    !- Field 12
    Until: 24:00,            !- Field 13
    .15,                     !- Field 14
    For: SummerDesignDay,    !- Field 15
    Until: 24:00,            !- Field 16
    1.0,                     !- Field 17
    For: Saturday,           !- Field 18
    Until: 08:00,            !- Field 19
    .15,                     !- Field 20
    Until: 12:00,            !- Field 21
    .5,                      !- Field 22
    Until: 13:00,            !- Field 23
    .4,                      !- Field 24
    Until: 17:00,            !- Field 25
    .25,                     !- Field 26
    Until: 24:00,            !- Field 27
    .15,                     !- Field 28
    For: WinterDesignDay,    !- Field 29
    Until: 24:00,            !- Field 30
    0.0,                     !- Field 31
    For: Sunday Holidays AllOtherDays,  !-
Field 32
    Until: 24:00,            !- Field 33
    0.30;                    !- Field 34

Schedule:Compact,
```

```
    Office Lights Schedule,  !- Name
    Fraction,                   !- Schedule
Type Limits Name
    Through: 12/31,          !- Field 1
    For: Weekdays,           !- Field 2
    Until: 05:00,            !- Field 3
    0.05,                    !- Field 4
    Until: 07:00,            !- Field 5
    0.1,                     !- Field 6
    Until: 08:00,            !- Field 7
    0.3,                     !- Field 8
    Until: 17:00,            !- Field 9
    0.9,                     !- Field 10
    Until: 18:00,            !- Field 11
    0.5,                     !- Field 12
    Until: 20:00,            !- Field 13
    0.3,                     !- Field 14
    Until: 22:00,            !- Field 15
    0.2,                     !- Field 16
    Until: 23:00,            !- Field 17
    0.1,                     !- Field 18
    Until: 24:00,            !- Field 19
    0.05,                    !- Field 20
    For: SummerDesignDay,    !- Field 21
    Until: 24:00,            !- Field 22
    1.0,                     !- Field 23
    For: Saturday,           !- Field 24
    Until: 06:00,            !- Field 25
    0.05,                    !- Field 26
    Until: 08:00,            !- Field 27
    0.1,                     !- Field 28
    Until: 12:00,            !- Field 29
    0.3,                     !- Field 30
    Until: 17:00,            !- Field 31
    0.15,                    !- Field 32
    Until: 24:00,            !- Field 33
    0.05,                    !- Field 34
    For: WinterDesignDay,    !- Field 35
    Until: 24:00,            !- Field 36
    0.0,                     !- Field 37
    For: Sunday Holidays AllOtherDays,   !-
Field 38
    Until: 24:00,            !- Field 39
    0.05;                    !- Field 40

Schedule:Compact,
    Office Occupancy Schedule,  !- Name
    Fraction,                   !- Schedule
Type Limits Name
    Through: 12/31,          !- Field 1
    For: Weekdays,           !- Field 2
    Until: 06:00,            !- Field 3
    0.0,                     !- Field 4
    Until: 07:00,            !- Field 5
    0,                       !- Field 6
    Until: 08:00,            !- Field 7
    0,                       !- Field 8
    Until: 12:00,            !- Field 9
    0.95,                    !- Field 10
    Until: 14:00,            !- Field 11
    0.5,                     !- Field 12
    Until: 17:00,            !- Field 13
    0.95,                    !- Field 14
    Until: 18:00,            !- Field 15
    .95,                     !- Field 16
    Until: 20:00,            !- Field 17
    0,                       !- Field 18
```

```
    Until: 24:00,             !- Field 19
    0,                        !- Field 20
    For: SummerDesignDay,     !- Field 21
    Until: 08:00,             !- Field 22
    0.0,                      !- Field 23
    Until: 18:00,             !- Field 24
    1.0,                      !- Field 25
    Until: 24:00,             !- Field 26
    0,                        !- Field 27
    For: Saturday,            !- Field 28
    Until: 06:00,             !- Field 29
    0.0,                      !- Field 30
    Until: 08:00,             !- Field 31
    0,                        !- Field 32
    Until: 12:00,             !- Field 33
    0.3,                      !- Field 34
    Until: 17:00,             !- Field 35
    0,                        !- Field 36
    Until: 19:00,             !- Field 37
    0.0,                      !- Field 38
    Until: 24:00,             !- Field 39
    0.0,                      !- Field 40
    For: WinterDesignDay,     !- Field 41
    Until: 24:00,             !- Field 42
    0.0,                      !- Field 43
    For:  Sunday Holidays AllOtherDays,   !-
Field 44
    Until: 06:00,             !- Field 45
    0.0,                      !- Field 46
    Until: 18:00,             !- Field 47
    0.0,                      !- Field 48
    Until: 24:00,             !- Field 49
    0.0;                      !- Field 50

Schedule:Compact,
    Office Work Eff. Schedule,  !- Name
    Fraction,                    !- Schedule
Type Limits Name
    Through: 12/31,           !- Field 1
    For: AllDays,             !- Field 2
    Until: 24:00,             !- Field 3
    0.0;                      !- Field 4

Schedule:Compact,
    Store Activity Schedule, !- Name
    ActivityLevel,               !- Schedule
Type Limits Name
    Through: 12/31,           !- Field 1
    For: AllDays,             !- Field 2
    Until: 24:00,             !- Field 3
    100;                      !- Field 4


!-    ===========   ALL  OBJECTS  IN  CLASS:
SCHEDULE:CONSTANT ===========

Schedule:Constant,
    Always On Discrete,       !- Name
    On/Off,                      !- Schedule
Type Limits Name
    1;                             !- Hourly
Value

Schedule:Constant,
    Always Off Discrete,      !- Name
    On/Off,                      !- Schedule
Type Limits Name
```

```
    0;                           !- Hourly
Value
Schedule:Constant,
    Always On Continuous,    !- Name
    On/Off,                     !- Schedule
Type Limits Name
    1;                           !- Hourly
Value


!-    ===========   ALL  OBJECTS  IN  CLASS:
MATERIAL ===========

Material,
    F06 EIFS finish,         !- Name
    Smooth,                  !- Roughness
    0.0095,                    !- Thickness
{m}
    0.72,                                 !-
Conductivity {W/m-K}
    1856,                      !- Density
{kg/m3}
    840;                     !- Specific
Heat {J/kg-K}

Material,
    F07 25mm stucco,         !- Name
    Smooth,                  !- Roughness
    0.0254,                    !- Thickness
{m}
    0.72,                                 !-
Conductivity {W/m-K}
    1856,                      !- Density
{kg/m3}
    840;                     !- Specific
Heat {J/kg-K}

[...]
!-    ===========   ALL  OBJECTS  IN  CLASS:
MATERIAL:AIRGAP ===========

[...]

!-    ===========   ALL  OBJECTS  IN  CLASS:
WINDOWMATERIAL:GLAZING ===========

[...]

!-    ===========   ALL  OBJECTS  IN  CLASS:
WINDOWMATERIAL:SHADE ===========

[...]

!-    ===========   ALL  OBJECTS  IN  CLASS:
WINDOWMATERIAL:BLIND ===========

[...]

!-    ===========   ALL  OBJECTS  IN  CLASS:
CONSTRUCTION ===========

Construction,
    DOOR,                    !- Name
    G06  50mm  wood;               !- Outside
Layer

Construction,
```

```
    FLOOR_GROUND,            !- Name
    Brick  -  fired  clay  -  1920  kg/m3  -
300mm,  !- Outside Layer
    M15  200mm  heavyweight  concrete;    !-
Layer 2

Construction,
    FLOOR_INTERIOR,          !- Name
    F16  Acoustic  tile,          !-  Outside
Layer
    F05  Ceiling  air  space  resistance,   !-
Layer 2
    M11  100mm  lightweight  concrete;    !-
Layer 3

Construction,
    FLOOR_INTERIOR Reversed, !- Name
    M11  100mm  lightweight  concrete,    !-
Outside Layer
    F05  Ceiling  air  space  resistance,   !-
Layer 2
    F16 Acoustic tile;       !- Layer 3

Construction,
    FLOOR_TOP,               !- Name
    Clay  tile  -  hollow  -  1  cell  deep  -
75mm,  !- Outside Layer
    F05  Ceiling  air  space  resistance,   !-
Layer 2
    LBP Insulation: Cellular glass - 20mm,
!- Layer 3
    G04 13mm wood;       !- Layer 4

Construction,
    WALL_EXT_01,             !- Name
    LBP  F07  10mm  stucco,        !-  Outside
Layer
    LBP Brick - fired clay - 1920 kg/m3 -
215mm,  !- Layer 2
    LBP F07 10mm stucco;     !- Layer 3

Construction,
    WALL_EXT_02,             !- Name
    LBP  F07  10mm  stucco,        !-  Outside
Layer
    Brick  -  fired  clay  -  1920  kg/m3  -
300mm,  !- Layer 2
    LBP F07 10mm stucco;     !- Layer 3

Construction,
    WALL_INT_01,             !- Name
    G01  16mm  gypsum  board,      !-  Outside
Layer
    F04  Wall  air  space  resistance,    !-
Layer 2
    G01 16mm gypsum board;   !- Layer 3

Construction,
    WALL_INT_01 Reversed,    !- Name
    G01  16mm  gypsum  board,      !-  Outside
Layer
    F04  Wall  air  space  resistance,    !-
Layer 2
    G01 16mm gypsum board;   !- Layer 3

Construction,
    WALL_INT_02,             !- Name
```

```
    G01  16mm  gypsum  board,     !-  Outside
Layer
    Hardboard Medium density,!- Layer 2
    F04  Wall  air  space  resistance,    !-
Layer 3
    Hardboard Medium density,!- Layer 4
    G01 16mm gypsum board;   !- Layer 5

Construction,
    WALL_INT_02 Reversed,    !- Name
    G01  16mm  gypsum  board,     !-  Outside
Layer
    Hardboard Medium density,!- Layer 2
    F04  Wall  air  space  resistance,    !-
Layer 3
    Hardboard Medium density,!- Layer 4
    G01 16mm gypsum board;   !- Layer 5

Construction,
    WINDOW_EXT,              !- Name
    CLEAR 6MM;                   !- Outside
Layer


!-    ===========   ALL  OBJECTS  IN  CLASS:
GLOBALGEOMETRYRULES ===========

GlobalGeometryRules,
    UpperLeftCorner,            !-  Starting
Vertex Position
    Counterclockwise,             !-  Vertex
Entry Direction
    Relative,               !- Coordinate
System
    Relative,              !- Daylighting
Reference Point Coordinate System
    Relative;              !- Rectangular
Surface Coordinate System


!-    ===========   ALL  OBJECTS  IN  CLASS:
ZONE ===========

Zone,
    10PAV_01,                !- Name
    -0,                        !- Direction
of Relative North {deg}
    0,                          !- X Origin
{m}
    0,                          !- Y Origin
{m}
    0;                          !- Z Origin
{m}

Zone,
    10PAV_02,                !- Name
    -0,                        !- Direction
of Relative North {deg}
    0,                          !- X Origin
{m}
    0,                          !- Y Origin
{m}
    0;                          !- Z Origin
{m}

Zone,
    10PAV_03,                !- Name
```

```
    -0,                         !- Direction
of Relative North {deg}
    0,                           !- X Origin
{m}
    0,                           !- Y Origin
{m}
    0;                           !- Z Origin
{m}

Zone,
    10PAV_04,                 !- Name
    -0,                         !- Direction
of Relative North {deg}
    0,                           !- X Origin
{m}
    0,                           !- Y Origin
{m}
    0;                           !- Z Origin
{m}

Zone,
    10PAV_HALL,               !- Name
    -0,                         !- Direction
of Relative North {deg}
    0,                           !- X Origin
{m}
    0,                           !- Y Origin
{m}
    0;                           !- Z Origin
{m}

Zone,
    10PAV_NAO_CONDICIONADA,  !- Name
    -0,                         !- Direction
of Relative North {deg}
    0,                           !- X Origin
{m}
    0,                           !- Y Origin
{m}
    0,                           !- Z Origin
{m}
    ,                         !- Type
    ,                         !- Multiplier
    ,                             !- Ceiling
Height {m}
    ,                         !- Volume {m3}
    ,                          !- Floor Area
{m2}
    ,                         !- Zone Inside
Convection Algorithm
    ,                                !- Zone
Outside Convection Algorithm
    Yes;                        !- Part of
Total Floor Area

Zone,
    1PAV_01,                  !- Name
    -0,                         !- Direction
of Relative North {deg}
    0,                           !- X Origin
{m}
    0,                           !- Y Origin
{m}
    0;                           !- Z Origin
{m}

Zone,
```

```
    1PAV_02,                 !- Name
    -0,                        !- Direction
of Relative North {deg}
    0,                          !- X Origin
{m}
    0,                          !- Y Origin
{m}
    0;                          !- Z Origin
{m}

Zone,
    1PAV_03,                 !- Name
    -0,                        !- Direction
of Relative North {deg}
    0,                          !- X Origin
{m}
    0,                          !- Y Origin
{m}
    0;                          !- Z Origin
{m}

Zone,
    1PAV_HALL,               !- Name
    -0,                        !- Direction
of Relative North {deg}
    0,                          !- X Origin
{m}
    0,                          !- Y Origin
{m}
    0;                          !- Z Origin
{m}

Zone,
    1PAV_NAO_CONDICIONADA,   !- Name
    -0,                        !- Direction
of Relative North {deg}
    0,                          !- X Origin
{m}
    0,                          !- Y Origin
{m}
    0,                          !- Z Origin
{m}
    ,                        !- Type
    ,                        !- Multiplier
    ,                            !- Ceiling
Height {m}
    ,                        !- Volume {m3}
    ,                         !- Floor Area
{m2}
    ,                        !- Zone Inside
Convection Algorithm
    ,                              !- Zone
Outside Convection Algorithm
    Yes;                         !- Part of
Total Floor Area

Zone,
    2PAV_01,                 !- Name
    -0,                        !- Direction
of Relative North {deg}
    0,                          !- X Origin
{m}
    0,                          !- Y Origin
{m}
    0;                          !- Z Origin
{m}
```

```
Zone,
    2PAV_02,                 !- Name
    -0,                        !- Direction
of Relative North {deg}
    0,                          !- X Origin
{m}
    0,                          !- Y Origin
{m}
    0;                          !- Z Origin
{m}

Zone,
    2PAV_03,                 !- Name
    -0,                        !- Direction
of Relative North {deg}
    0,                          !- X Origin
{m}
    0,                          !- Y Origin
{m}
    0;                          !- Z Origin
{m}

Zone,
    2PAV_04,                 !- Name
    -0,                        !- Direction
of Relative North {deg}
    0,                          !- X Origin
{m}
    0,                          !- Y Origin
{m}
    0;                          !- Z Origin
{m}

Zone,
    2PAV_HALL,               !- Name
    -0,                        !- Direction
of Relative North {deg}
    0,                          !- X Origin
{m}
    0,                          !- Y Origin
{m}
    0;                          !- Z Origin
{m}

Zone,
    2PAV_NAO_CONDICIONADA,   !- Name
    -0,                        !- Direction
of Relative North {deg}
    0,                          !- X Origin
{m}
    0,                          !- Y Origin
{m}
    0,                          !- Z Origin
{m}
    ,                        !- Type
    ,                        !- Multiplier
    ,                            !- Ceiling
Height {m}
    ,                        !- Volume {m3}
    ,                         !- Floor Area
{m2}
    ,                        !- Zone Inside
Convection Algorithm
    ,                               !- Zone
Outside Convection Algorithm
    Yes;                        !- Part of
Total Floor Area
```

```
[...]

Zone,
    9PAV_01,                 !- Name
    -0,                        !- Direction
of Relative North {deg}
    0,                          !- X Origin
{m}
    0,                          !- Y Origin
{m}
    0;                          !- Z Origin
{m}

Zone,
    9PAV_02,                 !- Name
    -0,                        !- Direction
of Relative North {deg}
    0,                          !- X Origin
{m}
    0,                          !- Y Origin
{m}
    0;                          !- Z Origin
{m}

Zone,
    9PAV_03,                 !- Name
    -0,                        !- Direction
of Relative North {deg}
    0,                          !- X Origin
{m}
    0,                          !- Y Origin
{m}
    0;                          !- Z Origin
{m}

Zone,
    9PAV_04,                 !- Name
    -0,                        !- Direction
of Relative North {deg}
    0,                          !- X Origin
{m}
    0,                          !- Y Origin
{m}
    0;                          !- Z Origin
{m}

Zone,
    9PAV_HALL,               !- Name
    -0,                        !- Direction
of Relative North {deg}
    0,                          !- X Origin
{m}
    0,                          !- Y Origin
{m}
    0;                          !- Z Origin
{m}

Zone,
    9PAV_NAO_CONDICIONADA,   !- Name
    -0,                        !- Direction
of Relative North {deg}
    0,                          !- X Origin
{m}
    0,                          !- Y Origin
{m}
```

```
    0,                          !- Z Origin
{m}
    ,                       !- Type
    ,                       !- Multiplier
    ,                           !- Ceiling
Height {m}
    ,                       !- Volume {m3}
    ,                        !- Floor Area
{m2}
    ,                       !- Zone Inside
Convection Algorithm
    ,                              !- Zone
Outside Convection Algorithm
    Yes;                        !- Part of
Total Floor Area


!-    ===========   ALL  OBJECTS  IN  CLASS:
ZONELIST ===========

ZoneList,
    stores,                 !- Name
    1PAV_01,                !- Zone 1 Name
    1PAV_02,                !- Zone 2 Name
    1PAV_03;                !- Zone 3 Name

ZoneList,
    offices,                !- Name
    10PAV_01,               !- Zone 1 Name
    10PAV_02,               !- Zone 2 Name
    10PAV_03,               !- Zone 3 Name
    10PAV_04,               !- Zone 4 Name
    2PAV_01,                !- Zone 5 Name
    2PAV_02,                !- Zone 6 Name
    2PAV_03,                !- Zone 7 Name
    2PAV_04,                !- Zone 8 Name
    3PAV_01,                !- Zone 9 Name
    3PAV_02,                    !-  Zone  10
Name
    3PAV_03,                    !-  Zone  11
Name
    3PAV_04,                    !-  Zone  12
Name
    4PAV_01,                    !-  Zone  13
Name
    4PAV_02,                    !-  Zone  14
Name
    4PAV_03,                    !-  Zone  15
Name
    4PAV_04,                    !-  Zone  16
Name
    5PAV_01,                    !-  Zone  17
Name
    5PAV_02,                    !-  Zone  18
Name
    5PAV_03,                    !-  Zone  19
Name
    5PAV_04,                    !-  Zone  20
Name
    6PAV_01,                    !-  Zone  21
Name
    6PAV_02,                    !-  Zone  22
Name
    6PAV_03,                    !-  Zone  23
Name
    6PAV_04,                    !-  Zone  24
Name
```

```
    7PAV_01,                    !-  Zone  25
Name
    7PAV_02,                    !-  Zone  26
Name
    7PAV_03,                    !-  Zone  27
Name
    7PAV_04,                    !-  Zone  28
Name
    8PAV_01,                    !-  Zone  29
Name
    8PAV_02,                    !-  Zone  30
Name
    8PAV_03,                    !-  Zone  31
Name
    8PAV_04,                    !-  Zone  32
Name
    9PAV_01,                    !-  Zone  33
Name
    9PAV_02,                    !-  Zone  34
Name
    9PAV_03,                    !-  Zone  35
Name
    9PAV_04;                    !-  Zone  36
Name

ZoneList,
    halls,                  !- Name
    10PAV_HALL,             !- Zone 1 Name
    1PAV_HALL,              !- Zone 2 Name
    2PAV_HALL,              !- Zone 3 Name
    3PAV_HALL,              !- Zone 4 Name
    4PAV_HALL,              !- Zone 5 Name
    5PAV_HALL,              !- Zone 6 Name
    6PAV_HALL,              !- Zone 7 Name
    7PAV_HALL,              !- Zone 8 Name
    8PAV_HALL,              !- Zone 9 Name
    9PAV_HALL;                  !-  Zone  10
Name

ZoneList,
    NC,                     !- Name
    10PAV_NAO_CONDICIONADA,  !- Zone 1 Name
    1PAV_NAO_CONDICIONADA,   !- Zone 2 Name
    2PAV_NAO_CONDICIONADA,   !- Zone 3 Name
    3PAV_NAO_CONDICIONADA,   !- Zone 4 Name
    4PAV_NAO_CONDICIONADA,   !- Zone 5 Name
    5PAV_NAO_CONDICIONADA,   !- Zone 6 Name
    6PAV_NAO_CONDICIONADA,   !- Zone 7 Name
    7PAV_NAO_CONDICIONADA,   !- Zone 8 Name
    8PAV_NAO_CONDICIONADA,   !- Zone 9 Name
    9PAV_NAO_CONDICIONADA;      !-  Zone  10
Name


!-    ===========   ALL  OBJECTS  IN  CLASS:
BUILDINGSURFACE:DETAILED ===========

BuildingSurface:Detailed,
    aim19519 Reversed,      !- Name
    Floor,                      !-  Surface
Type
    FLOOR_INTERIOR       Reversed,       !-
Construction Name
    10PAV_01,               !- Zone Name
    Surface,                    !-  Outside
Boundary Condition
```

```
    aim19519,                    !-  Outside
Boundary Condition Object
    NoSun,                           !-  Sun
Exposure
    NoWind,                         !-  Wind
Exposure
    ,                         !- View Factor
to Ground
    ,                           !- Number of
Vertices
    -5.420402,                !- Vertex 1 X-
coordinate {m}
    16.9017,                  !- Vertex 1 Y-
coordinate {m}
    35.1,                     !- Vertex 1 Z-
coordinate {m}
    -5.420402,                !- Vertex 2 X-
coordinate {m}
    11.30171,                 !- Vertex 2 Y-
coordinate {m}
    35.1,                     !- Vertex 2 Z-
coordinate {m}
    -7.170402,                !- Vertex 3 X-
coordinate {m}
    11.30171,                 !- Vertex 3 Y-
coordinate {m}
    35.1,                     !- Vertex 3 Z-
coordinate {m}
    -7.170402,                !- Vertex 4 X-
coordinate {m}
    6.901706,                 !- Vertex 4 Y-
coordinate {m}
    35.1,                     !- Vertex 4 Z-
coordinate {m}
    -15.4204,                 !- Vertex 5 X-
coordinate {m}
    6.901706,                 !- Vertex 5 Y-
coordinate {m}
    35.1,                     !- Vertex 5 Z-
coordinate {m}
    -15.4204,                 !- Vertex 6 X-
coordinate {m}
    14.97671,                 !- Vertex 6 Y-
coordinate {m}
    35.1,                     !- Vertex 6 Z-
coordinate {m}
    -13.4954,                 !- Vertex 7 X-
coordinate {m}
    14.97671,                 !- Vertex 7 Y-
coordinate {m}
    35.1,                     !- Vertex 7 Z-
coordinate {m}
    -13.4954,                 !- Vertex 8 X-
coordinate {m}
    16.9017,                  !- Vertex 8 Y-
coordinate {m}
    35.1;                     !- Vertex 8 Z-
coordinate {m}

BuildingSurface:Detailed,
    aim20207 Reversed,       !- Name
    Wall,                        !-  Surface
Type
    WALL_INT_01   Reversed,              !-
Construction Name
    10PAV_01,                !- Zone Name
```

```
    Surface,                    !- Outside
Boundary Condition
    aim20207,                   !- Outside
Boundary Condition Object
    NoSun,                          !- Sun
Exposure
    NoWind,                        !- Wind
Exposure
    ,                       !- View Factor
to Ground
    ,                         !- Number of
Vertices
    -5.420402,              !- Vertex 1 X-
coordinate {m}
    13.02668,               !- Vertex 1 Y-
coordinate {m}
    39,                     !- Vertex 1 Z-
coordinate {m}
    -5.420402,              !- Vertex 2 X-
coordinate {m}
    13.02668,               !- Vertex 2 Y-
coordinate {m}
    35.1,                   !- Vertex 2 Z-
coordinate {m}
    -5.420402,              !- Vertex 3 X-
coordinate {m}
    15.32671,               !- Vertex 3 Y-
coordinate {m}
    35.1,                   !- Vertex 3 Z-
coordinate {m}
    -5.420402,              !- Vertex 4 X-
coordinate {m}
    15.32671,               !- Vertex 4 Y-
coordinate {m}
    39;                     !- Vertex 4 Z-
coordinate {m}


[...]

!-    ===========   ALL  OBJECTS  IN  CLASS:
FENESTRATIONSURFACE:DETAILED ===========

FenestrationSurface:Detailed,
    aim20690,               !- Name
    Window,                     !- Surface
Type
    WINDOW_EXT,                         !-
Construction Name
    aim20679,                  !- Building
Surface Name
    ,                           !- Outside
Boundary Condition Object
    ,                       !- View Factor
to Ground
    ,                           !- Shading
Control Name
    ,                         !- Frame and
Divider Name
    ,                       !- Multiplier
    ,                         !- Number of
Vertices
    -15.4204,               !- Vertex 1 X-
coordinate {m}
    10.72671,               !- Vertex 1 Y-
coordinate {m}
```

```
    37.2,                    !- Vertex 1 Z-
coordinate {m}
    -15.4204,                !- Vertex 2 X-
coordinate {m}
    10.72671,                !- Vertex 2 Y-
coordinate {m}
    36.2,                    !- Vertex 2 Z-
coordinate {m}
    -15.4204,                !- Vertex 3 X-
coordinate {m}
    8.226706,                !- Vertex 3 Y-
coordinate {m}
    36.2,                    !- Vertex 3 Z-
coordinate {m}
    -15.4204,                !- Vertex 4 X-
coordinate {m}
    8.226706,                !- Vertex 4 Y-
coordinate {m}
    37.2;                    !- Vertex 4 Z-
coordinate {m}

FenestrationSurface:Detailed,
    aim20733,               !- Name
    Window,                     !- Surface
Type
    WINDOW_EXT,                          !-
Construction Name
    aim20722,                  !- Building
Surface Name
    ,                           !- Outside
Boundary Condition Object
    ,                        !- View Factor
to Ground
    ,                           !- Shading
Control Name
    ,                         !- Frame and
Divider Name
    ,                       !- Multiplier
    ,                         !- Number of
Vertices
    -10.4454,                !- Vertex 1 X-
coordinate {m}
    16.9017,                 !- Vertex 1 Y-
coordinate {m}
    37.2,                    !- Vertex 1 Z-
coordinate {m}
    -10.4454,                !- Vertex 2 X-
coordinate {m}
    16.9017,                 !- Vertex 2 Y-
coordinate {m}
    36.2,                    !- Vertex 2 Z-
coordinate {m}
    -12.9454,                !- Vertex 3 X-
coordinate {m}
    16.9017,                 !- Vertex 3 Y-
coordinate {m}
    36.2,                    !- Vertex 3 Z-
coordinate {m}
    -12.9454,                !- Vertex 4 X-
coordinate {m}
    16.9017,                 !- Vertex 4 Y-
coordinate {m}
    37.2;                    !- Vertex 4 Z-
coordinate {m}


[...]
```

```
!-    ===========   ALL  OBJECTS  IN  CLASS:
INTERNALMASS ===========

InternalMass,
    Merged  aim20195  -  aim20195  Reversed,
!- Name
    WALL_INT_02,                         !-
Construction Name
    10PAV_NAO_CONDICIONADA,  !- Zone Name
    19.50000078;                 !- Surface
Area {m2}

InternalMass,
    Merged  aim20219  -  aim20219  Reversed,
!- Name
    WALL_INT_02,                         !-
Construction Name
    10PAV_NAO_CONDICIONADA,  !- Zone Name
    9.75;                        !- Surface
Area {m2}

InternalMass,
    Merged  aim20231  -  aim20231  Reversed,
!- Name
    WALL_INT_02,                         !-
Construction Name
    10PAV_NAO_CONDICIONADA,  !- Zone Name
    9.75000078;                  !- Surface
Area {m2}

InternalMass,
    Merged  aim20417  -  aim20417  Reversed,
!- Name
    WALL_INT_01,                         !-
Construction Name
    10PAV_NAO_CONDICIONADA,  !- Zone Name
    7.5075;                      !- Surface
Area {m2}

InternalMass,
    Merged  aim21049  -  aim21049  Reversed,
!- Name
    WALL_INT_02,                         !-
Construction Name
    10PAV_NAO_CONDICIONADA,  !- Zone Name
    6.727383;                    !- Surface
Area {m2}

InternalMass,
    Merged aim8553 - aim8553 Reversed,   !-
Name
    WALL_INT_01,                         !-
Construction Name
    1PAV_NAO_CONDICIONADA,   !- Zone Name
    7.5075;                      !- Surface
Area {m2}

InternalMass,
    Merged aim8807 - aim8807 Reversed,   !-
Name
    WALL_INT_02,                         !-
Construction Name
    1PAV_NAO_CONDICIONADA,   !- Zone Name
    19.50000078;                 !- Surface
Area {m2}
```

```
InternalMass,
    Merged aim9572 - aim9572 Reversed,  !-
Name
    WALL_INT_02,                        !-
Construction Name
    1PAV_NAO_CONDICIONADA,   !- Zone Name
    9.75;                        !- Surface
Area {m2}

InternalMass,
    Merged aim9584 - aim9584 Reversed,  !-
Name
    WALL_INT_02,                        !-
Construction Name
    1PAV_NAO_CONDICIONADA,   !- Zone Name
    9.75000078;                  !- Surface
Area {m2}

InternalMass,
    Merged aim9619 - aim9619 Reversed,  !-
Name
    WALL_INT_02,                        !-
Construction Name
    1PAV_NAO_CONDICIONADA,   !- Zone Name
    6.727383;                    !- Surface
Area {m2}

InternalMass,
    Merged  aim10528  -  aim10528  Reversed,
!- Name
    WALL_INT_02,                        !-
Construction Name
    2PAV_NAO_CONDICIONADA,   !- Zone Name
    6.727383;                    !- Surface
Area {m2}

InternalMass,
    Merged aim9666 - aim9666 Reversed,  !-
Name
    WALL_INT_02,                        !-
Construction Name
    2PAV_NAO_CONDICIONADA,   !- Zone Name
    19.50000078;                 !- Surface
Area {m2}

InternalMass,
    Merged aim9690 - aim9690 Reversed,  !-
Name
    WALL_INT_02,                        !-
Construction Name
    2PAV_NAO_CONDICIONADA,   !- Zone Name
    9.75;                        !- Surface
Area {m2}

InternalMass,
    Merged aim9702 - aim9702 Reversed,  !-
Name
    WALL_INT_02,                        !-
Construction Name
    2PAV_NAO_CONDICIONADA,   !- Zone Name
    9.75000078;                  !- Surface
Area {m2}

InternalMass,
    Merged aim9890 - aim9890 Reversed,  !-
Name
```

```
    WALL_INT_01,                       !-
Construction Name
    2PAV_NAO_CONDICIONADA,   !- Zone Name
    7.5075;                      !- Surface
Area {m2}

InternalMass,
    Merged  aim10979  -  aim10979  Reversed,
!- Name
    WALL_INT_02,                       !-
Construction Name
    3PAV_NAO_CONDICIONADA,   !- Zone Name
    19.50000078;                 !- Surface
Area {m2}

InternalMass,
    Merged  aim11003  -  aim11003  Reversed,
!- Name
    WALL_INT_02,                       !-
Construction Name
    3PAV_NAO_CONDICIONADA,   !- Zone Name
    9.75;                        !- Surface
Area {m2}

InternalMass,
    Merged  aim11015  -  aim11015  Reversed,
!- Name
    WALL_INT_02,                       !-
Construction Name
    3PAV_NAO_CONDICIONADA,   !- Zone Name
    9.75000078;                  !- Surface
Area {m2}

InternalMass,
    Merged  aim11203  -  aim11203  Reversed,
!- Name
    WALL_INT_01,                       !-
Construction Name
    3PAV_NAO_CONDICIONADA,   !- Zone Name
    7.5075;                      !- Surface
Area {m2}

InternalMass,
    Merged  aim11841  -  aim11841  Reversed,
!- Name
    WALL_INT_02,                       !-
Construction Name
    3PAV_NAO_CONDICIONADA,   !- Zone Name
    6.727383;                    !- Surface
Area {m2}

InternalMass,
    Merged  aim12294  -  aim12294  Reversed,
!- Name
    WALL_INT_02,                       !-
Construction Name
    4PAV_NAO_CONDICIONADA,   !- Zone Name
    19.50000078;                 !- Surface
Area {m2}

InternalMass,
    Merged  aim12318  -  aim12318  Reversed,
!- Name
    WALL_INT_02,                       !-
Construction Name
    4PAV_NAO_CONDICIONADA,   !- Zone Name
```

```
    9.75;                        !- Surface
Area {m2}

InternalMass,
    Merged  aim12330  -  aim12330  Reversed,
!- Name
    WALL_INT_02,                         !-
Construction Name
    4PAV_NAO_CONDICIONADA,   !- Zone Name
    9.75000078;                  !- Surface
Area {m2}

InternalMass,
    Merged  aim12518  -  aim12518  Reversed,
!- Name
    WALL_INT_01,                         !-
Construction Name
    4PAV_NAO_CONDICIONADA,   !- Zone Name
    7.5075;                      !- Surface
Area {m2}

InternalMass,
    Merged  aim13156  -  aim13156  Reversed,
!- Name
    WALL_INT_02,                         !-
Construction Name
    4PAV_NAO_CONDICIONADA,   !- Zone Name
    6.727383;                    !- Surface
Area {m2}

InternalMass,
    Merged  aim13609  -  aim13609  Reversed,
!- Name
    WALL_INT_02,                         !-
Construction Name
    5PAV_NAO_CONDICIONADA,   !- Zone Name
    19.50000078;                 !- Surface
Area {m2}

InternalMass,
    Merged  aim13633  -  aim13633  Reversed,
!- Name
    WALL_INT_02,                         !-
Construction Name
    5PAV_NAO_CONDICIONADA,   !- Zone Name
    9.75;                        !- Surface
Area {m2}

InternalMass,
    Merged  aim13645  -  aim13645  Reversed,
!- Name
    WALL_INT_02,                         !-
Construction Name
    5PAV_NAO_CONDICIONADA,   !- Zone Name
    9.75000078;                  !- Surface
Area {m2}

InternalMass,
    Merged  aim13833  -  aim13833  Reversed,
!- Name
    WALL_INT_01,                         !-
Construction Name
    5PAV_NAO_CONDICIONADA,   !- Zone Name
    7.5075;                      !- Surface
Area {m2}

InternalMass,
```

```
    Merged  aim14471  -  aim14471  Reversed,
!- Name
    WALL_INT_02,                          !-
Construction Name
    5PAV_NAO_CONDICIONADA,   !- Zone Name
    6.727383;                    !-  Surface
Area {m2}

InternalMass,
    Merged  aim14924  -  aim14924  Reversed,
!- Name
    WALL_INT_02,                          !-
Construction Name
    6PAV_NAO_CONDICIONADA,   !- Zone Name
    19.50000078;                 !-  Surface
Area {m2}

InternalMass,
    Merged  aim14948  -  aim14948  Reversed,
!- Name
    WALL_INT_02,                          !-
Construction Name
    6PAV_NAO_CONDICIONADA,   !- Zone Name
    9.75;                        !-  Surface
Area {m2}

InternalMass,
    Merged  aim14960  -  aim14960  Reversed,
!- Name
    WALL_INT_02,                          !-
Construction Name
    6PAV_NAO_CONDICIONADA,   !- Zone Name
    9.75000078;                  !-  Surface
Area {m2}

InternalMass,
    Merged  aim15148  -  aim15148  Reversed,
!- Name
    WALL_INT_01,                          !-
Construction Name
    6PAV_NAO_CONDICIONADA,   !- Zone Name
    7.5075;                      !-  Surface
Area {m2}

InternalMass,
    Merged  aim15786  -  aim15786  Reversed,
!- Name
    WALL_INT_02,                          !-
Construction Name
    6PAV_NAO_CONDICIONADA,   !- Zone Name
    6.727383;                    !-  Surface
Area {m2}

InternalMass,
    Merged  aim16239  -  aim16239  Reversed,
!- Name
    WALL_INT_02,                          !-
Construction Name
    7PAV_NAO_CONDICIONADA,   !- Zone Name
    19.50000078;                 !-  Surface
Area {m2}

InternalMass,
    Merged  aim16263  -  aim16263  Reversed,
!- Name
    WALL_INT_02,                          !-
Construction Name
```

```
    7PAV_NAO_CONDICIONADA,   !- Zone Name
    9.75000000000001;            !- Surface
Area {m2}

InternalMass,
    Merged  aim16275  -  aim16275  Reversed,
!- Name
    WALL_INT_02,                           !-
Construction Name
    7PAV_NAO_CONDICIONADA,   !- Zone Name
    9.75000078000001;            !- Surface
Area {m2}

InternalMass,
    Merged  aim16463  -  aim16463  Reversed,
!- Name
    WALL_INT_01,                           !-
Construction Name
    7PAV_NAO_CONDICIONADA,   !- Zone Name
    7.50750000000001;            !- Surface
Area {m2}

InternalMass,
    Merged  aim17101  -  aim17101  Reversed,
!- Name
    WALL_INT_02,                           !-
Construction Name
    7PAV_NAO_CONDICIONADA,   !- Zone Name
    6.72738300000001;            !- Surface
Area {m2}

InternalMass,
    Merged  aim17554  -  aim17554  Reversed,
!- Name
    WALL_INT_02,                           !-
Construction Name
    8PAV_NAO_CONDICIONADA,   !- Zone Name
    19.50000078;                 !- Surface
Area {m2}

InternalMass,
    Merged  aim17578  -  aim17578  Reversed,
!- Name
    WALL_INT_02,                           !-
Construction Name
    8PAV_NAO_CONDICIONADA,   !- Zone Name
    9.75;                        !- Surface
Area {m2}

InternalMass,
    Merged  aim17590  -  aim17590  Reversed,
!- Name
    WALL_INT_02,                           !-
Construction Name
    8PAV_NAO_CONDICIONADA,   !- Zone Name
    9.75000078;                  !- Surface
Area {m2}

InternalMass,
    Merged  aim17778  -  aim17778  Reversed,
!- Name
    WALL_INT_01,                           !-
Construction Name
    8PAV_NAO_CONDICIONADA,   !- Zone Name
    7.5075;                      !- Surface
Area {m2}
```

```
InternalMass,
    Merged  aim18416  -  aim18416  Reversed,
!- Name
    WALL_INT_02,                          !-
Construction Name
    8PAV_NAO_CONDICIONADA,   !- Zone Name
    6.727383;                    !- Surface
Area {m2}

InternalMass,
    Merged  aim18869  -  aim18869  Reversed,
!- Name
    WALL_INT_02,                          !-
Construction Name
    9PAV_NAO_CONDICIONADA,   !- Zone Name
    19.50000078;                 !- Surface
Area {m2}

InternalMass,
    Merged  aim18893  -  aim18893  Reversed,
!- Name
    WALL_INT_02,                          !-
Construction Name
    9PAV_NAO_CONDICIONADA,   !- Zone Name
    9.75000000000001;            !- Surface
Area {m2}

InternalMass,
    Merged  aim18905  -  aim18905  Reversed,
!- Name
    WALL_INT_02,                          !-
Construction Name
    9PAV_NAO_CONDICIONADA,   !- Zone Name
    9.75000078000001;            !- Surface
Area {m2}
InternalMass,
    Merged  aim19093  -  aim19093  Reversed,
!- Name
    WALL_INT_01,                          !-
Construction Name
    9PAV_NAO_CONDICIONADA,   !- Zone Name
    7.50750000000001;            !- Surface
Area {m2}

InternalMass,
    Merged  aim19731  -  aim19731  Reversed,
!- Name
    WALL_INT_02,                          !-
Construction Name
    9PAV_NAO_CONDICIONADA,   !- Zone Name
    6.72738300000001;            !- Surface
Area {m2}


!-    ===========   ALL  OBJECTS  IN  CLASS:
SHADING:BUILDING:DETAILED ===========

Shading:Building:Detailed,
    Shading Surface 1,       !- Name
    ,                                     !-
Transmittance Schedule Name
    ,                            !- Number of
Vertices
    9.329598,                !- Vertex 1 X-
coordinate {m}
    16.9017,                 !- Vertex 1 Y-
coordinate {m}
```

```
    2.1,                    !- Vertex 1 Z-
coordinate {m}
    9.329598,               !- Vertex 2 X-
coordinate {m}
    16.9017,                !- Vertex 2 Y-
coordinate {m}
    1.5,                    !- Vertex 2 Z-
coordinate {m}
    9.329598,               !- Vertex 3 X-
coordinate {m}
    17.0017,                !- Vertex 3 Y-
coordinate {m}
    1.5,                    !- Vertex 3 Z-
coordinate {m}
    9.329598,               !- Vertex 4 X-
coordinate {m}
    17.0017,                !- Vertex 4 Y-
coordinate {m}
    2.1;                    !- Vertex 4 Z-
coordinate {m}

Shading:Building:Detailed,
    Shading Surface 10,     !- Name
    ,                                   !-
Transmittance Schedule Name
    ,                         !- Number of
Vertices
    7.829598,               !- Vertex 1 X-
coordinate {m}
    16.9017,                !- Vertex 1 Y-
coordinate {m}
    6,                      !- Vertex 1 Z-
coordinate {m}
    7.829598,               !- Vertex 2 X-
coordinate {m}
    16.9017,                !- Vertex 2 Y-
coordinate {m}
    5.4,                    !- Vertex 2 Z-
coordinate {m}
    7.829598,               !- Vertex 3 X-
coordinate {m}
    17.0017,                !- Vertex 3 Y-
coordinate {m}
    5.4,                    !- Vertex 3 Z-
coordinate {m}
    7.829598,               !- Vertex 4 X-
coordinate {m}
    17.0017,                !- Vertex 4 Y-
coordinate {m}
    6;                      !- Vertex 4 Z-
coordinate {m}

[...]

!-    ===========   ALL  OBJECTS  IN  CLASS:
PEOPLE ===========

People,
    people_01,              !- Name
    stores,                     !- Zone or
ZoneList Name
    Office  Occupancy  Schedule,   !-  Number
of People Schedule Name
    Area/Person,              !- Number of
People Calculation Method
    ,                         !- Number of
People
```

```
    ,                        !- People per
Zone Floor Area {person/m2}
    2,                       !- Zone Floor
Area per Person {m2/person}
    0.3,                       !- Fraction
Radiant
    autocalculate,             !- Sensible
Heat Fraction
    Store  Activity  Schedule,  !-  Activity
Level Schedule Name
    0.0000000382,                !-  Carbon
Dioxide Generation Rate {m3/s-W}
    No,                          !- Enable
ASHRAE 55 Comfort Warnings
    ZoneAveraged,                  !-  Mean
Radiant Temperature Calculation Type
    ,                           !- Surface
Name/Angle Factor List Name
    ,                              !- Work
Efficiency Schedule Name
    ClothingInsulationSchedule;          !-
Clothing Insulation Calculation Method

People,
    people_02,              !- Name
    offices,                   !- Zone or
ZoneList Name
    Office  Occupancy  Schedule,   !-  Number
of People Schedule Name
    Area/Person,              !- Number of
People Calculation Method
    ,                         !- Number of
People
    ,                        !- People per
Zone Floor Area {person/m2}
    11.6,                    !- Zone Floor
Area per Person {m2/person}
    0.3,                       !- Fraction
Radiant
    autocalculate,             !- Sensible
Heat Fraction
    Office  Activity  Schedule,!-  Activity
Level Schedule Name
    0.0000000382,                !-  Carbon
Dioxide Generation Rate {m3/s-W}
    No,                          !- Enable
ASHRAE 55 Comfort Warnings
    ZoneAveraged,                  !-  Mean
Radiant Temperature Calculation Type
    ,                           !- Surface
Name/Angle Factor List Name
    ,                              !- Work
Efficiency Schedule Name
    ClothingInsulationSchedule;          !-
Clothing Insulation Calculation Method

People,
    people_03,              !- Name
    halls,                     !- Zone or
ZoneList Name
    Office  Occupancy  Schedule,   !-  Number
of People Schedule Name
    Area/Person,              !- Number of
People Calculation Method
    ,                         !- Number of
People
```

```
    ,                             !- People per
Zone Floor Area {person/m2}
    11.6,                         !- Zone Floor
Area per Person {m2/person}
    0.3,                            !- Fraction
Radiant
    autocalculate,                  !- Sensible
Heat Fraction
    Office  Activity  Schedule,!-  Activity
Level Schedule Name
    0.0000000382,                     !- Carbon
Dioxide Generation Rate {m3/s-W}
    No,                               !- Enable
ASHRAE 55 Comfort Warnings
    ZoneAveraged,                       !- Mean
Radiant Temperature Calculation Type
    ,                                !- Surface
Name/Angle Factor List Name
    ,                                   !- Work
Efficiency Schedule Name
    ClothingInsulationSchedule;           !-
Clothing Insulation Calculation Method


!-    ===========   ALL  OBJECTS  IN  CLASS:
LIGHTS ===========

Lights,
    lights_01,               !- Name
    stores,                      !- Zone or
ZoneList Name
    Store  Lights  Schedule,     !-  Schedule
Name
    Watts/Area,                    !-  Design
Level Calculation Method
    ,                               !- Lighting
Level {W}
    18.1,                         !- Watts per
Zone Floor Area {W/m2}
    ,                             !- Watts per
Person {W/person}
    ,                             !- Return Air
Fraction
    ,                               !- Fraction
Radiant
    ,                               !- Fraction
Visible
    1,                              !- Fraction
Replaceable
    General,                         !- End-Use
Subcategory
    No;                           !- Return Air
Fraction Calculated from Plenum Temperature

Lights,
    lights_02,               !- Name
    offices,                     !- Zone or
ZoneList Name
    Office  Lights  Schedule,    !-  Schedule
Name
    Watts/Area,                    !-  Design
Level Calculation Method
    ,                               !- Lighting
Level {W}
    10.5,                         !- Watts per
Zone Floor Area {W/m2}
```

```
    ,                          !- Watts per
Person {W/person}
    ,                         !- Return Air
Fraction
    ,                           !- Fraction
Radiant
    ,                           !- Fraction
Visible
    1,                          !- Fraction
Replaceable
    General,                     !- End-Use
Subcategory
    No;                       !- Return Air
Fraction Calculated from Plenum Temperature

Lights,
    lights_03,              !- Name
    halls,                      !- Zone or
ZoneList Name
    Office  Lights  Schedule,   !-  Schedule
Name
    Watts/Area,                   !-  Design
Level Calculation Method
    ,                           !- Lighting
Level {W}
    10.5,                      !- Watts per
Zone Floor Area {W/m2}
    ,                          !- Watts per
Person {W/person}
    ,                         !- Return Air
Fraction
    ,                           !- Fraction
Radiant
    ,                           !- Fraction
Visible
    1,                          !- Fraction
Replaceable
    General,                     !- End-Use
Subcategory
    No;                       !- Return Air
Fraction Calculated from Plenum Temperature


!-    ===========   ALL  OBJECTS  IN  CLASS:
ELECTRICEQUIPMENT ===========

ElectricEquipment,
    equipment_01,           !- Name
    stores,                     !- Zone or
ZoneList Name
    Store  Equipment  Schedule,!-  Schedule
Name
    Watts/Area,                   !-  Design
Level Calculation Method
    ,                             !- Design
Level {W}
    1.00,                      !- Watts per
Zone  Floor  Area  {W/m2}  LBP:  very  little
equipment expected
    ,                          !- Watts per
Person {W/person}
    ,                           !- Fraction
Latent
    0.3,                        !- Fraction
Radiant
    ,                           !- Fraction
Lost
```

```
    General;                    !- End-Use
Subcategory

ElectricEquipment,
    equipment_02,            !- Name
    offices,                    !- Zone or
ZoneList Name
    Office Equipment Schedule,  !- Schedule
Name
    Watts/Area,                  !- Design
Level Calculation Method
    ,                            !- Design
Level {W}
    8.61,                     !- Watts per
Zone Floor Area {W/m2}
    ,                         !- Watts per
Person {W/person}
    ,                          !- Fraction
Latent
    0.3,                       !- Fraction
Radiant
    ,                          !- Fraction
Lost
    General;                    !- End-Use
Subcategory

ElectricEquipment,
    equipment_03,            !- Name
    halls,                      !- Zone or
ZoneList Name
    Office Equipment Schedule,  !- Schedule
Name
    Watts/Area,                  !- Design
Level Calculation Method
    ,                            !- Design
Level {W}
    2.69,                     !- Watts per
Zone Floor Area {W/m2} LBP: minimum office
ASHRAE
    ,                         !- Watts per
Person {W/person}
    ,                          !- Fraction
Latent
    0.3,                       !- Fraction
Radiant
    ,                          !- Fraction
Lost
    General;                    !- End-Use
Subcategory


!-    ===========   ALL  OBJECTS  IN  CLASS:
ZONEINFILTRATION:DESIGNFLOWRATE ===========

ZoneInfiltration:DesignFlowRate,
    zone_infiltration_01,    !- Name
    stores,                     !- Zone or
ZoneList Name
    Always On,                 !- Schedule
Name
    AirChanges/Hour,         !- Design Flow
Rate Calculation Method
    ,                        !- Design Flow
Rate {m3/s}
    ,                          !- Flow per
Zone Floor Area {m3/s-m2}
```

```
    ,                           !- Flow per
Exterior Surface Area {m3/s-m2}
    0.75,                    !- Air Changes
per Hour {1/hr}
    1,                          !- Constant
Term Coefficient
    ,                        !- Temperature
Term Coefficient
    ,                           !- Velocity
Term Coefficient
    ;                           !- Velocity
Squared Term Coefficient

ZoneInfiltration:DesignFlowRate,
    zone_infiltration_02,    !- Name
    offices,                     !- Zone or
ZoneList Name
    Always On,                  !- Schedule
Name
    AirChanges/Hour,         !- Design Flow
Rate Calculation Method
    ,                        !- Design Flow
Rate {m3/s}
    ,                           !- Flow per
Zone Floor Area {m3/s-m2}
    ,                           !- Flow per
Exterior Surface Area {m3/s-m2}
    0.75,                    !- Air Changes
per Hour {1/hr}
    1,                          !- Constant
Term Coefficient
    ,                        !- Temperature
Term Coefficient
    ,                           !- Velocity
Term Coefficient
    ;                           !- Velocity
Squared Term Coefficient

ZoneInfiltration:DesignFlowRate,
    zone_infiltration_03,    !- Name
    halls,                       !- Zone or
ZoneList Name
    Always On,                  !- Schedule
Name
    AirChanges/Hour,         !- Design Flow
Rate Calculation Method
    ,                        !- Design Flow
Rate {m3/s}
    ,                           !- Flow per
Zone Floor Area {m3/s-m2}
    ,                           !- Flow per
Exterior Surface Area {m3/s-m2}
    0.75,                    !- Air Changes
per Hour {1/hr}
    1,                          !- Constant
Term Coefficient
    ,                        !- Temperature
Term Coefficient
    ,                           !- Velocity
Term Coefficient
    ;                           !- Velocity
Squared Term Coefficient


!-    ===========   ALL  OBJECTS  IN  CLASS:
HVACTEMPLATE:THERMOSTAT ===========
```

```
HVACTemplate:Thermostat,
    Constant Setpoint Thermostat,  !- Name
    ,                              !- Heating
Setpoint Schedule Name
    22,                           !- Constant
Heating Setpoint {C}
    ,                              !- Cooling
Setpoint Schedule Name
    25;                           !- Constant
Cooling Setpoint {C}


!-    ==========   ALL  OBJECTS  IN  CLASS:
HVACTEMPLATE:ZONE:PTHP ===========

HVACTemplate:Zone:PTHP,
    10PAV_01,                !- Zone Name
    Constant   Setpoint   Thermostat,     !-
Template Thermostat Name
    autosize,                    !- Cooling
Supply Air Flow Rate {m3/s}
    autosize,                    !- Heating
Supply Air Flow Rate {m3/s}
    ,                            !- No Load
Supply Air Flow Rate {m3/s}
    ,                               !-  Zone
Heating Sizing Factor
    ,                               !-  Zone
Cooling Sizing Factor
    Flow/Person,             !- Outdoor Air
Method
    0.0075,                  !- Outdoor Air
Flow Rate per Person {m3/s}
    ,                        !- Outdoor Air
Flow Rate per Zone Floor Area {m3/s-m2}
    ,                        !- Outdoor Air
Flow Rate per Zone {m3/s}
    Hours of Operation Schedule,  !- System
Availability Schedule Name
    Hours of Operation Schedule,  !- Supply
Fan Operating Mode Schedule Name
    BlowThrough,              !- Supply Fan
Placement
    0.7,                      !- Supply Fan
Total Efficiency
    75,                       !- Supply Fan
Delta Pressure {Pa}
    0.9,                      !- Supply Fan
Motor Efficiency
    SingleSpeedDX,               !- Cooling
Coil Type
    Hours   of   Operation   Schedule,     !-
Cooling Coil Availability Schedule Name
    autosize,                    !- Cooling
Coil Gross Rated Total Capacity {W}
    autosize,                    !- Cooling
Coil Gross Rated Sensible Heat Ratio
    3,                           !- Cooling
Coil Gross Rated COP {W/W}
    SingleSpeedDXHeatPump,     !-  Heat  Pump
Heating Coil Type
    Hours of Operation Schedule,   !- Heat
Pump  Heating  Coil  Availability  Schedule
Name
    autosize,                  !- Heat Pump
Heating Coil Gross Rated Capacity {W}
```

```
    2.75,                    !- Heat Pump
Heating Coil Gross Rated COP {W/W}
    -8,                      !- Heat Pump
Heating    Minimum    Outdoor    Dry-Bulb
Temperature {C}
    5,                       !- Heat Pump
Defrost    Maximum    Outdoor    Dry-Bulb
Temperature {C}
    ReverseCycle,            !- Heat Pump
Defrost Strategy
    Timed,                   !- Heat Pump
Defrost Control
    0.058333,                !- Heat Pump
Defrost Time Period Fraction
    Electric,                          !-
Supplemental Heating Coil Type
    Always  Off,                       !-
Supplemental   Heating   Coil   Availability
Schedule Name
    autosize,                          !-
Supplemental Heating Coil Capacity {W}
    21,                                !-
Supplemental  Heating  Coil  Maximum  Outdoor
Dry-Bulb Temperature {C}
    0.8,                               !-
Supplemental Gas Heating Coil Efficiency
    ,                                  !-
Supplemental   Gas   Heating   Coil   Parasitic
Electric Load {W}
    ,                        !- Dedicated
Outdoor Air System Name
    SupplyAirTemperature,        !-  Zone
Cooling Design Supply Air Temperature Input
Method
    14,                               !- Zone
Cooling Design Supply Air Temperature {C}
    11.11,                            !- Zone
Cooling   Design   Supply   Air   Temperature
Difference {deltaC}
    SupplyAirTemperature,        !-  Zone
Heating Design Supply Air Temperature Input
Method
    50,                               !- Zone
Heating Design Supply Air Temperature {C}
    30,                               !- Zone
Heating   Design   Supply   Air   Temperature
Difference {deltaC}
    ,                              !- Design
Specification Outdoor Air Object Name
    ,                              !- Design
Specification Zone Air Distribution Object
Name
    None,                    !- Baseboard
Heating Type
    ,                        !- Baseboard
Heating Availability Schedule Name
    autosize;                !- Baseboard
Heating Capacity {W}


[...]


!-    ===========   ALL  OBJECTS  IN  CLASS:
SIZING:PARAMETERS ===========

Sizing:Parameters,
```

```
    1.15,                        !- Heating
Sizing Factor
    1.25;                        !- Cooling
Sizing Factor


!-    ===========   ALL  OBJECTS  IN  CLASS:
LIFECYCLECOST:PARAMETERS ===========

[...]

!-    ===========   ALL  OBJECTS  IN  CLASS:
LIFECYCLECOST:NONRECURRINGCOST ===========

[...]

!-    ===========   ALL  OBJECTS  IN  CLASS:
LIFECYCLECOST:USEPRICEESCALATION
===========

[...]

!-    ===========   ALL  OBJECTS  IN  CLASS:
OUTPUT:VARIABLEDICTIONARY ===========

Output:VariableDictionary,
    IDF,                     !- Key Field
    Unsorted;                !- Sort Option


!-    ===========   ALL  OBJECTS  IN  CLASS:
OUTPUT:TABLE:SUMMARYREPORTS ===========

Output:Table:SummaryReports,
    AllSummary,                 !- Report 1
Name

EndUseEnergyConsumptionElectricityMonthly,
!- Report 2 Name
    ElectricComponentsOfPeakDemandMonthly;
!- Report 3 Name


!-    ===========   ALL  OBJECTS  IN  CLASS:
OUTPUTCONTROL:TABLE:STYLE ===========

OutputControl:Table:Style,
    HTML,                         !- Column
Separator
    JtoKWH;                         !- Unit
Conversion


!-    ===========   ALL  OBJECTS  IN  CLASS:
OUTPUT:SQLITE ===========

Output:SQLite,
    SimpleAndTabular;        !- Option Type
```

APPENDIX B

Appendix B shows the code for the automatic creation of alternative values, this code can also be found on the enclosed DVD.

```
//
//  main.c
//  altvaluetest
//
//  Created by Lennart Bertram Poehls on
13/06/16.
//  Copyright © 2016 Lennart Bertram
Poehls. All rights reserved.
//

#include <stdio.h>

float liminf, limsup, r, dvinf, dvsup, v,
c1, c2, i, valt1, valt2;


int main() {

// RESET FLOATS
    liminf=0;
    limsup=0;
    r=0;
    dvinf=0;
    dvsup=0;
    v=0;
    c1=0;
    c2=0;
    i=0;
    valt1=0;
    valt2=0;

// INPUT LIMITS
    liminf=2.4;
    limsup=6.2;

// INPUT BASE VALUE
    v=3.9;

// CALCULATE RANGE (r)
    r=(limsup-liminf);
    dvinf=(v-liminf);
    dvsup=(limsup-v);



// ALTERNATIVE VALUE CREATION

  // CASE 1 (r/3 fits)
    c1=(v-(r/3));
    c2=(v+(r/3));
```

```
    if ((c1>=liminf) && (c2<=limsup)){
        i=(r/3);
        valt1=(v-i);
        valt2=(v+i);
    }

  // CASE 2 (r/3 does not fit inferior
range, r/4 does fit inferior range, value
is in the inferior half)
    c1=(v-(r/4));
    c2=(v-(r/3));
    if
((c2<liminf)&&(c1>=liminf)&&(dvinf<dvsup)){
        i=(v-liminf);
        valt1=(v-i);
        valt2=(v+i);
    }

  // CASE 3 (r/3 does not fit superior
range, r/4 does fit superior range, value
is in the superior half)
    c1=(v+(r/4));
    c2=(v+(r/3));
    if
((c2>limsup)&&(c1<=limsup)&&(dvsup<dvinf)){
        i=(limsup-v);
        valt1=(v-i);
        valt2=(v+i);
    }

  // CASE 4 (r does not fit inferior range,
value is in the inferior half)
    c1=(v-(r/4));
    if ((c1<liminf)&&(dvinf<dvsup)){
        i=(r/3);
        valt1=(v+i);
        valt2=(v+(2*i));
    }

  // CASE 5 (r does not fit superior range,
value is in the superior)
    c1=(v+(r/4));
    if ((c1>limsup)&&(dvsup<dvinf)){
        i=(r/3);
        valt1=(v-i);
        valt2=(v-(2*i));
    }


// PRINT v, valt1 AND valt2
    printf("%f\n",v);
    printf("%f\n",valt1);
    printf("%f\n",valt2);


}
```

APPENDIX C

Appendix C demonstrates the pseudo code for the *Semi-Automatic .idf Creator* (*moSAIC*), its code can also be found on the enclosed DVD.

```
begin {
/* declarations
n_lines:=0;
n_columns:=[];
column:=1;
i:=1;
combination:=[];
i_c:=1;
i_1, i_2, i_3, ... i_nlines;
n_f:=1;
j_c:=1;
/* opening files
open file (INPUT.txt);
open file (COMBINATIONS.txt);

/* program (part 1)
/* counting number of lines and columns for INPUT.txt
for each line of INPUT.txt {
            for each column of INPUT.txt {
                  n_column[i]:=column++;
            }
            i++;
            n_lines++;
}

/* generating all possible variable combinations from lines and columns /* of INPUT.txt and writing the vector into COMBINATIONS.txt
for i_1:=1 to n_column[1] {
            for i_2=1 to n_column[2] {
                  for i_3:=1 to n_column[3] {
                        ...
                        for i_nlines:=1 to n_column[n_lines] {
                              combination[i_c]:= line1[i_1], line2[i_2], line3[i_3], ... , linen[i_nlines];
                              write file (COMBINATIONS.txt, combination[i_c]);
                        }
                  }
            }
}
close file (INPUT.txt);
close file (COMBINATIONS.txt);

/* program (part 2)
/* generating .idf
open file (COMBINATIONS.txt);
open file (OUTPUT[n_f].idf);
```

```
for each line of COMBINATIONS.txt {
write   file   (OUTPUT[n_f].idf,   ““lorem
ipsum”, combination[j_c], “lorem ipsum”,
combination[j_c+1],     “lorem     ipsum”,
combination[j_c+2],  ...,  “lorem  ipsum”,
combination[j_c+...]”);
            close file (OUTPUT[n_f].idf);
            n_f++;
}
close file (COMBINATIONS.txt);
}
end program.
```

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