Next generation energy simulation tools:
Coupling 3D sketching with energy simulation tools

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Abstract

This dissertation primarily deals with investigating the barriers to the adoption of simulation into the conceptual design stage. In this stage, the most important decisions that determine the future of a building project are taken, and the 70% to 80% of capital resources are committed. An in depth analysis to the conceptual designer's needs and priorities is conducted, to identify which are the primary drivers for introducing simulation into the conceptual design stage.

Sketches produced in the conceptual design stage, are driven by the response of the designer to a parameter optimisation procedure. These parameters include building functionality, aesthetics, costs and lately, energy and environmental performance. However, with regards to the later, the primary need of the designer is to ensure that a particular design proposal will not have to be “sent back” for revision in order to conform with building regulations. Thus, strategic information should be provided in order to guide the designer on issues such as orientation, glazing area, thermal mass, internal daylight optimisation, maximisation of sunlight in outdoor recreation areas, costs, aesthetic impact, functionality, etc.

Many design guidelines and rules of thumb have been developed to assist the Conceptual designer in early design decisions. However, these design guidelines cannot provide decision support based on a quantitative analysis, with regards to the particular project they are applied to.

Simulation should be applied at the conceptual design stage to provide the designer with the decision support needed to ensure that the building will perform as required

There is a variety of CAD-sketching tools available to the Conceptual designer. However, there is limited integration of these tools with state of the art simulation tools. In addition, there is a paucity of information available regarding some aspects of the building, which create difficulties and uncertainties about the application of simulation into the conceptual design process

A method that allows a non simulation expert to perform a simulation exercise and get strategic design decision support is proposed in this dissertation. This method is based on three key parameters:

- ➔ 3D CAD-Sketching integration
- ➔ Ease of use
- ➔ interoperability among different purpose energy simulation software

Two general tools are identified in this process – a 3D sketching tool and an energy simulation tool. The selection of these tools was based on their ease of use and their popularity among conceptual designers. However, in order to link the sketching tool with simulation tool, a bespoke tool (plug-in) to the sketching environment has been developed.

The specifications of the specifications of the bespoken tool were defined through the use of the Data Mining System (DMiS) and the data management system (DMaS). This dissociation was made so that the development team and future developers can decompose what information is entering the system (mining) and what is processed by the system (management). The general concept behind the development of this plug-in was user functionality. Thus the majority of the processes are automated while a few require some level of user interaction.

The central concept in the development of the interface of the plug-in is to enable a non expert in building energy modelling to define certain properties of a simulation model. Hence, a considerable amount of effort was made to develop a “user objectives” model and a “user interaction” diagram. These were used to design a user friendly interface. The specifications of the interface are presented in an activity diagram where both automated and semi-automated processes are included.

The interface consists of several “modules”. The concept of modules was introduced in order to help the user to understand the philosophy behind the tool. Four modules were implemented in the GUI: The “Space definition module”, the “Surface and Openings definition module”, the “Building information module” and the “Green Building Studio or gbXML file export module”. In addition, the concept of a cube GUI was introduced. The “Cube interface” enables each side of the cube to represent a different module.

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Chapter 1

Introduction

1. 1 Chapter structure

Chapter One provides an introduction to key subjects surrounding the problem addressed in this Dissertation. It provides general knowledge about building design regarding its energy and environmental performance. It covers issues such as building regulations and energy and environmental assessment throughout the building design process. In addition, it provides an introduction to Design Decision Support Systems and discusses the use of these systems within architectural and engineering practice. In more detail, the chapter consists of the following sections:

- ➔ **“The evolution of buildings: Energy and Environmental considerations”**, where the evolution of building design to conform with the trend of the time is described. In addition, modern environmental concerns in building design are mentioned and a short introduction to Design Decision Support Systems (DDSS) is given.
- ➔ **“Building regulations”**, where the EU directive regarding energy performance in buildings is discussed and the UK government’s approach to this directive is presented. Furthermore, the approved methodologies for issuing Energy Performance Certificates (EPCs) and an explanation of where each methodology is used is given.
- ➔ **“Building design”**, where the role of each major stakeholder in building design is analysed and an introduction in the RIBA's design plan of work given. In addition, the greatest potential, in terms of energy savings, stages are described in details and examples are given.
- ➔ **“The simulation supported design process”**, where a more detailed definition of Energy and Environmental Design Decision Support Systems (EEDDSS) is given and why Simulation is considered the most powerful technique in assessing a building's energy and environmental performance is explained.
- ➔ **“The application of simulation in the building design process”**, where the poor uptake of simulation during the past is discussed and reasons why this happened are given. In addition, schemes developed to address this issue and the drivers of this effort are briefly discussed, Finally, given the presence of new barriers and drivers, the likelihood of a change is also discussed.
- ➔ **“Building energy simulation tools”**, where different energy simulation taxonomies are presented and how these tools have evolved over time is given. Also, a short introduction to

the concept of simulation languages and simulators is presented. In addition, the need to have different tool interfaces for different design stages and an overview of available easy to use (for the conceptual designer) software tools, are presented.

1. 2 The evolution of building design: Energy and Environmental considerations

Human survival through out the ages was based upon the need for shelter among several other p-arameters. These shelters, which were primarily used to provide protection from the environment, were initially caves, cliff overhangs and the like. Later, people started to construct their own artificial protected areas in the form of buildings. After this initial phase a second period started where protection from the climatic conditions was not the only objective. Occupants started to desire an internal environment which they perceived as pleasant and comfortable. Examples of this trend can be found throughout history. Ancient Romans, for example, used underfloor heating systems to provide heat in order to increase the comfort perception of the occupants [*Lechner 2001*] while in North Africa the use of cooling towers in conjunction with massive walls and small windows generated a pleasant environment for the occupants [*Lechner 2001*]. In addition, ancient Greeks built their houses with massive stones painted with light colours to prevent overheating due to the environmental conditions in the Mediterranean region.

Despite the fact that in the early ages humans built their houses with respect to the climatic conditions, the industrial revolution was the catalyst to overcome several limitations imposed by nature. The third wave of the industrial revolution (1900-1950) [*Brunel University 2000*] enabled the opportunity to design buildings so that the desired internal conditions were achieved and maintained though mechanical means (fossil fuel boilers, chillers, fans, etc.). For example, it was possible for a fully glazed façade building with high internal heat loads to be constructed in a hot arid climate and still provide acceptable thermal comfort conditions. In addition to this, the invention of the light bulb in conjunction with all the previously mentioned systems, enabled the design of deep core buildings that were lit by artificial light and ventilated by mechanical systems [*Morbitzer 2003*]. Furthermore, the development of lifts combined with the evolution of steel structural engineering methods (steel beams, reinforced or pre-stressed concrete, etc.) enabled the design of skyscrapers giving a new route to the built environment.

The rapid pace of development throughout the last century had profound benefits to the technological advance of both humans and buildings. Nevertheless this development had several implications upon the welfare of people creating a controversy surrounding the issue. One of the aspects of this controversy relates to the environment where people live and work. This is constantly changing to conform the trend of the time. For example, there is a considerable difference between the way building blocks were built in 1950 and the way modern building blocks are built. Until forty years ago buildings were designed without any energy and environmental considerations. Nowadays, due to several phenomena deriving from the Greenhouse effect, building designers are increasingly aware of Energy and Environmental issues. In addition, building designers are more and more aware of several other implications that affect human welfare (i.e. indoor air quality).

The environmental impact of the built environment tends to become one of the most significant consideration in designing buildings in which people live and work. Buildings are responsible for approximately 40% of the world's annual energy consumption [*Abdeen 2007*]. Most of this energy is the provision of lighting, heating, cooling and air conditioning and it is desirable to reduce the energy required. One way of reducing the energy required is to design buildings which are more economical in their use of energy for lighting, heating, cooling, ventilation and hot water supply. Passive measures, in particular natural or hybrid ventilation rather than air conditioning, can dramatically reduce primary energy consumption [*Abdeen 2007*].

Another issue that is becoming more and more important for building designers is the ability of the building to provide good indoor air quality. It is commonly accepted [*Morbitzer 2003*] that buildings often provide poor indoor air quality. Sick building syndrome is an umbrella term for a number of phenomena relating to buildings that provide an environment that is not pleasant and/or can affect the health of the occupants. Even on a smaller scale, it is common for the occupants to complain about poor ventilation, inappropriate heating control or even overheating of spaces in the summer period [*Jones 2001*].

Even if contemporary building design tends to develop forms and shapes which take energy and quality issues under deep consideration, there are still significant barriers to providing a holistic approach to design. It is the complexity of the design parameters that inhibits the designers implementing such an approach. Lawson [*Lawson 1990*] stated that building design was moved from a craft-based approach to a process that involves advanced technologies and inherits endless difficulties. Despite the design difficulties outlined previously, the modern building designer also has to address legislative issues, ranging from planning to fire protection measures, increasing the complexity of the design phase. To address the problem of complexity in this multi-objective planning process, tools have been developed to support the designer in decision making [*Henrikson 2000*]. These systems are called Design Decision Support Systems and primarily address aspects regarding the structural frame of the building, the energy and environmental performance as well as the cost of the building, while some others provide 3D animations of the building to give the designer and the client a 'feel' for the design.

During the progress of this dissertation, an extensive discussion is given with regards to the role each stakeholder plays in the design of a building, the use of DDSS as well as how each stakeholder can contribute to achieving a good energy and environmental performance is given.

1. 3 Building regulations

Building regulations are produced by government bodies with the aim of ensuring that building stock conforms with a minimum standard regarding energy and environmental performance. They are the only energy and environmental considerations that the building designers are obliged to address.

The first building regulations were developed in response of the energy crisis in the early seventies [*Oostrerhuis and Nieuwlaar 1998, Gero et al 1983*]. These schemes were the result of an effort made by governments to reduce the energy consumption in the building stock. Initially these schemes were focused in energy consumption with regards to heating (since it was responsible for the primary consumption) with an emphasis paid on conductive heat loss through the building envelope. Later they expanded to address phenomena such as plant efficiencies, ventilation heat loss and solar gains as well as consider other energy consumers in the built environment such as cooling lighting and mechanical ventilation [*Morbitzer 2003*].

A building's energy needs for heating, cooling, lighting, ventilation as well as electrical appliance usage account for about half of both the energy used and carbon emitted in the UK. Given the aim of the government to reduce carbon emissions by 50 % by 2020 [*Abdeen 2007*] energy use in buildings will play a significant role in achieving this goal. This conclusion led the EU to produce the Energy Performance of Building Directive (EPBD) in 2002 [*TRADA 2007*], which defines a number of measures which are to be introduced into every member state by specified deadlines. The most important of these measures is the introduction of Energy Performance Certificates (EPCs). These are designed to provide prospective buyers and renters of properties with objective and comparative data on the energy performance of buildings. The Ultimate goal is to significantly influence decisions made by purchasers through:

- ➔ Providing comparative data which can be used as part of the decision making process
- ➔ Raising the profile of energy efficiency as a significant factor in the choice of which building to buy or sell

Different methodologies (with associated software tools) have been developed to calculate and produce EPCs for different building types in different EU member countries. This is because it is neither efficient nor practical to have one methodology covering all building types (*TRADA 2007*). Currently in the UK software based methodologies have been developed by approved bodies driven by EU Building regulations. to be used as part of the design process (for new build). In the case of existing buildings, reduced forms of these programs have been developed as a pragmatic way of creating the required certificates. However, there is a series of problems associated with how information about existing building can be audit.

The software programs which are used in issuing EPCs are presented in the following table:

SAP	SAP is the governments Standard Assessment Procedure for energy assessment of dwellings. The current version of SAP (2005) has been adopted by government as part of England and Wales' national methodology for calculation of the energy performance of buildings. It is used to demonstrate compliance for dwellings with part L of the Building regulations (part J for Scotland)
RdSAP	Reduced data SAP. RdSAP is the new government-approved standardized assessment procedure for energy assessment of existing dwellings. A full SAP assessment requires many data items that cannot be seen in a survey (or take too long to collect). RdSAP is therefore a simplified version of SAP that is designed to estimate data values which are difficult to survey in an existing dwelling.
SBEM	Simplified Energy Model. SBEM is a computer program developed by BRE that provides an analysis of a building's energy consumption. The SBEM tool is designed to cover buildings that are not dwellings. It has been accepted by the government as part of the UK national methodology for calculation of the energy performance of buildings. It is used to demonstrate compliance for dwellings with Part L of the buildings regulations
RdSBEM	This does not exist at present (2007) but the government is about to approve a method to assess existing non-dwellings, in the same way that it has for dwellings. This may be a reduced form of SBEM or some other methodology.
DSM	Dynamic Simulation Model. A Dynamic Simulation Model is software that models energy inputs for different types of buildings over time. In certain situations SBEM will not be sophisticated enough to provide an accurate assessment of a building's energy efficiency. In these cases government-approved proprietary dynamic simulation software may be used.

Table 1.1 UK Government-approved methodologies and tools for EPCs

1. 4 Building Design

1.4.1 Introduction

Architectural design is a very complex activity, juggling scientific, economical, social and cultural elements, all at the same time [*Laarousi 2005, Zarli et al 2005*]. The first objective in design is to identify a solution to an unsatisfied need. The evolution of the chosen solution, while the design is still at an early stage, is a consequence of various cognitive activities undertaken by the design team. However, in the many cases, the design team consists of people with different academic backgrounds and experience, thus making the design stage an even more complex task.

There are various economical consequences of the decisions made during the design process. For instance, it may seem less expensive to design and construct a simple building structure, where emphasis is only paid to the cost of the materials and its construction. However, with the increase of Private Funding Initiative (PFI) projects, where costs are considered in a larger time scale, emphasis is paid on balancing the initial costs, the environmental costs and the cost to the users (maintenance, usability, etc.) of the building. Thus, given the legislation guidelines regarding energy use in buildings as well as Corporate Social Responsibility (CRS) issues, the cost of construction is transformed from an economic to a socio-economic concern and contemporary building design is inevitably affected by this concern [*Obanye 2006]*

1. 4. 2 Stakeholders

A large number of designers are involved in the design of a building (*figure 1.1*). The implications of design decisions made by different team members on the energy and environmental performance of the building differ. However, the impact of Architects, Building services engineers and Clients have the greatest impact. This is due to the fact that architects deal with parameters like material properties, glazing areas, orientation, etc. that have great impact on the energy and environmental performance of the building. In addition, building services engineers design systems that ensure that the building provides appropriate indoor environmental conditions while these systems operate with respect to the energy conservation. Last but not least, Clients have the primary role in influencing a building's design. Despite the legislative requirements regarding the use of spaces (fire protection measures, emergency exits, energy use, environmental impact, etc.) the client is responsible for taking the final decision about the shape and the components of the building (since it is the one that pays for the building), significantly affecting the design. In addition, the client makes the decision whether the building will exceed the minimum legislative restrictions regarding energy use. For example, there might be an additional requirement from the client to develop a building that is more energy efficient than what the building regulations define (increasing the cost of construction).

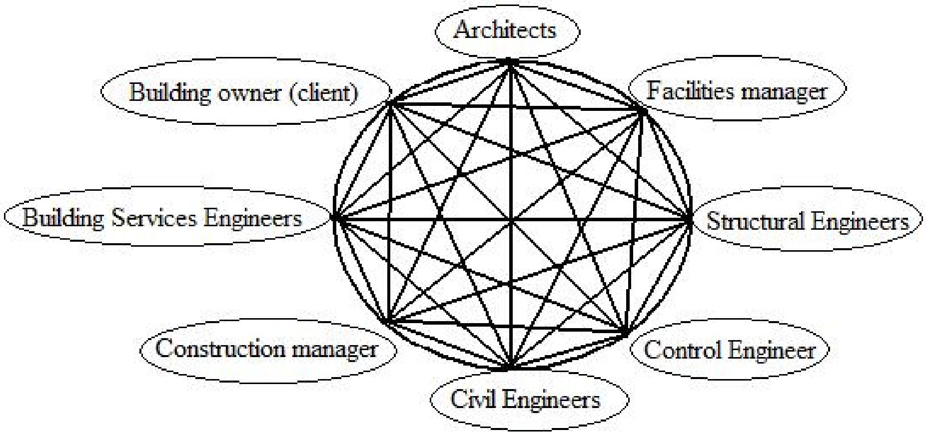

Figure 1.1 Stakeholders of building Design (source Obanye 2006)

1. 4. 3 Building design stages: Analysis and discussion

According to the RIBA's Design plan of work [*RIBA 1995*], which is the most widely recognized plan of work in the construction industry in the UK, design process is divided into different stages. It groups the building design process into twelve different work stages, ranging from an Inception Stage, where the first contact with the client is made, to a Feedback Stage at the very end of the project, where experience is reported for future reference. These stages are briefly described in the appendix (*table A*).

Morbitzer [*Morbitzer 2003*] indicates that five design stages are the most potential for energy savings: the Inception, the Feasibility, the Outline, the Scheme and the Detailed design stage. In the following sections, a short analysis and a discussion upon energy and environmental issues is given for each design stage.

Inception and Feasibility design stage:

During the Inception design stage, the first conversations with the Client start. Client's requirements are being discussed covering issues upon time scale, financial limits, energy use, environmental impact, etc. The outcome of the this stage is to fully understand the Client's needs and give general advice on how to proceed. In the Feasibility design stage the Client's needs are analysed and a study is carried out to determine the feasibility of the Client's requirements.

During the Inception and Feasibility stages the designer does not design the building, but determines the objectives and constraints that will then influence design decisions. This includes planing permission issues, energy and environmental considerations, health and safety, financial considerations and any other aspect that is relevant for the particular project. In the Inception and the Feasibility design stages energy and environmental aspects should be addressed by pointing out to the client the benefits of investing in environmental design studies [*Morbitzer 2003*].

Outline design stage:

During the Outline design stage the designers produce a range of designs, which will in the first instance be an intuitive response to factors such as site conditions, size, orientation and views. These options are then analysed and presented in the form of a feasibility study, which shows the design analysis and options considered. The study should be sufficiently detailed to establish the outline proposal preferred. The analysis also includes a cost appraisal. In addition, part of the Outline design stage is the conceptual design stage. Further information regarding the conceptual design stage is presented in the following chapter where definition and analysis are given.

In the Outline design stage the designer needs to know how the design decisions made in every design option might affect the energy and environmental performance of the building in order to ensure that the designer does not give preference to a design concept without realising energy and environmental implications.

The Outline design stage is the design stage that most energy savings can be achieved [*Morbitzer 2003, Obanye 2006*]. This is because decisions made at the early stages of design can fundamentally affect the performance of the building. For example, the use of a well designed ventilation strategy can supplement the need for air conditioning in a building under specific climatic conditions. This preference can significantly affect the design in terms of energy and environmental performance. In addition, decisions made regarding the orientation, the glazing area and the use of materials can also affect both design and environmental performance. Despite the fact that in the Outline design stage information regarding the use of specific construction materials or glazing is not fully defined, the designer should be provided with an indication of the expected energy consumption [*Morbitzer 2003*].

Scheme design stage and Detailed design stage:

The Outline design stage proposal, approved by the Client, is taken to a more detailed planning level in the Scheme design stage. The designer will have to ensure that all the Client's needs and requests are integrated into the design proposal. In the Detailed design stage the approved Scheme design solution is worked through on detail. Detailed design drawings are produced for coordinating structure, services and specialist installations. Internal spaces may also be detailed to include fittings equipments and finishes.

Energy and environmental considerations at the Scheme and the Detailed design stages are more advance than the ones presented for the Outline design stage. Thus this design stages are more likely to be carried out by engineering consultants and technicians. Engineering consultants can significantly affect the aesthetics of the building, which is an important aspect for architects. For example, the glazing area of a façade of the building might be responsible for excess energy losses. In this case, the consultant will either have to use more efficient glazing materials or modify the area of the glazing. In some cases, the designer will not change neither the glazing material nor the area, but will increase the energy performance of other building components as a trade off to the losses in the glazing façade [*Mortbitzer et al 2003*]. Despite the later case, in the majority of the projects, the complexity of the energy performance prediction tasks undertaken is beyond the knowledge of an architect.

1. 5 The simulation supported design process

1. 5. 1 Energy and Environmental Design Decision Support Systems

As mentioned in section 1.2, in order to address the problem of complexity in multi-objective design planning process, systems have been developed to support the designer in decision making [*Henrikson 2000*]. These tools are called Design Decision Support Systems and primarily address aspects regarding the structural frame of the building, the energy and environmental performance as well as the cost of the building, while some others provide 3D animations of the building to give the designer and the client a 'feel' for the design. When a system is primarily addressing energy and environmental problems, it is mentioned as an Energy and Environmental Design Decision Support System (EEDDSS).

There is a variety of EEDDSS available to the designer. These range from general design guidelines to highly sophisticated simulation tools, which aim to predict the building performance of a certain architectural and/or engineering proposal. The main groups of these EEDDSS are presented in the following table.

EEDDSS	Description
Design guidelines or rules of thumb	Do not predict performance but give general design advice.
Traditional physical calculation methods (steady state)	Focus on a limited number of physical phenomena in a building, in some cases only on one.
Correlation based methods	Try to consider all physical aspects that influence a certain building performance; restrictions in design specification and performance assessments.
Building simulation	Philosophy of creating a virtual building where the user can specify in detail parameters that influence the building performance, with resulting performance predictions that are as close to reality as possible.

Table 1.2 Main groups of Energy and Environmental Design Decision Support Systems [Morbitzer 2001 a]

1 . 5. 2 Discussion upon EEDDSS

Simplified design tools such as design guidelines, rules of thumb, traditional calculation methods or correlation based methods have well served research upon the energy assessment of buildings throughout almost forty years (it is worth mentioning that rules of thumb exist more than that) [*Morbitzer 2003*]. However, these have limitations related to the fact that designers have to ensure that the design proposal deriving are appropriate for the specific project they are applied to. Problems can occur if a specific design type was not accounted for when the simplified tool was produced [*Mortibzer 2003*]. Thus, these systems do not provide a holistic approach regarding the energy use and the environmental performance. In addition, the level of accuracy of the calculations and the implementation of these tools within the design process depends on the experience of the person undertaking the task as well as the time available.

Building energy consumption and indoor climate are determined by complex dynamic thermal interactions between the outdoor environment (air temperature, humidity, solar radiation, wind speed, wind direction), building structure, internal heat gains, occupancy and the building services systems, which perform duties such as heating, cooling, lighting and ventilation. To help the designer to determine the impact of these interactions, tools should be used to provide a prediction of the energy and environmental performance of the building is a holistic way. The designer should use these tools to assess environmental data and consider them as the basis of his/her cognitive analysis to determine the building's optimum environmental design. In addition these tools should encourage the user to parametrically analyse and predict these complex interaction patterns.

Hensen [*Hensen 1994*] concludes that the most powerful method available for the analysis and design performance assessment of complex building systems, is building energy simulation. This is because it takes into an account all parameters influencing a building's performance by providing design decisions based on accurate results. In addition, Clarke [*Clarke 1997*] states that the advantage of the use of simulation lay to the fact that it permits an evaluation of building performance in a manner that corresponds to reality and enables integrated performance in which no single issue is unduly prominent.

1. 6 The application of simulation in the building design process

1. 6. 1 Introduction

Over the past 18 years simulation tools and skills have moved from the academic domain into specialist practices. However, the uptake of such a technology from engineering and architectural firms has not been not very successful. Mahdavi [*Mahdavi 1994*] states that simulation tools have not been integrated in the design process to the degree expected due to many contributing factors. Almost all of these factors agree to the point that there is a lot of shortcomings in conventional simulation tools, ending to difficulties in responding to the necessities and the background of current design practice. Many years later, Macdonald [*Macdonald 2004*] makes a more comprehensive and in-depth analysis and identifies the barriers to adoption of simulation. The outcome of this research has indicated that the main reasons are due to the steep learning curve, the poor ease of use, the fear of user error, the scale of complexity of real projects and the demanding input resource requirements. He also states that discontinuity between program capabilities and the lack of supportive network have also contributed to the lack of adoption.

1. 6. 2 Initiatives and drivers to increase the use of simulation into the building design process

In a UK context, the transition of building simulation practice from the academic into the architectural and engineering domain was originally driven by organizations such as the Energy Design Advice Service (EDAS) and the Scottish Energy Systems Group. Both have contributed to equip designers with the necessary skills to allow them to apply simulation tools routinely in practice. Initially the EDAS approach to providing simulation based advice relied on the services of modelling specialists who remained detached from the design process. This has caused a delay between the delivery of the simulation results and the evolution of the design hypothesis. The foundation of SESG gave a new route to the role of simulation within the design practice believing that industry was ready to commerce the process of of adopting a computational approach to energy systems design whereby modelling tools were fully integrated within the design process. [*Macdonald et al 2005*]

The SEGS was founded on the basis that computer modelling tools had reached the level of maturity that enabled them to be readily deployed in practice. Prior to this scheme, the EDAS had enabled engineers to gain access to modelling specialists on a consultancy basis. While EDAS was highly successful in introducing low energy design solutions, the approach being adopted had several shortcomings (extra costs to use consultants, increased design times while waiting for reports from specialists and the design team was not able to freely explore options as the consultant directed the process). SESG was established to address these shortcomings. The goal is to demonstrate that integrated building performance modelling provides cheaper, quicker and better design solutions than the conventional methods. By the use of seminars, training and in-house assistance the designers have more opportunities to develop skills in tools that address energy and environmental issues and receive help to translate the outcomes of a simulation in meaningful for design suggestions. [*Macdonald et al 2005*]

EDAS and SESG schemes provided the link between the academia and industry for the later to make use of the simulation capabilities. There have been several drivers originating from commercial and legislative demands faced by companies. Commercial divers relate to the fact that simulation can increase the level of services to the clients. Thus, when a company applies simulation within its practice, can remain competitive enough to survive the market. On the other hand, legislative demands relate to the EU buildings directive and the need to move towards a more sustainable building design. The main drivers are outline in following table (*table 1.3*).

Legislative drivers	The upcoming Energy Performance Buildings Directive (EPBD)
	International protocols such as the Kyoto Protocol and the Local agenda 21
	National legislation schemes such us Energy Performance Certificates (EPCs) and BREEAM

Commercial drivers	Commercial pressures due to competition. There has been an increased desire by companies to bring simulation work in-house in order to increase the value and control of the process.
	Design pressures due to new technical demands in design (double skin façades, building integrated renewables, etc.). These has forced architectural companies to work in partnerships with engineering companies in the design team. This has led to calls for performance quantification on time-scales which can only delivered on time if the work is undertaken in-house.
	The increase of privately financed public building projects (PFI/PPP) where the investor who pays for the construction of the building is also responsible for its maintenance and running costs .

Table 1.3 Drivers for the use of simulation within design process [after Macdonald et al 2005 and Morbitzer 2003]

1. 6. 3 New and perceiving barriers

Despite all the previously mentioned initiatives and drivers for the uptake of simulation within architectural and engineering practice, there are still obstacles to overcome. These are mainly related to early design stages where decisions fundamentally affect energy and environmental performance.

Through the use of schemes such as the EDAS and SESG, simulation has managed to establish its position in the scheme and the detailed design stage where mainly engineers (buildings services engineers and experienced simulation users) predominate. However, in most of the cases, the use of simulation is used for verification purposes during the back-end of the design process [*Mahdavi et al 1994*]. This neglects the fact that the most energy saving can be achieved if simulation is applied at the early stages of design [*Obanye 2006, Morbitzer 2003*]. Despite this fact, there are still some barriers to the uptake of simulation in this early stage. Two major factors can be identified. First, many of the existing simulation tools require fairly detailed input information which is often unavailable in the early stages of design, and second, the functionality of these tools reflect the conventional notion of the design process whereby formal and aesthetic decision making and the fulfilment of building performance requirements (thermal lighting and acoustics) are regarded as discrete and sequential rather than concurrent activities [*Mahdavi 1998*].

Some new challenges have been identified from the experience gained by EDAS and SESG schemes. These are related to software development and user skill based issues. In essence, designers using simulation tools need to translate the results into meaningful information for the design team. This has forced simulation tool developers to to make changes to the reporting of prediction analysis available form their tools and create bespoke tools to achieve a standard reporting mechanism. This indicated the significance of interoperability among a variety of software because companies often use different software depending on the problem to be solved. In addition, issues have arisen related to the ability of the designers and modellers to tackle with the question of which tool should be used to obtain the information needed. For example, when the question of whether a particular office can be naturally ventilated or not is risen, the designer will have to assume openable areas and then test this hypothesis with the use of an airflow network. This will indicate the air change rate. However, this rate varies over time. Thus, the distribution of air with in the space still remains as a question to be answered. The designer should be able to translate this information into his/her design and be experienced enough to ask for a CFD analysis to identify the risk of failure. Simulation tools can provide detailed information upon the problem analysed but often do not directly answer the design question.

Experts in simulation are generally capable of deciding which type of simulation study is appropriate to support design decision at each design stage (taking into account issues such as time requirements, data availability, results reliability, etc.). However, the situation is different when decisions have to be made by a user with limited or no background in energy and environmental performance issues. With regards to the later type of user, it is difficult to decide which simulation study is appropriate for a particular design question. In order to integrate simulation into the conceptual design process, it is necessary to develop procedures that allow designers to utilise design questions into well defined simulation exercises [*Mahdavi et al 1993*].

1. 6. 4 The likelihood of a change

It is a general fact that clients require reduced life cycle costs. This has led to an increased demand for buildings that have been designed to take this under consideration. In conjunction with this, the prestige of a "green building" can increase the profile of the client mainly due to Social Corporate Responsibility (SCR) reasons. Given the desire not to increase the capital cost and still satisfy the client's needs, the contemporary building design team should be able to quantify a building's energy and environmental performance as early as possible in the design process. This will enable the team to take informed decisions about design changes and their impact on the overall design. In addition, PFI/PPP projects will increase the demand on the designer to consider the life cycle cost of a building during its designing and planing phase. To achieve this, simulation should be fully deployed in the Outline (conceptual design stage) to ensure that the project will not be off budget.

Particularly in Scotland, commercial and legislative drivers, as mentioned in the previous section, will for the first time require a computational approach to building modelling at all design stages. This, in combination with the next phase of SESG which aims to consolidate and expand its activities program, will enable simulation to flourish as a method to deal with complex issues regarding energy and environmental performance quantification [*Macdonald et al 2005*].

1. 7 Building simulation tools

1. 7. 1 Software tool taxonomy

A large number of simulation tools have been developed over the last decades. The building energy software tool directory run by the US Department of Energy [*DOE 2007*] lists over 342 building software tools for evaluating energy efficiency, renewable energy and sustainability in buildings. The energy tools listed in this directory include databases, spreadsheets, component and systems analysis, and whole-building energy performance simulation programs. A short description is provided in this directory for each tool along with other information including expertise required, users, audience, input, output, computer platforms, programming language, strengths, weaknesses, technical contact, and availability. The visitor of the web directory can list these software according to the subject, the platform and the country developed.

Another directory for listing available building simulation tools is presented in a report [*Crawley et al 2005*] compiled by by Crawley, Hand, Kummert and Griffith with the support of the Department of Energy of the US (DOE), the Energy Systems Research Unit (ESRU) at the University of Strathclyde and the University of Wisconsin. According to this report the capabilities of 20 'mature' tools were contrasted and general results have been extracted. The report provides a brief overview of each of the programs. This is followed by a set of tables which contrasts the capabilities of each tool in the certain areas areas such as: general modelling features, zone loads, building envelope and daylight, infiltration, ventilation and multi zone airflow, renewable energy systems, electrical systems and equipment, HVAC systems, HVAC equipment, Environmental emissions, Economic evaluation, climate data availability, results reporting, validation, user interface, links to other programs and availability. This report aims to become a living document that will evolve over time to reflect the evolution of tools and the evolution of language the simulation community uses to discuss the facilities within the tools.

There is also a report [*ARTI 2002*] that makes a taxonomy among building simulation tools. In this report, tools are classified according to "who is likely to use the tool", "what tools currently are used by design practitioners" and "what tools require expert knowledge or complex input data". This classification was based on a survey made in the US where 200 practitioners were involved and the results are presented in Appendix (*tables B, C, D and E*).

1. 7. 2 The evolution of building energy simulation tools.

Building simulation aims to imitate the real physical conditions in a building by creating a mathematical model that represents all energy flow paths in a building as well as their interactions. Advances in simulation techniques and computer hardware have led to the development of very advanced simulation tools. Clark [*Clarke 2001*] has summarized this evolution from tools that are based on traditional calculation methods to contemporary simulation over four generations (*Table 1.4*)

1st generation	Such tools are handbook orientated computer implementations and are biased towards simplicity. There is no attempt to faithfully represent the energy and mass flow paths that occur in a real building but the aim is to provide the user with general indications of certain building performance criteria.
2nd generation	Such tools introduced the dynamics of a building in the evaluation process in an attempt to imitate real physical conditions. Multi-layered constructions were able to be analysed. However, air movement and HVAC systems were decoupled from the analysis [Hand 1998].
3rd generation	Given the advance in computing in the mid-eighties these tools have managed to perform a combined assessment of energy and mass flow. However, they assumed that only space and time are independent variables, taking all other system parameter as dependent. Thus, no single energy or mass transfer process can be solved in isolation [*Hensen 1991*]
4th generation	In the mid-nineties simulation software involved further domain integration and considered program interoperability. The later is an essential data modelling issue. In response to the growing uptake of simulation by researchers and engineers, new developments emerged, including more accessible user interfaces, application quality control, air flow simulation and user training. [After Morbitzer, 2003]

Table 1.4 The evolution of building simulation tools [Morbitzer 2003]

Morbitzer states [*Morbitzer 2003*] that the development of the fourth generation simulation tools is not yet complete. This can be attributed to three main reasons; complex user functionality, limited performance analysis and interoperability among different simulation purpose software. These problems have been identified in section 1.6.3 as barriers to widespread simulation in the building design process. A new generation of simulation software will rise only as soon as these barriers are addressed in an adequate level. It is also in the personal view of the author of this Dissertation, that introducing a new generation of building simulation software will be useless if user functionality and interoperability does not comply with the contemporary designer's needs.

1. 7. 3 Simulation languages and simulators

Robinson [*Robinson 1994*] distinguishes between the different philosophies in interface developments with the term simulation language and simulator, where the former relates to an advanced simulation tool that offers full flexibility in the model creation, and the latter stands for purpose-designed software that simulates a specific range of parameters. Simulators are generally menu driven, construction of models is faster, but they are less flexible than the simulation languages.

Simulation languages (or simulation engines) have reached a mature level since they are able to describe various phenomena related to a building [*Clarke 2001*]. However due to the lack of ease of use by 'practitioners', there is a tend towards the development of easy-to-use front-end interfaces (simulators) for complex simulation engines [*ARTI 2002*]. Examples can be found among the several front interfaces developed for DOE 2 (more than 20 privately funded) and EnergyPlus engines [*Crawley et al 2005*].

1. 7. 4 Front end interfaces bespoken for certain design stages

Simulators[1] were originally developed as a respond to the complexity of highly advanced simulation languages. These are bespoke front-end interfaces that address certain aspects of a building's design. Developing a simulator hides endless difficulties deriving from the decomposition of information and available data of design parameters at various design stages (see section 1.4.3). Front-end interfaces were originally designed from engineers primarily for engineers[2] and have a

1 From now on simulators will be referred as front interfaces and simulation languages will be referred as simulation engines

2 The only exemption is EcotecT which is entirely designed and written by architects and intended mainly for use by

relative success among simulation practitioners in the scheme and the detailed design stage where engineers predominate. However, interfaces developed for the Outline design stage, where most likely the practitioner will be an architect with limited or without experience in modelling, don't meet the same success. This can be mainly attributed to the fact that the interface designer and the typical user (architect) don't speak the same language. An extended analysis of how simulation is applied and what are the major barriers to adoption of simulation among architects is presented in section 2.5 of this Dissertation

1. 7. 5 Overview of easy to use building energy simulation tools

Over the last years there is a considerable amount of effort being made to develop friendly-to-use front-end interfaces. Examples can be found in many simulation software where conceptual stage wizards were introduced [*ARTI 2002*]. Some of the leading tools are presented bellow following a short description.

➔ **EcotecT** [Marsh 1996] is a highly visual and interactive complete building design and analysis tool that links a comprehensive 3D modeller with a wide range of performance analysis functions covering thermal, energy, lighting, shading, acoustics, resource use and cost aspects. EcotecT has two main advantages; can handle geometry of any size and complexity and focuses on feedback at the conceptual design stages. Its developers intent is to allow designers to take a holistic approach to the building design process making it easier to create a truly low energy building [*Crawley et al 2005*].

➔ **Ener-win** is an hourly energy simulation model for assessing annual energy consumption in buildings. Ener-Win has the advantage that requires only three basic inputs: (1) the building's location, (2) the building type, (3) and the building's geometrical data. Default data derived form the initial inputs include economic parameters, number of occupied days and holidays, occupancy, hot water usage, lighting power densities, HVAC system types and schedules for hourly temperature settings, lighting use and ventilation rates. This Intelligent Default Data (IDD) in combination with its sketching interface makes it a tool appropriate for the conceptual design stage. Its main drawback lies to the fact that the models cannot be exported to more technical and focused analysis engines nor imported from CAD tools [after *Crawley et al 2005*].

➔ **Energy express** is a design tool developed for evaluating energy performance for

architects [*Crawley et al 2005*]

commercial buildings by estimating energy consumption and cost at the design stage. The user interface can allow fast and accurate model creation and manipulation. Energy Express can be used for the analysis of alternative designs of new and the assessment of retrofit options in existing buildings. The energy and cost savings of different design options can be evaluated and compared to produce the an effective combination, before construction [*Crawley et al 2005*].

➔ **Energy 10** is a user friendly, early design stage, building energy simulation program that integrates daylighting, passive solar heating and low-energy cooing strategies with energy efficient shell design and mechanical equipment. Energy 10 runs an hourly thermal network simulation while allowing users to rapidly explore a wide range of energy efficient strategies and plot the results in a number of ways. Energy 10 takes a baseline simulation and automatically applies a number of predefined strategies ranging from building envelope to building services efficiency options [*Crawley et al 2005*].

➔ **HEED** is intended for use at the beginning of the design process. HEED uses an expert system to transform limited user inputs into two base case buildings. The first meets California's Title 24 energy code while the second is about 30% more efficient. The second mix incorporates the most appropriate mix of passive heating and cooling design strategies (already defined for the local climate of California), including improvements to geometry, orientation, construction, window shading, glazing, internal mass, natural/mechanical ventilation, daylighting, etc. HEED's strengths relate to the ease of use, simplicity of input data, a wide array of graphic output displays, computational speed and the ability to quickly compare multiple design alternatives. Finally, its major drawback is that it is set up only for California's climate [*after Crawley et al 2005*].

➔ **eQUEST** is an easy to use building energy use analysis tool which provides accurate results with an affordable level of effort. This is accomplished by combining a building creation wizard, an energy efficiency measure wizard and a graphical results display module with an enhanced DOE 2.2-delivered building energy use simulation program. EQUEST'S building creation wizard walks the user through the process of creating an effective building energy model [*Crawley et al 2005*].

➔ **SUNREL** is an hourly energy building simulation program that aims in the design of small energy efficient buildings were the loads are dominated by the dynamic interactions between the building envelope, its environment and its occupants. The program includes algorithms specifically for passive technologies, such as Trombe walls, programmable window shading, advanced glazing and natural ventilation. Its main drawback is that the user has to specify the external surface coefficients manually thus referring only to experienced in simulation designers [*Crawley et al 2005*].

- ➔ **SEMPER** is a prototype of an active design environment. It provides an design refinement using active design support involving the derivation of the design implications of the desired changes in performance attributes [*Mahdavi 1999*]. Even though SEMPER was originally developed as a 'stand alone' application, a newer version (SEMPER II (S2)) designed as an internet-based computational design support environment in order to facilitate geographically distributed design collaboration *[Mahdavi 2004]*.
- ➔ **Green Building Studio (GBS)** links architectural 3-D CAD building designs with energy analysis. Green Building Studio enables architects to quickly calculate the operational and energy implications of early design decisions. The Green Building Studio web service automatically generates geometrically accurate, detailed input files for major energy simulation programs. GBS uses the DOE-2 simulation engine to calculate energy performance and also creates geometrically accurate input files for other major simulation engines. Key to the integrated interoperability exhibited is the Green Building XML schema (gbXML), an open XML schema of the International Alliance of Interoperability (aecXML Group). By using gbXML-enabled applications, Green Building Studio users are able to eliminate redundant data entry and dramatically reduce the time and expense traditionally associated with whole-building energy simulation analyses [*DOE 2007*]

1.8 Closing remarks

The rapid pace of development throughout the last century had profound benefits to the technological advance of both humans and buildings. Nevertheless this development had several implications upon the welfare of people creating a controversy surrounding the issue. One of the aspects of this controversy relates to the environment where people live and work.

The environmental impact of the built environment tends to become one of the most significant consideration in designing buildings in which people live and work. Even if contemporary building design tends to develop forms and shapes which take energy and quality issues under deep consideration, there are still significant barriers to providing a holistic approach to design.

A building's energy needs for heating, cooling, lighting, ventilation as well as electrical appliance usage account for about half of both the energy used and carbon emitted in the UK. Given the aim of the UK government to reduce carbon emissions by 50 % by 2020 energy use in buildings will play a significant role in achieving this goal. This conclusion led the EU to produce the Energy Performance of Building Directive (EPBD), which defines a number of measures which are to be introduced into every member state by specified deadlines.

There are various economical consequences of the decisions made during the design process. However, with the increase of PFI projects, where costs are considered in a larger time scale, emphasis is paid on balancing the initial costs, the environmental costs and the cost to the users (maintenance, usability, etc.) of the building.

A large number of designers are involved in the design of a building. The implications of design decisions made by different team members on the energy and environmental performance of the building differ. However, the impact of Architects, Building services engineers and Clients have the greatest impact.

According to the RIBA's Design plan of work, the design process is divided into different stages. The most potential design stage for energy savings is the Outline design stage. This is because decisions made at the early stages of design can fundamentally affect the performance of the building. Despite the fact that in the Outline design stage information regarding the use of specific construction materials or glazing is not fully defined, the designer should be provided with an indication of the expected energy consumption.

In order to address the problem of complexity in the multi-objective design planning process, systems have been developed to support the designer in decision making. These tools are called Design Decision Support Systems. When a system is primarily addressing energy and environmental problems, it is mentioned as an Energy and Environmental Design Decision Support System (EEDDSS). There is a variety of EEDDSS available to the designer. These range from general design guidelines to highly sophisticated simulation tools, which aim to predict the building performance of a certain architectural and/or engineering proposal. The most powerful EEDDSS available for the analysis and design performance assessment of complex building systems, is building energy simulation. This is because it takes into an account all parameters influencing a building's performance by providing design decisions based on accurate results. However, simulation tools have not been integrated in the design process to the degree expected due to many contributing factors. The main reasons are due to the steep learning curve, the poor ease of use, the fear of user error, the scale of complexity of real projects and the demanding input resource requirements and the lack of supportive network.

There have been several drivers to the increase of simulation exercises in industry, originating from commercial and legislative demands faced by companies. Commercial divers relate to the fact that simulation can increase the level of services to the clients, while legislative demands relate to the EU buildings directive and the need to move towards a more sustainable building design. Despite these drivers there are still obstacles to the full implementation of simulation within architectural practice. These are mainly related to early design stages where decisions fundamentally affect energy and environmental performance. Thus, in most cases, the use of simulation is used for verification purposes during the back-end of the design process.

Experts in simulation exercises are generally capable of deciding which type of simulation study is appropriate to support design decision at each design stage (taking into account issues such as time requirements, data availability, results reliability, etc.). However, the situation is different when decisions have to be made by a user with limited or no background in energy and environmental performance issues. With regards to the later type of user, it is difficult to decide which simulation study is appropriate for a particular design question.

Front-end interfaces have been developed to improve user functionality and ease of use. These interfaces were designed from engineers primarily for engineers and have a relative success among simulation practitioners in the scheme and the detailed design stage where engineers predominate. However, interfaces developed for the Conceptual design stage, where most likely the practitioner will be an architect with limited or without experience in modelling, don't meet the same success.

Over the last years there is a considerable amount of effort being made to develop friendly-to-use front-end interfaces. Examples can be found in many simulation software where conceptual stage wizards were introduced. However, major improvements are still under way. Among these improvements are: complex user functionality, CAD integration and interoperability among different simulation purpose software issues.

Chapter 2

Conceptual design stage and Modelling

2.1 Introduction

In the previous chapter the role of each major stakeholder in building design was discussed and the the most potential, in terms of energy savings, stages of building design were indicated. Also, it was made clear that building energy simulation is currently the most powerful technique to evaluate a building's energy and environmental performance. However, despite the fact that simulation is commonly applied in the Scheme and the Detailed design stages, still finds limited acceptance among conceptual designers.

This chapter deals with a more in depth analysis of the Conceptual design stage, where the needs and priorities of the designer are highlighted and the role of modelling is presented. The barriers to the adoption of simulation into this stage are extensively analysed and discussed. Following a presentation of the design parameters the Conceptual designer will want to evaluate. Also Emerging building technologies are presented so that they can be contrasted with limitations in energy modelling in the Conceptual design stage. Then, an extended presentation of thoughts and a detailed discussion is made with regards to what the Author's believes that next generation simulation tools will consider. Finally, the general aim and the core research aim of this MSc project, as far as this is represented in this Dissertation, is given.

2.2 What is conceptual design

Conceptual design, along with need identification and analysis, make up the initial stage of the design process. Need analysis transforms the often vague statement of a design task into a set of design requirements. Conceptual design encompasses the generation of concepts and integration into system-level solutions, leading to a relatively detailed design. As the building scheme is being created, several design parameters influence and/or are influenced by basic decisions about the building’s shape, proportions, glazing, materials and the integration and the role of building services systems. The conceptual stage of the design is the stage where most decisions that determine the future of the project are taken, and about 70% to 80% of resources are committed [*Rafiq et al 2005*].

Conceptual design focuses on the functionality of buildings as a whole, consisting of various functional and interrelated entities. A resulting and consistent conceptual sketch forms the basis of all following design stages. These sketches allow the identification of the organizational configuration of a building and ensures its usability. A large number of constraints have to be regarded, arising from various domains, such as legal, technical, functional, and financial restrictions. The majority of these restrictions are specific to a class of buildings, e.g. office buildings, car garages, or residential buildings. [*Kraft and Manfred 2006*].

The conceptual designer has a considerable amount of interrelated parameters to evaluate. Thus, strategic information should be provided in order to guide the designer on issues such as orientation, disposition of glazing, thermal mass, internal daylight optimisation, maximisation of sunlight in outdoor recreation areas, costs, aesthetic impact, functionality, etc. [*Building design 2007*].

The major Conceptual designers are architects and building services-architectural engineers[1]. Both have the biggest impact on the energy and environmental performance of a building. Design decisions made by building services engineers also have big impact because they design the systems that should later ensure that the building provides appropriate environmental conditions [M*orbitzer 2003*]. However, their decisions mainly affect design in later design stages (Scheme and Detailed)

2.3 Conceptual designer's needs

2.3.1 Introduction

There is a series of parameters that the Conceptual designer will have to take under consideration when developing the concept of a building. These are mainly related to the functionality of the building, its aesthetics and the associated costs. However, due to the EU Buildings Directive (see sections 1.3 and 1.6.4) energy and environmental performance is also among the top priorities of a conceptual designer. Originally, the use of energy in buildings was among the considerations of engineers that design the building services systems. However, due to the associated costs of these services systems, design parameters such as orientation, glazing areas, material use, shading and daylighting have begun to emerge as essential design considerations to be taken into an account while the building is still at early design stages.

Computer energy simulations can be used to assess energy conservation measures early in the design process. The design team collaborates early in conceptual design to generate many alternative concepts for building form, envelope and landscaping, focusing on minimizing peak energy loads, demand and consumption. However, the building information models created do not contain the appropriate level of information to support a simulation exercise to support design

1 Building services-architectural engineers are primarily building services engineers with particular knowledges or experience upon building design and architectural history.

decisions.[*Sustainable Architecture and Building Design 2007*].

2.3.2 Discussion

During the past, simulation was usually commissioned after finalizing the design, mainly for performance verification [*Hien et al 2000, Morbitzer 2003*]. Nowadays, the architectural community has gradually begun to consider simulation as a design support tool[2]. The drivers to increase the use of simulation into the design process have been presented and analysed in section 1.6.2. However, some of these drivers derive from the need of Conceptual designers to quantify the effects of early design decisions.

There are many detailed design guidelines regarding energy and environmental performance in buildings. These can be found among several publications provided by BRE, RIBA and several other research institutes [*RIBA 2007, BRE 2005]*. However, these guidelines do not provide the designer with information about how early design decisions affect the performance of the building (in terms of quantity). Thus, the Conceptual designer, will need to perform a simulation to obtain the information required and give preference to a particular design option. However, as this has been indicated in the previous chapter (section 1.6.2) and will be further analysed in section 2.4, given the complexity of a simulation exercise, the conceptual designer will need assistance from a simulation expert among the design team. If the design team does not include such an expert (which is the case in most architectural firms), the performance quantification is assigned to an external associate affecting the time required to deliver the project.

The conceptual design stage is the design stage with the shortest time available to the designer in terms of decision making. At this stage the architectural company has normally not won the contract for a project, but is competing with other design teams. Thus, there will be limited or no fees paid to commission a sub-contractor to undertake the simulation exercise [*Morbitzer 2003*].

2.3.3 Needs and Priorities

Since energy and environmental considerations have begun to be among the Conceptual designer's priorities, the need to quantify the effect of early decisions is imperative. The majority of Conceptual designers have limited or no background relative to energy use in buildings and thus will have to commission a simulation expert to undertake the simulation.

The main need of Conceptual designers is to know whether the building will comply with the building regulations. However, designers still consider the conceptual design stage as discrete

2 However, as this has already been presented and will be analysed later this chapter, the conceptual designer cannot use simulation in practice due to several limitations

and isolated from the following design stages (Scheme and Detailed) [*Mahdavi 1998*]. This has resulted to additional time required to deliver a particular project, since the simulation is carried out by an external associate (simulation expert). In addition, due to the lack of "quantitative" feedback about certain aspect of design (with regards to energy and environmental performance) a particular design is likely to be "sent back" to the Conceptual designer for revision and/or re-design to conform with building energy and environmental standards. Thus, the time required to deliver a project is increased dramatically, resulting to frustration and finally increased costs to re-design and/or to apply high efficient building services systems to offset energy demand. Thus, among the primary needs of Conceptual designers is to design buildings that ensure a particular design proposal will not have to be "sent back" to the designer for revision in order to conform with building regulations.

2.4 The role of modelling in the conceptual design stage

Human interaction with a Computer Aided Design (CAD) environment, in order to contribute to a focused and concentrated exploration among shapes, has led to the discovery of new knowledge, impossible to retrieve by other means [*Rafiq 2005*]. Use of interactive visualisation supported by evolutionary computation tools allows designers to evaluate alternative designs and in their decision making. Currently there is a variety of CAD and 3D sketching applications available to the conceptual designer. In addition, these tools have been to the edge of software development and thus, can represent and address the designer's needs adequately.

Mahdavi [*Mahdavi 1998*] points out that modelling has a long tradition in the architectural design process, but that the main concern of architectural modelling has been visual appearance. He also suggests that the increased complexity of building technologies has led to a broader view of architectural modelling. This modelling should cover aspects of buildings such as their performance, in terms of energy consumption, thermal, lighting and acoustic quality. However, Refiq [*Rafiq et al 2005*] states that due to discrete, fuzzy and incomplete nature of information in the conceptual design stage, the design and decision making process is difficult to be modelled in a computer program.

As this will be indicated in section 2.5, there is limited integration of CAD-sketching tools with simulation tools. Bespoke interfaces for state of the art simulation tools have been created, which provide the user with a basic CAD functionality. However, these do not respond to the needs of Conceptual designers since the CAD-Sketching functionality is far from the functionality of state of the art CAD-sketching applications

2.5 Barriers to the adoption of simulation into the conceptual design stage

In section 1.6.3 the barriers to the adoption of simulation within the design practice were mentioned and briefly described. In this section, a more detailed analysis is conducted to investigate the barriers to adoption of simulation tools in the conceptual design stage.

Morbitzer [*Morbitzer 2003*] states that there are three key barriers to the adoption of simulation tools into the conceptual design process; complex user inputs, performance analysis outputs and interoperability among different simulation purpose software. However, another definition of those parameters was introduced by Mahdavi [*Mahvadi 1999*]. Part of this research has indicated more contributing factors such us material and time implications, problematic user interfaces, poor integration with general CAD systems and absence of active design support. Some of these factors are extensively analysed in the following sections..

2.5.1 Poor interaction with general CAD systems

The issue of Building Graphical Representation (BGR) has well been addressed in the past. There is a variety of CAD or Building Information Modelling (BIM) tools available to the Conceptual designer [*Morbitzer 2003*]. These tools have contributed to the design of numerous building projects. Support to the end-users of these applications is also well established. However, they lack functionality with regards to energy and environmental assessment.

Despite the worldwide trend among simulation tool developers to introduce functions so that CAD drawings can be imported to their tools, there are still barriers to fully implement this feature [*Mahdavi 1999*]. The integration of detailed simulation methods and CAD systems is complicated by the fact that the building representation needed for detailed simulation methods does not adequately match the representation used in commercially available CAD systems [Mahdavi 1999]. For example, detailed thermal simulation methods require the definition of spaces and zones, and not just bounding surfaces (combination of walls and slabs). The majority of commercial CAD systems rely on building representations that do not include spaces. A space-based CAD system however, would provide a representation that needed for most detailed performance simulation routines [*Morbitzer 2003*]. The lack of CAD integration among many simulation programs is commonly found in literature [*Hien et al 2000, Donn 1997, Robinson 1996*]

Over the last 5 years[3] there is a considerable amount of effort to address the issue of CAD and simulation tools integration. Examples can be found among many BIM and CAD tools that enable the user to export a specific model in various formats. Also, many simulation tools have

3 Conclusion based on the Author's own research. (reference date: the publishing date of Morbitzer [Morbitzer 2003] thesis.)

included mechanisms to import drawings from such tools. In addition, many CAD vendors have increased the functionality of their tools by enabling the user to define zones. However, the geometrical models produced by CAD tools are often very detailed (overhangs, wall and window finishes, detailed façades, etc.) thus the zone definition becomes more difficult than creating the model from scratch using the simulation tool's geometry definition functions.

The geometry definition of a simulation model is an important issue. For example both thermal and lighting simulation require an accurate geometry definition of the building or the building section to be simulated [*Morbitzer 2003*]. Despite the fact that building simulation tool developers have integrated enhanced geometry definition functions in their tools, they are still not as flexible as state-of-the-art CAD tools. However, most conceptual designers will be familiar with advanced geometry definition functions of CAD tools, allowing them a quick definition of the model geometry. Thus, the conceptual designer is unlikely to use simulation tools, due to limited functionality.

2.5.2 Complex user functionality and input data

From an engineering point of view frequent users of building simulation software are generally confident in the application of simulation tools. However, as mentioned in section 1.6.3, the most energy savings can be achieved if simulation is applied at the early stages of design, where architects predominate. Given the considerable complex user functionality of such tools and the limited energy modelling knowledge of architects, the lack of ease of use will reject simulation practice from practitioners.

In addition, the increased amount of input data required to fully define a model for an energy analysis is a repressive factor to the uptake of simulation. Inputs such as occupancy, hot water usage, lighting power densities, HVAC system types and schedules for hourly temperature settings, lighting use and ventilation rates can be a nightmare for a non experienced user. Furthermore, some other information about the building is not clearly defined yet. This information is related to glazing area, material use, construction type, orientation, etc. These are very important parameters in a simulation exercise since they constitute some of the primary energy and environmental performance variables. The paucity of information is creating endless difficulties to potential simulation users.

2.5.3 Interoperability issues

A survey has indicated that interoperability can contribute to the uptake of simulation in all design stages [*ARTI 2002*]. Software interoperability is the ability to share data amongst a variety of related but still different purpose tools. Data that are input into, and generated by, each individual tool, can be transferred to other programs. The data sharing can be achieved by mapping the relevant data within each program to a data model that comprises a superset of the information required by the full set of programs [*Hitchcock 2002*].

There are several problems associated with creating interoperable tools and getting them adopted by market [*Hitchcock 2002*]. Some of them form a chicken-and-egg problem. This is because software users that do not fully understand the benefits of interoperability do not create a market for interoperability, and on the other hand, software vendors who do not perceive a strong market demand are unwilling to commit resources to developing new capabilities to enhance interoperability.

During the past, each simulation software defined its own unique data representation (data format) This was due to the lack of a standard. However, over the last years, the International Alliance for Interoperability (IAI) has made a great contribution to the development of two international standard formats. The first, which is called the Industry Foundation Classes (IFC), is an object-oriented specification of the attributes of, and relationships between, building related entities. The IFC data model represents tangible building entities such as walls, windows, ducts, and chillers, and intangible entities such as project, task, and budget, as objects with sets of attributes [*Hitchcock 2002*]. The second, which is called green building's Extended Markup Language schema (gbXML), is is a solution to the problem of how to share data between 3D-CAD and energy simulation software. This schema was published and shared openly with other software developers worldwide to expedite the significant economic and environmental benefits to come from linking the two types of software. GbXML is also the draft schema for the International Alliance for Interoperability aecXML Building Analysis & Performance working group. Efforts are under way to coordinate gbXML and other aecXML standards with IAI's ongoing Industry Foundation Classes standards development effort. [*PIER 2002*].

2.6 Parameters the Conceptual designer will want to evaluate

2.6.1 Introduction

There is a number of design parameters that Conceptual designers will want to evaluate because they know that can influence the energy and environmental performance of a particular design. One example is the glazing area of a façade, which has an impact on the heat loss through the building envelope, solar radiation entering the building and on natural light penetration.

However, Conceptual designers are often uncertain of the implications of large glazing areas. Another example is the impact of thermal mass on the summer performance. All these are parameters that designers are generally aware, but are not able to evaluate [*Morbitzer 2003*]. The following sub-sections provide more information with regards to what kind of parameters the designers will want to evaluate, with respect to the energy and environmental performance of a building. Also, a short discussion is given, regarding building technologies popular among designers.

2.6.2 Parameters to evaluate

Building orientation

Building orientation is the most common design alternative among conceptual designers. The orientation of a building's façade can be modified so that passive heating, lighting, heat losses, etc. can be examined. How far the orientation of the building can be altered, depends upon design constraints. The site may allow one orientation for a building or the architect might not be prepared to consider another orientation due to prestigious reasons[4]. In addition, the availability of different possible orientation may also be restricted by site access or fire regulations.

Insulation of building envelope

The construction types used in the building can significantly effect the energy and environmental performance of a building. These are often defined by Conceptual designers. However, the designers will probably be unfamiliar with the underlying physics of different construction types (and thus the thermal and acoustic properties of the materials used). Hence, they prefer to describe a construction type according to the U-value [*Morbitzer 2003*]

Construction types are an an important element of the conceptual design stage since they commit a significant amount of the capital invested. Conceptual designers need to be familiar with construction in order to establish the cost of a building. In addition, construction time depends upon the building materials used. Furthermore, the finishes (material use) of the building envelope influence the aesthetic appearance of the building. Aesthetics is among the high-level priorities of Conceptual designers. Thus, the designer will have to take under consideration aesthetics, costs, energy performance and implementation time before deciding which construction types to use.

Another important issue about the insulation of the building envelope is the use of U-values

4 Perhaps in order to direct a certain building section with a prestigious façade towards a certain orientation.

with regards to glazing. A preliminary investigation about the optical and thermal characteristics of glazing takes place in the conceptual design stage. This was indicated by two non-related (to each other) market surveys undertaken in the US and the UK [*Vanguard 2006* and *ARTI 2002*]. However, in conventional building design, the client will probably ask for simple double glazing. If the intention is to design a low energy building, high insulation glazing should be taken into an account [*Morbitzer 2003*].

Glazing area

Glazing area is an important issue for Conceptual designers. This is mainly attributed to the influence of glazing areas to the aesthetics of a building. Prestigious fully glazed entrance halls or fully glazed façades are common in the built environment. Decisions about glazing are are usually taken in the conceptual design stage. Further to aesthetic implications, glazing's thermal and optical properties have a great influence to the energy and environmental performance of the building. The main objective of a conceptual designer, in terms of energy performance, is to investigate the optimum glazing/wall ratio.

Thermal mass

The massing of the building is also affected by early decisions related to the building construction. The thermal mass can significantly influence summer comfort within the building. A number of considerations will influence the design decision. Lightweight partitions are cheaper than brick partitions and also offer a higher degree of flexibility for future changes of the room layout. Suspended ceilings are often used for the building services. Despite these disadvantages a designer might still chose a heavyweight construction if benefits are drawn from such a thing.

Shading devices-Solar control

Despite the fact that a detailed design of shading devices and solar control will be elaborated at later (Scheme and Detailed) design stages, it is still feasible to evaluate the general potential to improve summer comfort conditions. In addition, since shading devices have an impact upon the aesthetics of the building, designers will want to examine some aspects of shading and solar control as early as possible. Thus, the study will have to be carried out in a pragmatic way, e.g. by enabling the designer to incorporate an advanced solar control mechanism, such as external blinds, to give an understanding of the potential of applying solar control. With this approach the designer obtains a general understanding in how far solar control can or cannot enhance the summer performance of the building (solar control might actually in some cases not be useful because cooling loads are produced for example by internal heat gains).

Floor plan depth, Daylighting and Ventilation

Floor plan depth is another important design parameter at the Outline Design Stage, and the implication of the choices made should be made clear to the designer. Decisions made have influence on the heating and cooling loads, the natural light in the building and the energy requirements for mechanical ventilation.

The floor plan depth, and hence the ratio of the building volume to the external surface area, affects both the heating and cooling load of the building. A compact building design reduces the external surface area and hence the conductive heat loss of the building. In addition, uncontrolled infiltration does not occur in areas located in the centre of the building (except if there is an atrium). Rooms in the core of the building will also not receive any direct solar heat gains. The cooling load that needs to be provided by the air conditioning plant can thus be reduced to the cooling of ambient air and the removal of internal heat gains but not solar gains.

Daylight is only available at the perimeter of a building. A number of parameters that influence the daylight availability in the building are often not determined at this design stage. Examples are the colour of surface finishes, the window shape and location in external wall. Making a prediction of the daylight factors at early design stages will provide results with some degree of uncertainty, but the information is still of significance for later design stages and the general performance of the building. Energy requirements for mechanical ventilation is another factor affected by the floor plan depth. Deep core buildings can have significantly higher energy requirements caused by the need for mechanical ventilation.

Space usage

A significant part of the design decisions made at the Conceptual Design Stage is the location of different functional zones in the building. This can be influenced by operational (distance between two different functional zones of a building) or external conditions (place the ward section of a hospital so that the occupants have a nice view towards the outside). A change in space usage can influence both energy consumption and comfort of a building. For example, positioning a building zone with high internal gains in a south or west-orientated building section can increase summer overheating problems. The designer might then deliberately change the distribution of different space functions to improve the performance of a building [*Morbitzer 2003*].

Enabling a designer to assess these implications can support the decision process and space usage was therefore included as a parameter.

2.6.3 Emerging technologies and discussion

The parameters presented in the previous sub-section are related to what the designers will need to evaluate so that they can give preference to a particular design proposal. However, as this will be discussed in section 2.7, not all of these parameters can be evaluated when the building is at early design stages.

The parameters presented in the previous sub-section are a small part of the so-called “Building Technologies”. These technologies are related to the application of certain techniques for improving the energy and environmental performance of the building. A report from the Air conditioning and Refrigeration Technology Institute [*ARTI 2002*] based on a web survey among architectural practitioners (among others), has indicated the emerging technologies that Conceptual designers would like to incorporate into their designs. In essence this report has shown that designers are interested on various techniques which require relatively complex simulation exercises. The following table (*table 2.1*) indicates the ten most popular building technologies among architects.

Daylighting/ Skylighting
High performance windows
Passive solar heat
Ventilated Façade
Photovoltaic panels
Transpired solar walls
Radiant Heating and Cooling
Mass Cooling
Cool Roofs
Natural and hybrid mode ventilation

Table 2.1 Emerging building technologies among Conceptual designers [after ARTI 2002]

Questions are risen with regards to whether these technologies can be part of the conceptual design stage or not. This is because they typically require a a considerable amount of time to be modelled and time is not plenty in the conceptual design stage (also see section 2.3.2).

2.7 Discussion about energy modelling limitations in the Conceptual Design stage

As mentioned earlier (sections 1.7.6 and 2.5), information about certain aspects of design is not clear. Hence, many of the parameters that the designer will want to evaluate cannot be modelled and simulated unless some interrelated parameters are set to a default value. For example, it is not possible to introduce natural or hybrid ventilation schemes at the conceptual stage without having to make a large number of assumptions on thermal mass accessibility, ventilation control, occupancy type, etc.

In order to avoid confusion when dealing with energy simulation modelling in the conceptual design stage, an informal modelling framework is used. This framework consists of assumptions assigned to reduce the "level of freedom" between interrelated parameters. For example, by assigning parameters such as construction type, glazing area, building geometry, etc. at a constant value, the modeller can investigate the optimum orientation of the building as well as indicate where significant heat losses occur. Thus, by allowing one single parameter to "free float", useful for the Conceptual designer conclusions can be made. A similar approach is implemented in the LT-method to assist designers with optimizing building/glazing ratios [*Baker and Steemers*].

Making a prediction of certain parameters by setting some others as constant will provide results with some degree of uncertainty, but the information is still of significance because it can provide information about design guidelines applied on the actual project. This information can be useful for later design stages and the general performance of the building. However, despite the benefits of this type of modelling, the framework cannot be used to provide feedback for all design parameters, when there is a strong interrelation among them.

Another important implication when applying simulation into the Conceptual design process, is risk. Despite the benefits, the use of simulation at early design stages is not risk free. MacDonald [MacDonald et al 2005] states that there are many unknowns and although the impact of assumptions can be quantified it is not routinely applied. Strachan [*Strachan et al 2003*] states that the simulation practitioner relies on his/her knowledge leading to new problems, such as increased risk of liability to the practice, unfamiliar working methods, lack of fundamental knowledge and increased in workload.

2.8 Discussion and Thoughts about the next generation of building simulation software.

Through this chapter the major barriers to adopt simulation in the design practice were mentioned and some of the most essential parameters influencing the uptake of simulation in the conceptual design stage are analysed in details. As a result to these parameters, energy analysis is often postponed to a later point in the design process, resulting in a limited number of cost-effective options for improving energy performance than if simulation exercises had been considered from the beginning. In this section of the chapter a discussion will take place surrounding issues mentioned earlier and suggestions regarding what features the next generation of building simulation tools should incorporate will be presented.

Many CAD and BIM have started to incorporate modules that enable the user to define spaces within his/her models. Examples can be found in vendors such as Autodesk, Artifice and Bentley [*gbXML schema 2007*]. This trend is a result of an increased need for whole building energy analysis starting from the conceptual design stage. However, classical simulation techniques do not allow a non simulation expert to perform a simulation exercise.

According to CIBSE [*CIBSE 1998*] there are two ways of addressing the issue mentioned in the previous paragraph. These will be either to apply simplified simulation tools at early building design stages and sophisticated tools at later design stages, or use sophisticated tools throughout the design process. However, as this will be presented in section 2.9, this MSc project proposes a different approach.

Mahdavi [*Mahdavi 1999*] states that the introduction of simplified simulation tools in the conceptual design stage had led to problematic conclusions. He discusses the appropriateness of "simplified" models to cope with the "complex" nature of early design. This is due to the fact that the nature of the physical phenomena involved in the building performance do not imply lesser levels of complexity in the early design stage than other design stages. The relevant difference for the simulation process lies rather in the resolution of the specifications of constitutive building components both in terms of geometry and behavioural properties. Thus, the initial building model, even if it is not well defined with regards to component specification, should be evaluated and the process should be based on simulation methods taking into an account fundamental physical processes involved.

Morbitzer [*Morbitzer 2003*] and Clarke [*Clarke 2001*] suggest that the approach of "one software during the process" is more efficient than using a succession of tools. Through this mechanism communication is improved between the different design parties and performance predictions are based on the same simulation engine. The implementation of this concept has resulted in an efficient tool (named ODS-interface) which aims to guide the inexperienced designer to perform a simulation exercise [*Morbitzer 2003*]

Addressing the issue of interface complexity, which is one of most essential factors to the widespread adoption of simulation tools in the early design stages, is not a trivial task. Suggestions have been presented regarding the way information should be imported and viewed [*Mahdavi 1998*]. A promising concept is the one presented by Clarke and MacRandal [Clarke 1993]. According to this research, the issue of different knowledge-experience among different architects regarding energy and environmental implications in buildings, is addressed. A "user conceptualization" interface that adjusts its functionality depending on the experience of the user, is proposed. This implementation will result in a simulation tool that will have different user functions depending on the background of the user. However, the concept has not (yet) been implemented in a software tool which is currently available for designers.

Another promising concept that can contribute to the adoption of simulation into the conceptual design stage is the use of Intelligent Default Data (IDD). These can partially address the problem of increased amount of input data requirements to fully define a model for an energy analysis. The importance of input data is frequently mentioned in literature [*CIBSE 1998, Mahdavi 1998, Morbitzer 2003, PIER 2002*] particularly in the scheme and the detailed design stage. In addition, an important point relates to missing data in early design stages. If the required data are hardly known or even unavailable, then logical assumptions can be taken according to the type and the use of the building. However, there is a paucity of consensus on "default" values and thus, should be used with cautiousnes.

Well known software that take advantage of IDD are EnerWin, Energy Express, EcotecT, ENERGY 10, SEMPER and Green Building Studio (see section 1.7.5). These tools enable the conceptual designer to overcome the difficulty of missing data by specifying the type of the building. A different module is then used to calculate the size of the building by accessing its geometry file and assumptions are taken in terms of occupancy, hot water usage, lighting power densities, HVAC system types and schedules, lighting use and ventilation rates. In addition, several software have incorporated the use of default libraries were the user can select among different occupancy types or HVAC system configurations.

World wide web is considered to be the primary medium for commerce and trading. One of the reasons of its success is that it allows the interaction of a user with a client server through a Service Oriented Architecture Protocol (SOAP). It is quite likely that simulation will be introduced to a web based context throughout the next years as a SOAP application. For example, a highly sophisticated simulation engine can be "on-line" and ready to respond to energy analysis queries. Software developers can focus on developing interfaces that work with this structure. However, a significant barrier towards the implementation of this concept is the development of a standard format for such an application. Currently, the gbXML schema has demonstrated that can address this issue [*Green Building Studio, 2007*]. Since gbXML is a XML schema, it can provide the appropriate medium format for internet applications. The development and the adoption of gbXML by state of the art simulation tools will enhance further development. Currently gbXML data format is supported by more than 15 software vendors (CAD/BIM and Building Energy and Environmental Analysis (BEEM) systems [*gbXML schema 2007*].

There are several reasons to implement such a concept through the internet. Morbitzer [Morbitzer 2003] states that with the current developments in the working environment of building designers, it is likely that Internet or Intranet based applications will, at some point, be necessary to utilise simulation programs in the building design process. Mahdavi [Mahdavi et al 1999] mentions that Internet and Intranet are used to connect offices located in different parts of the world in order to enable staff to work from home. In addition, the use of a web-based simulation software will enable the users of the software to collaborate on a specific project with an on-line support team that operates the system. Hence, enhanced support options can be provided to the user.

Ideally, next generation systems will incorporate the use of interfaces varying according to the problem addressed and the level of user experience. These interfaces will enable the user to quickly define a model in a format that promotes interoperability. In addition, the performance predictions will be in a standard format according to the design stage in which the design question is addressed as a certain modelling task. For example, a standard performance prediction analysis format will be issued according to the design to which the simulation is taking place. This can also enhance the comparison between simulation engines. The use of one software during the whole design process will not be necessary if one data format is to be supported by all major vendor developers[3].

2.9 Research aim and tasks

Through the sections of the introductory chapters (chapters two and three) of this dissertation a description was made regarding why the conceptual designer will need to take energy and environmental performance issues under further consideration. It was made clear that the decisions made in each design stage do not have the same impact to the building's performance. The most potential savings can be made while the building is still at early design stage. Simulation is the most accurate way of quantifying the energy and environmental performance of a particular design option.

Through the literature research conducted and presented in these chapters, it became clear that there is a series of barriers to the uptake of simulation in the design practice. Despite the fact that simulation is well established in the Scheme and the Detailed design stages, the smallest uptake

3 However, as this will be discussed later in this dissertation, this will not be an easy task.

of simulation occurs at the conceptual design stage. This is due to the fact that not all the design stakeholders experience the same difficulties in using simulation.

The general aim of this research project is to address the problems that inhibit Conceptual designers to use simulation within their practice, by suggesting a method which is based upon three key principles:

- ➔ Interoperability among building energy simulation software
- ➔ Friendly user interface
- ➔ Full 3-D CAD-sketching integration

These principles have been identified as the primary drivers to enable the use of simulation by non experts to building modelling tools as this was discussed in sections 2.5 and 2.8.

The method proposed focuses on the conceptual design stage were a preliminary simulation model is created by using a modified 3D sketching tool. This model is then saved in a gbXML data format and exported to a model manipulation and simulation tool where it is populated with Intelligent Default Data. Then a simulation is run and the results are presented to the user. Hence, the Conceptual designer can have an idea (strategic decision support) about the energy and environmental performance of his/her designs, without having to spend too much time in modelling. The same procedure can be carried out as many times as required to determine the optimum design proposal. The user can either continue defining different design versions creating a more detailed model, or pass the model to a simulation expert for further component definition (since a standard data formatting has been applied). One way or another the conceptual designer will be sure that the design proposal will not "fail" to comply with energy and environmental performance standards since the optimum design option (in terms of energy consumption) will have been selected. The method is presented in chapters three and four.

The core research aim of the project is to build the specifications of a tool that allows the Conceptual designer (who has no experience in building simulation modelling) to create a simulation model and perform a simulation exercise. The tool should be able to provide the user with strategic advice about certain aspects of design. The development of this a tool will assist the conceptual designer to adopt simulation within his/her practice.

In order to pursue the core research aim, the following tasks (including research tasks) have been specified:

- ➔ Investigate what are the needs and priorities of conceptual designers.
- ➔ Develop an interface based on ease of use, that corresponds to the conceptual designer's

needs and translates requirements into operating tasks.

- ➔ Investigate the specifications of a tool that addresses certain aspects of design and translates operating tasks into simulation tasks.
- ➔ Build prototypes
- ➔ Use a 3D CAD-sketching tool and adjust the prototypes to this tool.
- ➔ Identify what modelling information need to be defined and save this information in a gbXML format.
- ➔ Demonstrate integration with external energy analysis systems using custom gbXML upload clients or direct web services/ SOAP interaction *(justification provided in chapters three and four)*

Chapter 3:
Method Proposal, Requirements and Considerations

3.1 Introduction

The previous chapters of this Dissertation indicated what kind of information is available and what kind of information is required in the conceptual design stage, as this was found in literature. This chapter initially presents a method to address the issues responsible for the small uptake of simulation within the conceptual design stage of a building. Then discusses issues related to both the structure and the interface of a tool that provides the link between the sketching environment and the simulation engine. The main purpose of the tool is to provide the conceptual designer (with limited or no previous experience on building energy modelling) with strategic advice about certain aspects of design by assisting him/her to perform a quick energy and environmental analysis at the early stages of design. Finally, general considerations regarding the functionality and the tasks this tool should be able to perform, are presented.

3.2 Method proposal

3.2.1 The method

The method that led to the core research aim of this project was first mentioned in the previous chapter of this Dissertation (section 2.8). This section (section 3.2) presents more details about the structure and the tools necessary to apply the method.

The method consists of a sequence of two tools. The process is described below:

- ➔ Model generation using a specific 3D CAD-sketching tool
- ➔ Zone creation and attribution by using a Data Mining[4] and Management tool[2] applied on the CAD-sketching application, which allows the designer to save the model in a specific[3] format
- ➔ Upload the model in an external web-based energy analysis system using an upload client or a direct SOAP application. The model is then populated with Intelligent Default Data (IDD)

4 Data mining normally relates to the extraction of hidden predictive information from large databases, but when the Author refers to Data Mining, the 3D sketching model is viewed as a database.

2 When referring to "Data Mining and Management tool" we refer to a tool that can extract first-level information from Google's SketchUp.

3 When referring to a "specific format", a format that allows data exchange with several other software is meant.

so that a complete, with regards to simulation, model is created. The simulation is then handled by an advanced simulation engine and results are 'sent' to the designer.

Two general tools can be identified in this process – The 3D sketching tool and the web-based energy and environmental analysis tool. However, in order to link the sketching tool with the web-based tool there is a need to develop and introduce a bespoke tool (plug-in) to the sketching environment. A building's visual representation in the conceptual design stage is usually defined by using a tool that can generate 3D forms quickly and easy. When the model creation is finished, a bespoke Data Mining and Management (DMM) tool that works as a plug-in on the CAD-sketching application is used to define certain information necessary for building energy modelling (zones, surface type, openings type, construction types, material use, etc). The model is then saved in a specific format and the designer can upload the model on the web to get a quick energy and environmental performance assessment of the design option. This is achieved by using a Service Oriented Architecture Protocol (SOAP) application. The following figure (*figure 3.1*) gives an overview of this method as well as which tool is applied to which step.

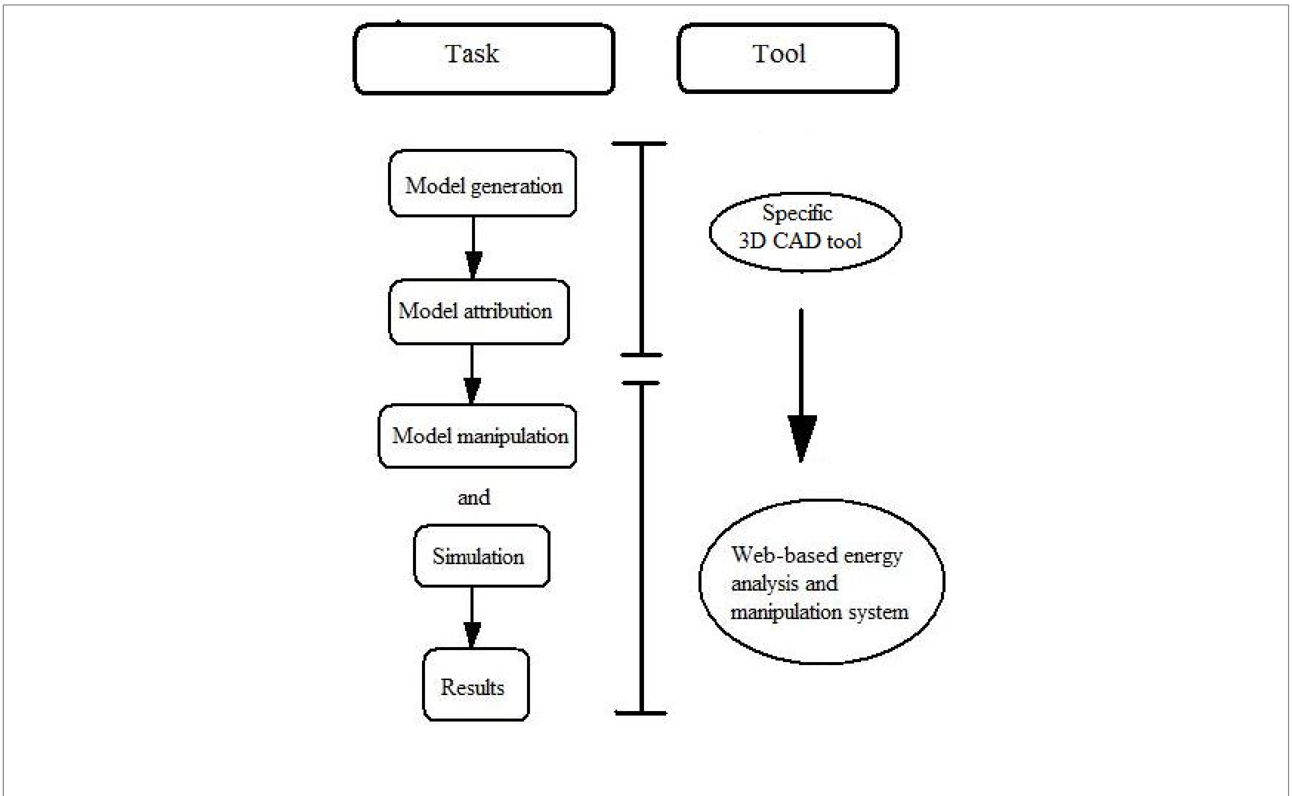

Figure 3.1 *Method Proposal*

3.2.2 Discussion of the proposed method

As indicated by research conducted by the Key Centre of Design Computing and Cognition

(Bilda et al 2006), there is no significant difference between sketching and not sketching as far as this concerns the design outcome, the cognitive activity and idea links. However, these conclusions were made with regards to experienced architects in defining design objectives. Nevertheless sketching is an important element of early design decisions because it allows the quick representation of concepts made by the designer, especially when using 3D CAD-sketching tools. The designer by using these tools can easily generate 3D forms. This is one of the primary considerations of the method presented above due to the fact that the conceptual designer needs to create, view and modify his/her ideas quickly and easily. In other words, the environment that a designer will need to work in the conceptual design stage will have to provide high level of flexibility. State-of-the-art CAD or BIM tools can provide this level of flexibility. However, as mentioned in section 2.5, the majority of these tools do not support zone definition[4] and surface attribution[4] (both essential in defining an energy simulation model). Also, it is worth mentioning that a very detailed representation of the building is not recommended in the early design stages. That is because in the early stages of design the model(s) is constantly changing. Thus, a more friendly to the needs of the conceptual designer 3D CAD tool should be used such as a 3D sketching tool. The tool used in the conceptual design stage should not block the designer's most essential feature – spontaneity.

The design at the early stages of a building undergoes constant and rapid changes. The designer should be able to apply changes in terms of functionality and aesthetics, but ideally should also be able to undertake a more or less immediate evaluation of the energy and environmental assessment of a design proposal [*Morbitzer 2003*].

There is a variety of 3D sketching tools available in the market. However, not all tools support a global geometry definition system, which is an essential element of geometry definition in building simulation tools [*Mahdavi 1998]*. Information regarding vertexes, edges and surfaces is very important in defining a simulation model and thus, if a sketch tool is to be used for the geometry definition of a model, a special plug-in that translates relative coordinates into a global coordinate system is required. This plug-in should integrate a Data Mining System (DMiS) to “extract” the information required and an Data Management System (DMaS) to enable the designer to define zones and assign attributes to surfaces as well as modify and group components. The development of such a plug-in and its interface is the core research of this dissertation and will be extensively discussed in this and the next chapter.

Geometry definition is only one important parameter in building energy modelling. As indicated in the second chapter of this dissertation, a considerable amount of information regarding several aspects of the building, is not well defined while the building is still at early design stages.

4 However, leading CAD and BIM vendors have started to incorporate this feature in new versions of their tools

However, the use of simulation is essential in identifying the impact of early decisions upon the energy and environmental performance and should be applied by setting some simulation parameters at a default value. Intelligent Default Data (IDD) is commonly applied to address this issue by implementing default values in missing simulation parameters. The default values are based on building practices and codes for a specific area of the globe. However, this generates questions about the accuracy of the results of the method. The use of “default” values should be reconsidered and carefully analysed when developing a conceptual design tool. Further details can be found in the fifth chapter of this Dissertation.

A web-based manipulation and simulation system can provide the IDD attribution mechanism using a SOAP application. Hence, the model created from the sketching tool and attributed in the Data Mining and Management tool, can be populated with IDD to create a complete for simulation model. Then a web-based energy simulation can take place providing the user with an energy and environmental analysis. The main advantage of having a model manipulation tool “on-line” is that the construction database can be up to dated according to regional, national and international standards. Also, the fact that internet protocols run on a variety of computer platforms, makes the tool platform independent and enables the development of bespoke interfaces for certain design stages. In addition, the infrastructure of an internet application that enables the use of a web-based manipulation and simulation system will enable different conceptual designers to collaborate on a specific project. This can be implemented by adding new and/or amending older design versions of the model and comparing their energy and environmental performance on-line. Hence, sharing all the information required to describe the rapidly changing model with all the design stakeholders is easy.

3.2.3 Justification of the proposed method

According to the Building energy and Environmental modelling guide [*CIBSE 1998*] there are two ways of obtaining an energy and environmental analysis. These will be either to apply simplified simulation tools at early building design stages and sophisticated tools at later design stages, or use sophisticated tools throughout the design process. With regards to the conceptual design stage, Mahdavi [1999] reports that the use of simplified tools cannot cope with the complexity of decision making. Hitchcock [*Hitchcock 2002*] mentions that this procedure is not only costly in time and resources but also prone to error. Morbitzer [*Morbitzer 2003*] and Clarke [*Clarke 2001*] suggest that using the same tools throughout the conceptual design process is the best way of introducing simulation at this stage. However, the development of such a tool is not a trivial task. Tools that can assist the conceptual designer have already incorporated the use of conceptual design wizards and guided design process tools. However, despite the use of these "Intelligent" systems, simulation is still not implemented to a great extent (justification provided in section 2.5). Another method will be to use advanced tools in early stages of design by forming a multidisciplinary design team. Nowadays, more and more design teams consist of designers with different disciplines (architects, modelling experts, building services engineers) working together. However, this is a rather costly option which small companies cannot afford.

The method proposed in this dissertation is based on the use of two tools and relates to the conceptual design stage. The problem of interoperability among these two tools as well as among all design stages tools is addressed by using a standard data format (gbXML). In addition, the conceptual designer can work in a 3D sketching tool that he/she is familiar with. Furthermore, the complexity of defining a preliminary simulation model is automatically or semi-automatically handled by a Data Mining and Management tool and by the use of "Intelligent Default Data".

3.3 Considerations about the basic framework of the tool

3.3.1 Introduction

The previous section of this chapter has presented a method that enables conceptual designers to get a quick energy and environmental performance analysis for their concepts. This section presents general considerations about the development of a plug-in (Data Mining and Management plug-in) to be used in this method in conjunction with a sketching 3D environment. In more details, the requirements from such a plug-in, in terms of structure and user interface, will be discussed.

The data mining and management (DMM) plug-in is an essential part of the method described above. This is because it provides a fundamental link between the sketching tool (3D CAD application) and the simulation engine (web-based). The basic structure of such a plug-in should allow the "extraction" of the required information from the sketching tool, support algorithms to process this information so that a semi-complete model can be created and save this information into a format that can be imported to a simulation engine. On the other hand, the interface of this tool must be designed with respect to user functionality and general aesthetic rules[5].

3.3.2 Tool's structure general considerations

As mentioned previously the structure of this plug-in should be able to extract the necessary

5 General aesthetic rules can be applied to make the interface of the tool look more attractive to the end users so that adoption within their practice will be enhanced.

information from the sketching tool and process this information to create a preliminary simulation model. When referring to a preliminary simulation model, a complete model in terms of geometry, building type, surface and openings type, construction type and locational information is meant. The model can then be attributed in terms of occupancy type, HVAC configuration, infiltration and ventilation rate and internal gains though the use of Intelligent Default Data (IDD) in the “Model manipulation and Simulation” part of the method presented in section 3.2. In the following paragraphs the basic tasks the plug-in should be able to perform, are presented.

Geometry configuration

Geometry is one of the most essential parts of a simulation model. The development of the building's shape should be only limited by the designer's imagination. The use of a 3D sketching tool can provide the designer with the flexibility required within the conceptual design. The basic structure of a 3D geometry model consists of three coordinates (xyz) that form vertexes. Vertexes form edges and surfaces. Surfaces form spaces[6] and spaces form the functional structure of the building.

Ideally the plug-in should incorporate a generic algorithm to automatically identify spaces. Thus, the designer-user will not have to spend time to specify the surfaces a zone consists of. The algorithm to support this feature should be based on geometric facts (for example, if two surfaces are adjacent to each other, then they share an edge, etc.). Also, while spaces are created, there is a need to ensure that the particular space is contiguous. This can be achieved by developing and integrating algorithms to perform this task.

Surface and space attribution

The model created in the sketching environment consists of many surfaces which form spaces. Each surface should have its own identity (ID) so that it can be referenced whenever this is necessary. Surface attribution is also an essential part of building simulation modelling. By attributing surfaces the user can specify whether the specific surface is an external or an internal wall, underground or roof slab, etc. In terms of openings attribution, the tool should be able to identify whether a sub-surface is attached to another so that the opening (sub-surface) can be referenced with regards to the surfaced attached. Then the attribution of the openings could be

6 In some simulation tools “spaces” are defined as “Zones”

established by specifying the opening type (fixed window, air, skylight. sliding door, etc.)

Ideally the plug-in should be able to identify the type of a surface without any user interaction. Hence, the designer can focus on other aspects of the model attribution minimizing the time required to define a simulation model.

Construction and materials

After the geometry has been defined and surfaces, sub-surfaces and spaces have been referenced (in terms of surface type) each surface should be linked to a specific construction type. Construction types consist of several material layers with different thickness. The use of a material database in conjunction with a support database referring to transparent and translucent construction types is mandatory.

Most conceptual designers are familiar with the use of construction types according to their U-value [*ARTI 2002, GreenSpace research 2006*]. Hence, the construction database of the plug-in should provide a variety of construction types according to their U-values and not according to the materials that form the construction type.

Building type and building name

As indicated in the second chapter of this dissertation, there is a paucity of information regarding several building's components in the conceptual design stage. However, the benefits deriving from the introduction of an energy analysis at early design stages is of great importance. The use of simulation is essential in identifying the impact of decisions upon the energy and environmental performance and should be applied by setting unknown simulation parameters at a default value according the building type, using IDD and Support Databases. Thus, it is mandatory that the tool supports the definition of the building type (office, hotel, hospital, dormitory, residences,etc.) so that the appropriate use of default data is loaded when filling the “missing parts” of the simulation model in the web-based manipulation and energy simulation tool. In addition, the user should be able to define the building's or project's name so that it can be referenced later in the design process.

Location

A building's energy consumption and indoor climate are determined by complex dynamic functions between the outdoor environment (air temperature, humidity, solar radiation, wind speed, wind direction), and several other components of the building. Hence, the conceptual designer should be able to define the location of the building so that the results of the simulation will be with regards to the specific environmental conditions. An efficient way of specifying the location of the building is by using the post code of the area. A support weather database will have to be linked with the post code and provide the local weather data.

Model exporting

The plug-in should be able to export the preliminary simulation model into a gbXML format. Thus the model can be attributed further in a more advanced simulation tool (IES, EnergyPlus, ESP-r, etc.). The advantage of exporting into a gbXML format type is that the same model is passed for further analysis as appropriate in later design stages (Scheme and Detailed). In addition and according to the proposed method (section 3.2) the same model can be sent using a SOAP application to the web-based manipulation and energy simulation tool by the conceptual designer.

Data management system

In order to process the data collected by the Data Mining and Management plug-in, a basic Data Management System (DMS) should be applied. This system will handle all information about geometry mined from the 3D sketching tool. Algorithms to support the data processing will be based in logical assumptions and general geometrically true facts. For example, after the extraction of the vertexes that form a specific surface, the DMS can process this data and make logical conclusions about the type of the surface (exterior wall, interior wall, etc.) by using “tilt”, “azimuth” and “surface normal” values. In addition, the DMS could support the automatic (or at least semi automatic) creation of spaces (as mentioned earlier in this section).

The data processing functions that support the 'intelligent' space definition and surface type attribution are complex and demanding in terms of computing resources. This has consequences on the effort required when developing the related computer code, effecting the developing of the code and the time to ensure its correctness [*Morbitzer 2003*]. However, by introducing a DMS the developer can create additional data processing options such as highlight the surfaces that have a certain construction attribution or delete or copy a space.

3.3.3 Tool's interface general considerations.

One of the main reasons for the small uptake of simulation in the conceptual design stage is that the functionality of simulation tools reflects the conventional notion of the design process. According to this notion, formal and aesthetic decision making and the fulfilment of building performance requirements (thermal lighting and acoustics) are regarded as discrete and sequential rather than concurrent activities [*Mahdavi 1998*]. In section 2.5 it was indicated that the interfaces of most simulation tools were developed from engineers primarily for engineers. This has resulted in difficult to use tools, from a conceptual designer's point of view. In addition, most of these applications are using outdated programming language applications (mainly based on Fortran and C). Hence, incorporating new technological features, like Rich Internet Applications (RIA), to enhance the Graphical User Interface (GUI) by using modern programming languages (Java, Ruby, Flex, etc.) is a difficult task, in terms of time and effort.

The development of a user friendly interface for the DMM plug-in is a challenging task for the knowledge of an engineer. Interface design is very different from the engineering-structural design of the tool, which specifies architectural and programming details of how the tool is implemented. The process of interface design involves a set of steps for translating requirements into operating tasks. The process begins by getting at the structure of the tool, the central concept, and proceed by organizing functionality from the user's point of view. The interface design concept involves seven discrete steps (*table 3.1*).

Task	**Description**
Define the central concept	A concise statement of what the application is and what is not. This clearly defines the boundaries of the application and characterizes the overall user's view of the application
Describe user roles and their requirements	A list of who the target users are, what are their roles in their use of the application and what is important to them.
Define and prioritize measurable objectives and constraints	Objectives for the user interface are the designer's intentions such as: • to reduce repetitive tasks • to have users feel in control, and • to provide satisfactory feedback on results Operational definitions specify how the design will be measured against the objectives (e.g. usability testing).

Design the user's objective model	A table with all the user needs along with their attributes,actions, contents and relationships among objectives.
Design the user's task model	A list of all tasks the user needs to perform with procedures on how to perform each task using the application.
Synthesize a user interface model	The user interface model organizes the functionality according to the object and task models. This is rough outline of the user interface that guides the detailed design stage
Evaluate results against the objectives	Various evaluation methods, such as heuristic evaluation and usability testing. These are selected to measure how well the objectives have been achieved.

Table 3.1 Interface design steps [after "Interface Concepts" 2007]

It is important to follow these steps when developing a conceptual interface for an application. These steps are essential to creating a solid, user-centred foundation on which to build a successful user interface. A simple, well-defined interface design that is clearly and accurately represented in the user interface, makes it easier for users to learn and use the tool.

There are two ways of creating user interface designs: implicitly and explicitly. Implicit interface design happens when everyone believes that there is an understanding of (and agreement on) the concepts underlying the design, but no one writes them down or discuss them openly. Each person working on the interface design, develops his or her own ideas about what the tool is, what it can do and how is intended to be used. Explicit interface design, on the other hand, involves adopting the user's point of view and defining the concepts the users will need to learn, in order to use the tool and in a systematic and effective way.

There are several benefits to apply such a detailed approach to the design of an interface. First, the process is detailed and systematic enough so that the interface design team finds out early what information is lacking or needs to be further clarified. Hence, the process of interface design can be stable without the need to return to previous stages to correct mistakes or misunderstandings. In addition, designing the underlying concepts of the interface as early as possible is more cost-effective than trying to fix conceptual problems that have been built into a prototype. When the functionality is organized around user objects and tasks that the user is familiar with, applications are easier to use. The result is a better user interface from the beginning, instead of the one that requires major revisions to meet minimum usability standards.

3.4 Other considerations about the application

3.4.1 Introduction

In the previous section of this chapter some of the basic considerations about the DMM tool were discussed. These include considerations about the basic tasks the plug-in should be able to perform, as well as the importance of introducing a systematic approach when developing its interface. In this section of the chapter general considerations about the functionality of the plug-in as well as several surrounding issues are discussed.

3.4.2 Guided input process

The DMM plug-in is primarily responsible for enhancing the designer to create a preliminary simulation model. However, the user may still have difficulties in working with the plug-in. This is mainly attributed to the lack of knowledge of building energy modelling fundamentals. Especially if more advanced definition of model components (airflow networks, etc.) is to be introduced to the plug-in, the Conceptual designer will need as much guidance as possible to specify an accurate model. Thus, introducing conceptual design wizards into the model creation process can assist the designer in model definition. A similar approach is used by Energy10 [*NREL 2002*] and was identified in Robinson [*Robinson 1996*] and Pohl [*Pohl et al 2000*] as a necessary development.

3.4.3 Support databases

As mentioned in section 1.7.6 the significant amount of data to define a simulation model is one of the main reasons for the poor uptake of simulation in the early stages of design. However, a way of addressing this issue is the use of IDD and support databases. The use of such features in the DMM tool will have to be supported with the minimum user interaction as this was indicated in section 3.3.2. However, their use can also have a different functionality. Especially the use of support databases can help the designer by providing design guidelines. For example, if the designer decides to examine different design options with regards to air conditioning versus natural-mechanical ventilation, the plug-in could load the appropriate guide to provide a guideline about what kind of design approach the designer should take. Thus, the user can, for example, have an idea about how far a heavy construction could contribute towards lower temperatures in the building as well as which performance prediction data can inform him/her towards a decision.

3.4.4 Link to other design aspects

In order to encourage the integration of simulation into the conceptual design process it is important to link the DMM plug-in with additional not simulation related functionality such as cost calculations. Morbitzer [*Morbizer 2003*] states that a link to cost calculations will enable architects to evaluate energy consumption figures obtained from the simulation exercise in the context of additional initial investment cost against savings over the building lifetime, payback periods, etc. Such an additional feature is of great importance given the increase of PFI/PPP projects where the investor is also responsible for the maintenance and running costs of the building. The construction industry has already started looking buildings using a holistic approach in terms of life cycle costs.

Cost calculation is one of the top ten of emerging technologies in building design among architects [*ARTI 2002*]. Cost estimation tools have been developed especially for the preliminary design phases (definition of needs, project planning) because design decisions made at this stage have the greatest impact on the capital, operation and maintenance costs during the building life cycle. These tools enable estimation of capital, operation and maintenance cost implications of different design decisions. Particular emphasis should be placed on estimations which have the greatest impact for energy economy during the life cycle of a whole building or part of a building.

3.4.5 Graphical User Interface

The GUI of the plug-in is of great importance because it is responsible for providing the visual background in which to build the user functionality. Hence, it is one of the primary stakeholders “in charge” for the acceptance of the plug-in (especially when commercial aspects derive from its use). Since conceptual designers are most likely to use the plug-in, the GUI should reflect the aesthetic requirements of a user that is familiar with advanced design objects. The GUI of the plug-in should conform with one of the most important aspects of architectural design - Aesthetics.

However, building the aesthetic requirements of a plug-in to be used by conceptual designers is beyond the scope of this project. Hence, there is no deterministic justification provided for designing the layout of such a tool in this dissertation (chapter 4). Thus, the GUI is a product influenced by the Author's point of view about software aesthetics.

3.5 General considerations for the development of the data model

Before describing the data model of the DMM plug-in, there is a need to display some background information related to the basic concepts of a data model.

A data model represents information related to a certain part of the real or abstract world. This is the so-called Universe of Discourse (UoD). In the IFC and the gbXML schemas (see section 1.7.6.3) the UoD relates to the entire building. However, as this will be presented in the next chapter (section 4.3), the data model of the DMM plug-in mainly address geometry, zone definition and surface attribution issues. In the process of a data model definition the UoD is divided into different components. This process is called decomposition. The appropriate decomposition of a UoD will depend on the intended usage of the data model [*Morbitzer 2003*].

Dividing the UoD into different entities is one of the tasks that has to be undertaken when creating a data model. Another task is the definition of the relationship between the different entities while maintaining model integrity, allowing the management and traceability of information flow and avoiding data redundancy. After the decomposition of data and the definition of the relationships between the different entities, an Entity (or class) -Relationship Model is created in order to map these information onto an actual application. An E-RM is represented by means of three primitive objects:

➔ Entities, which represent the components being modelled.
➔ Attributes, which represent the properties of the entities.
➔ Relationships, which represent the associations among entities.

An entity can be seen as a “set” containing “sub-sets” and stores descriptive information about a particular component such as a zone or a surface. An entity itself is defined by its attributes. An attribute of the entity “space” would be data about the space name or the surfaces that consist the specific space. An entity type has normally a number of instances. An instance would then be the “24/7” occupancy schedule of the entity “space usage” . To be able to uniquely identify each instance it is necessary to define one or several primary key(s) (also named ID) from among the different attributes.

A relationship is a named association between two or more entity types. Three different relationships are commonly used in DBM systems [*Morbitzer 2003*]:

➔ one-to-one-relationships,

- ➔ one-to-many-relationships,
- ➔ many-to-many relationships.

However, the main relationship type in databases is the one-to-many. A one-to-many relationship example will be: each surface is always related to a space but each space can be related to many surfaces. Thus, the specific entity type “space” will have a one-to-many relationship with the specific entity type “surface”.

3.6 Closing remarks

This chapter described a method of introducing simulation into the Conceptual design stage. This method consists of a sequence of tools. In essence, the first is a friendly to use 3D sketching environment tool with a bespoke Data Mining and Management plug-in. The second tool is a web-based energy analysis and manipulation system that is responsible for completing the model in terms of HVAC configuration, occupancy type, zone function, etc. The model is manipulated using IDDs and primarily addresses the problem of limited information upon specific aspects of the building. Hence, simulation can be integrated in the conceptual design process providing the designer with an indication regarding the energy and environmental performance of a particular design option.

After the method proposal, considerations regarding the structure and the Interface of the Data Mining and Management plug-in are presented. According to these considerations, the structure of such a plug-in should be able to extract first level information about the geometry configuration of a model and support several algorithms to process these data so that surfaces and spaces can be defined, attributed and exported into a gbXML format. Hence, interoperability among different purpose simulation software is enhanced. In addition, the structure of the plug-in should support algorithms that ensure an accurate definition of a preliminary model by incorporating a basic Data Management System. Thus the relationship between the different entities is managed while the algorithms to maintain model integrity and space contiguity are supported. In addition traceability of information flow can be modelled.

The GUI of the plug-in should be the outcome of a solid framework, so that a user-centred foundation on which to build a successful user interface is created . A simple, well-defined interface design that is clearly and accurately represented in the user interface, makes it easier for users to learn and use the plug-in and hence the method. The benefits of implementing such an approach are of great importance to the functionality and the time required to develop the interface. The result is a better user interface from the beginning, instead of one that requires major revisions to meet minimum usability standards. This process adopted in the development of the user interface of the plug-in is supported by a relatively new theory of developing user interfaces and argues with classical approach of the “trial and error” method [after *Interface Concepts 2007*].

The chapter also presents some general considerations regarding the development of the Data Mining and Management plug-in emphasizing on the importance of a guided input procedure and the need to link the plug-in with non simulation related aspects such as cost calculations. Finally, the chapter ends with providing introductory information about the development of a data model which provide the fundamentals to present how the plug-in was implemented.

The next chapter relates to the implementation of the DMM plug-in developed through the scope of this research project. However, not all the specifications mentioned in this chapter (chapter 3) where implemented (justification provided in section 4.3). In addition, chapter 4 also presents a description of the rest components of the method providing the reasons why specific tools were selected

Chapter 4: Implementation

4.1 Introduction

The previous chapter presented a method to address the issues responsible for the small uptake of simulation within the conceptual design stage of a building. The method consists of three steps and a sequence of two tools. The chapter particularly focuses on presenting general considerations for the development of a Data Mining and Management tool that provides the link between the model's 3D sketching tool and the simulation engine. These considerations can be taken as general specifications about the tasks the tool should be able to perform.

This chapter initially presents how the proposed method was implemented in practice through the scope of this MSc project. Thus, the specifications and the capabilities of the 3D sketching tool and the web-based simulation tool are described as these are essential parts of this method. This is followed by an analysis and a discussion regarding which of the considerations, mentioned in the previous chapter, were taken into an account when developing the specifications of the DMM plug-in (in terms of structure and interface). Finally, the chapter explains how the plug-in was implemented providing information about its architecture and the relationship between its components (classes) for both its core and interface.

4.2 Method components

As mentioned in the previous chapter, the proposed method consists of three steps and a sequence of two tools (see section 3.2). Choosing the first tool was the product of an extended market survey [*Vanguard 2006*] (among others) undertaken by the research body[1] that supported this MSc project. The outcome of this survey indicated which 3D CAD tools are commonly used in the UK and how many conceptual designers are familiar with low carbon building design. In addition, the same research body was responsible for localizing a unique web-based energy and environmental performance analysis tool in the UK market. This tool was a good choice as it allowed interoperability with 3D CAD and simulation tools by using the gbXML standard.

4.2.1 3D CAD-sketching tool

Sketching is an important element of early design decisions because it allows the quick

1 The MSc project was carried out with the support of GreenSpace Research in the UHI college, Isle of Lewis, Scotland.

representation of ideas thought by the designer, especially when using 3D CAD-sketching tools. The designer by using these tools can easily generate 3D forms. This is one of the primary considerations of the method presented above because the conceptual designer needs to create, view and modify his/her ideas quickly and easily. According to a survey issued to Conceptual designers in the UK [*Vanguard 2006*], ninety per cent where using Sketching tools. The same survey has indicated that the most popular 3D CAD-Sketching tool was Google's SketchUp.

SketchUp is a simple but still powerful tool for creating, viewing, and modifying 3D ideas quickly. It was originally developed to combine the spontaneity of a pencil with the speed and flexibility of up-to-dated CAD tools. Thus, SketchUp is ideal for the needs of the conceptual design as these ware indicated in section 3.2.2. SketchUp has is the most-favoured 3D sketching-modelling tool among Conceptual designers, as this was indicated by a market survey [*Vanguard 2006*]. Its intuitive design, high ease of use, integration with Google Earth and free entry-level price make are the main reasons for its popularity. It is worth mentioning that SketchUp is not a BIM tool but rather a 3D sketching tool that can respond to the Conceptual designer's needs adequatelly. However, some BIM vendors have developed functions to support the import of SketchUp models into their software.

One feature of SketchUp that is promising for using it as a base on which to develop a DMM plug-in is its Application Programming Interface (API). SketchUp contains a Ruby[2] application programming interface (API) for users who are familiar with (or want to learn) Ruby scripting and want to extend the functionality of SketchUp. This interface allows users to create macros, such as automated component generators and additional tools, to be included in the menus within SketchUp [*SketchUp API developers guide 2007*]. In addition to its API advantage, SketchUp also includes a Ruby console, which is an environment where developer's can experiment with Ruby commands and methods.

4.2.2 *Web-based energy and manipulation tool*

The concept of the web-based energy and manipulation tool is based on the main deliverables of the "Conceptual Design Energy Analysis Tool (CDEAT) Research and Development" project supported by the Public Interest Energy Research (PIER) and sponsored by the California Energy Commission.

One of the several deliverables of this project was the Energy Analysis Module (EAM). It refers to an easy-to-use web-based energy software tool that provides a quick estimate of energy use

2 Ruby is a reflective, dynamic, object-oriented programming language. It combines syntax inspired by several other... languages such as Perl, Python, Lisp, Dylan, and CLU. Ruby is a single-pass interpreted language. Its official implementation is free software written in C [Wikpedia b 2007].

and cost and automatically creates a robust simulation model to share with other design team members. The EAM software makes significant productivity improvements possible by greatly reducing the amount of time required to do plan take-off and build up the simulation model. The technology realized through this project represents a major breakthrough in building energy analysis software [*PIER 2002*]. However, the model is populated with IDD and thus questions are risen about the accuracy of the prediction analysis. Further analysis about this issue can be found in the fifth chapter of this dissertation. Another deliverable of the project is Green Building XML (gbXML). As mentioned in a previous chapter (section 2.5) gbXML is standard data format that enables data sharing among 3D-CAD and energy simulation software.

Originally, the Energy Analysis Module (EAM) development effort was intended to produce a software module for distribution as a "plug-in" component to the hosting 3D-CAD program. Instead, in response to the trend toward Internet-based computing and XML enabled client/server architecture, GeoPraxis[3] developed a server-based application that can be called from any gbXML-compatible application running on a client computer connected to the Internet anywhere in the world. The Energy Analysis Module (EAM) is a software program that enables any 3D-CAD application that supports the Green Building XML schema (gbXML) to access an energy simulation analysis tool. The structure of the EAM is such that once enabled, alternative simulation engines can also be called, based on the user's licensing and preference. One of the basic requirements of any 3D-CAD tool supporting the EAM is that it can read and write gbXML files.

Presenting a detail diagram of the EAM working specifications is beyond the scope of this MSc project. However, an overview diagram of the 3D CAD-Sketching – EAM data flow using gbXML is presented in figure 4.1.

The EAM runs on GeoPraxis' web servers and is accessible using the Simple Object Access Protocol (SOAP) over the Internet. The EAM consists of a Visual Basic ActiveX Dynamic Link Library (DLL), a SQL Server database, numerous XSLT stylesheets, and active server page files. To ensure the EAM is available for all computer platforms it is available over the Internet using the widely used SOAP protocol. The EAM communicates with GeoPraxis' IDEA Server program, functioning as a pre/post processor for any registered simulation engine. The architecture of the EAM was designed to allow CAD developers the most flexibility and the fewest support issues with regard to the technology. Once an Internet connection is established, the EAM only requires the architectural end user to input the location of the building (postcode), the type of building, and the geometry of its major components. All data required to complete a preliminary energy simulation are provided from the EAM database. The EAM uses the user-provided information to expand this

3 GeoPraxis, an energy efficiency research and development consultancy based in the US which was split into two companies. One of them is Green Building Studio.

simplified dataset to what needed for energy simulation using defaults based on building practices and codes in a specific region of the world.

The Energy Analysis Module is currently being implemented by Green Building studio and managed by Geopraxis. The simulation engine on the back-end is DOE 2.2 E but there is an option to extract the gbXML file into EnergyPlus[4] and eQUEST for a more detailed analysis. Figure 4.2 presents a simple diagram outlining the EAM functionality as this is currently being implemented by Green Building studio.

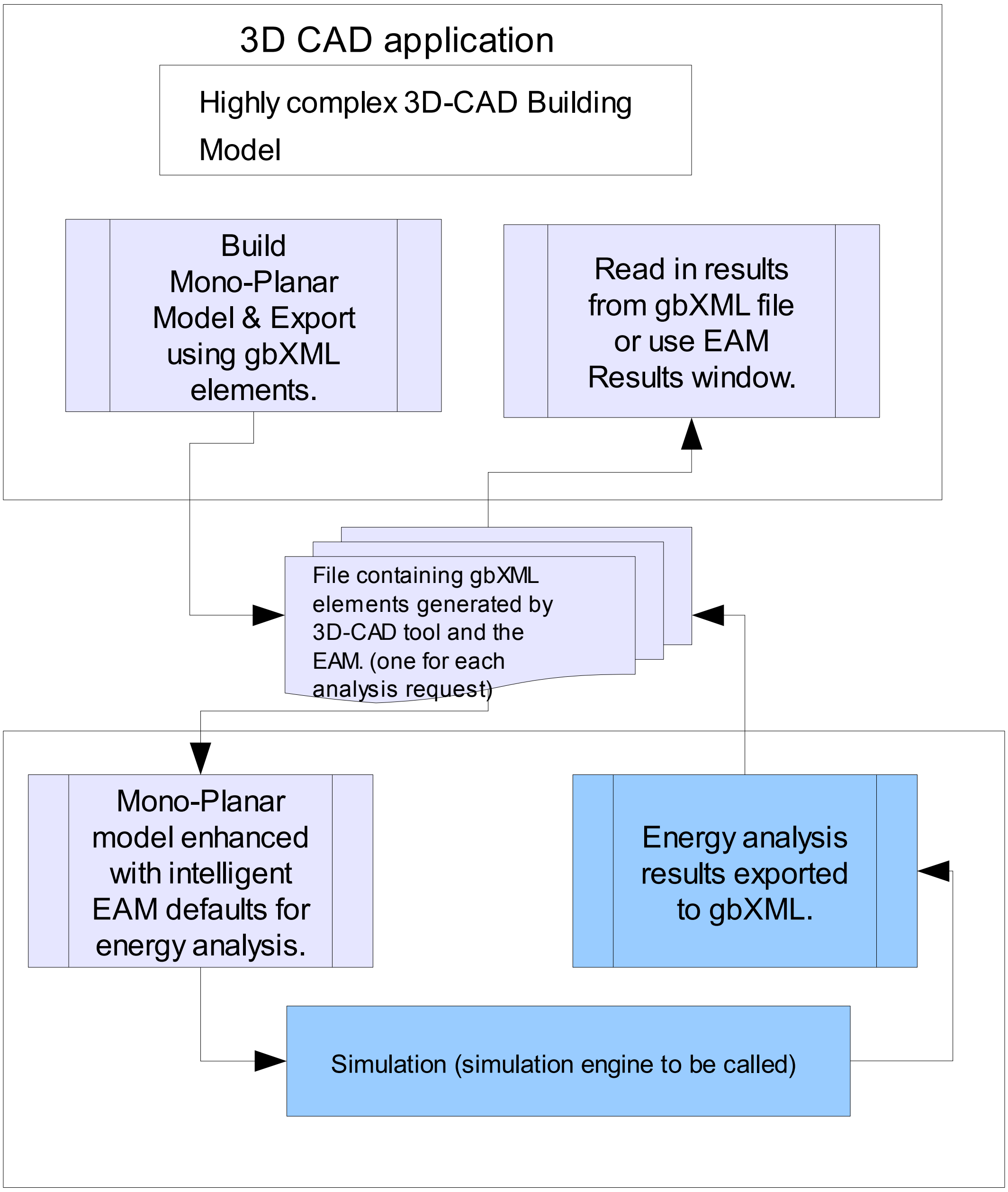

Figure 4.1 CAD – EAM data flow using gbXML [after PIER 2002]

4 EnergyPlus is a stand-alone simulation program without a 'user friendly' graphical interface. EnergyPlus reads input and writes output as text files.

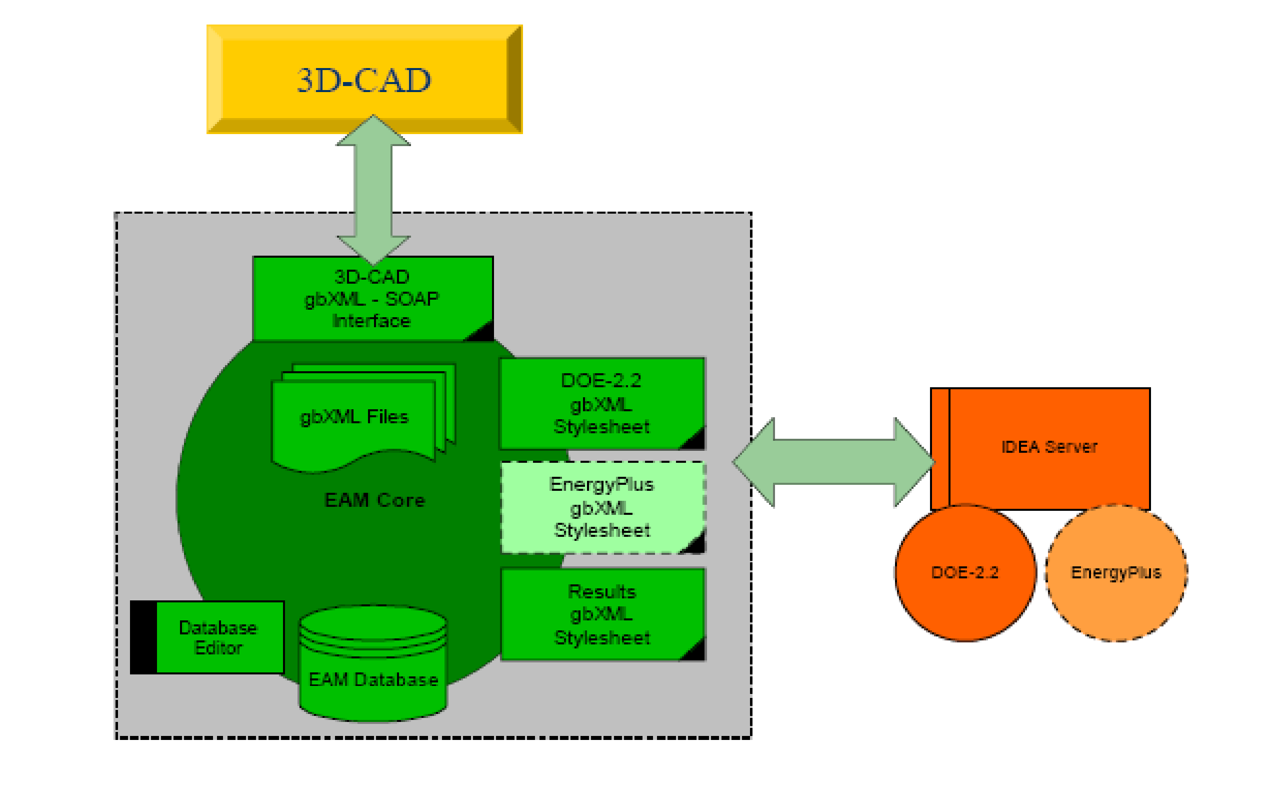

Figure 4.2 Green Building Studio components and Functionality [PIER 2002]

4.2.3 Method implementation

The 3D Sketching part of the method is based on Google's SketchUp and a Data Mining and Management plug-in. It was among the intentions of the development team (in which the Author was the link between simulation practice and the software developers) to use the free version of SketchUp[5] so that the DMM tool, as well as the whole method, can be tested by third parties. The DMM plug-in was developed upon the version 6.0.515 of SketchUp and the developers guide used includes versions 4.0, 5.0 and 6.0. As soon as the model is created within the SketchUp environment and attributed in the DMM plug-in, it is exported into a gbXML format. The specifications and the implementation of the DMM plug-in are described in the next section of this chapter.

The data flow of the method differs from the one presented in figure 4.1. The results are displayed in a web browser instead the CAD application itself. In addition, the model is created and attributed by different tools (however, the DMM plug-in is hosted). Finally, it was decided that the EAM should be used as it is implemented in Green Building studio (with the DOE 2.2 e engine on the back-end). The main reason of doing so was that introducing a new engine to the back-end of the EAM was beyond the scope of this project.

5 The free version of SketchUp is available for download in: http://sketchup.google.com/download.html

The data flow diagram of the proposed method, as this was implemented through the scope of this MSc project, is presented in the following diagram (figure 4.3).

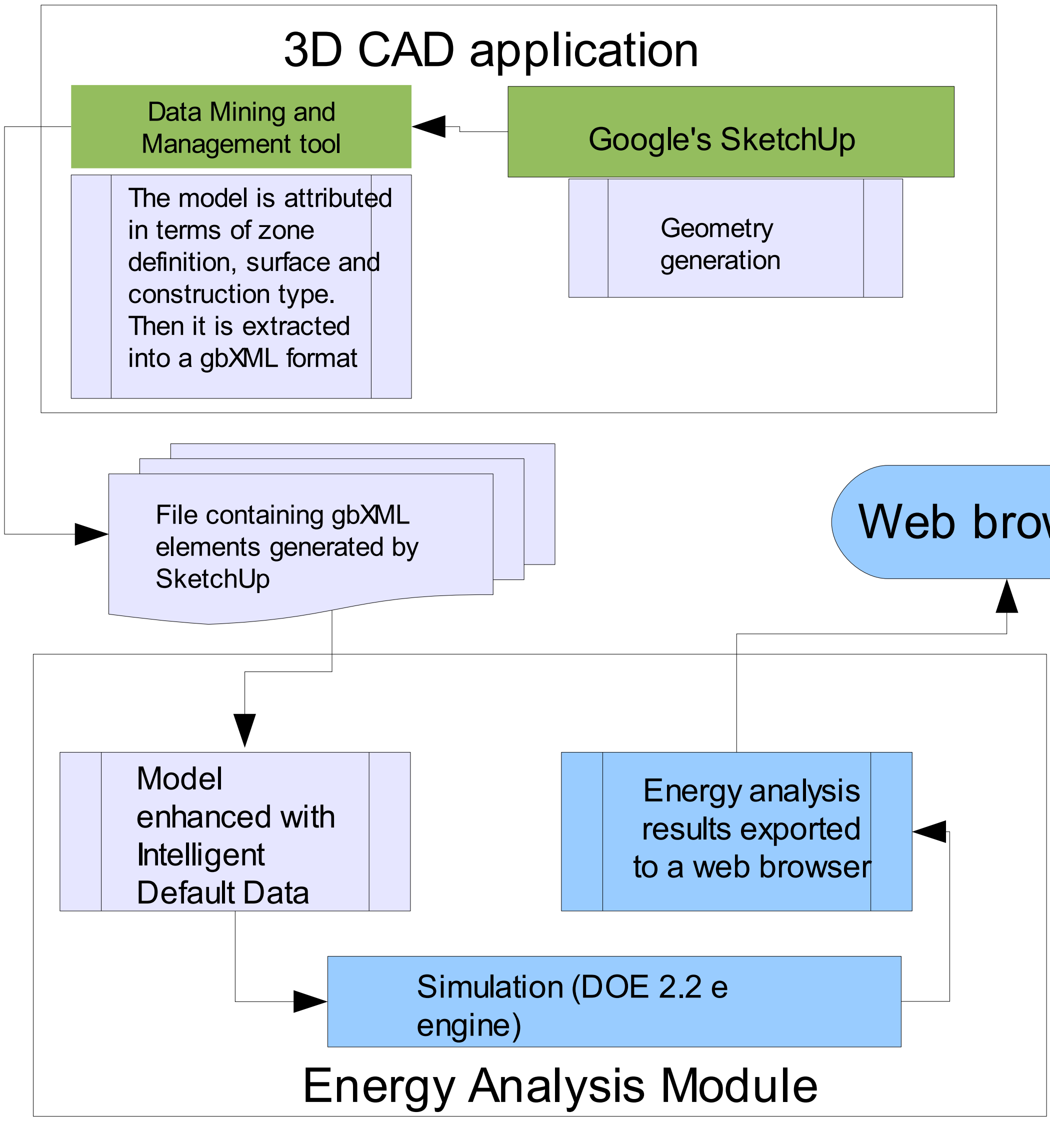

Figure 4.3 Data flow of the proposed method

4.3 System specifications

4.3.1 Introduction

This section of the chapter provides a high-level overview of how the functionality and responsibilities of the system were partitioned and then assigned to subsystems or components. The main purpose of this section is to provide the reader with a general understanding of why the system was decomposed. A description of how the system was broken down into its components-subsystems is provided. In addition, the major responsibilities the plug-in undertakes and the various roles that its system plays are described.

As mentioned earlier, not all of the specifications mentioned in the previous chapter were implemented in this MSc project. Building the specifications of a plug-in that aims to help the conceptual designer to create a simulation model was the product of literature research carried out through a five month period. However, the implementation of the plug-in carried out during only the last two months of the placement. Hence, the team focused on implementing some basic features mainly for demonstration purposes (as well as raising funds to support further development). These features are related to the definition of the geometry of the model, type of surfaces and sub-surfaces, building type and location.

4.3.2 Specifications for the structure of the DMM plug-in

The specifications of the DMM plug-in can be defined through the use of two main systems: the Data Mining System (DMiS) and the data management system (DMaS). This dissociation was made due to the nature of SkechUp's API. As SketchUp is copyrighted, information about geometry entities are stored and managed in way that is difficult to access. Hence, the only way of communicating is through a pre-defined API. Thus, first level (geometry) information has to be extracted (mined). Following this, a Data Management System accepts this information and process the data to define a model. The process of data mining is completely automated without the need for user interaction. However, as this will be presented later in this section, the data management is a semi-Automated Process (sAP) (i.e. some user interaction is required). The following figure (*figure 4.4*) indicates the tasks each system performs.

In the DMM plug-in, when referring to an Automated Process (AP), a process supported only by algorithms is meant. These algorithms ensure that there is no need for user interaction. Hence, the “get geometry” function is an AP since the user does not insert vertexes, faces and edges manually (however, the user still performs certain tasks while using the Sketching environment). Subsequently, the “Building information” function prompts the user to specify the building type and the location of the building, making it a procedure that requires user interaction (sAP). A function that consists of Automated Processes (AP) and semi-Automated Processes (sAP) is considered to be a semi-Automated Process (sAP). A detailed description of which function performs which task is provided at the following paragraphs.

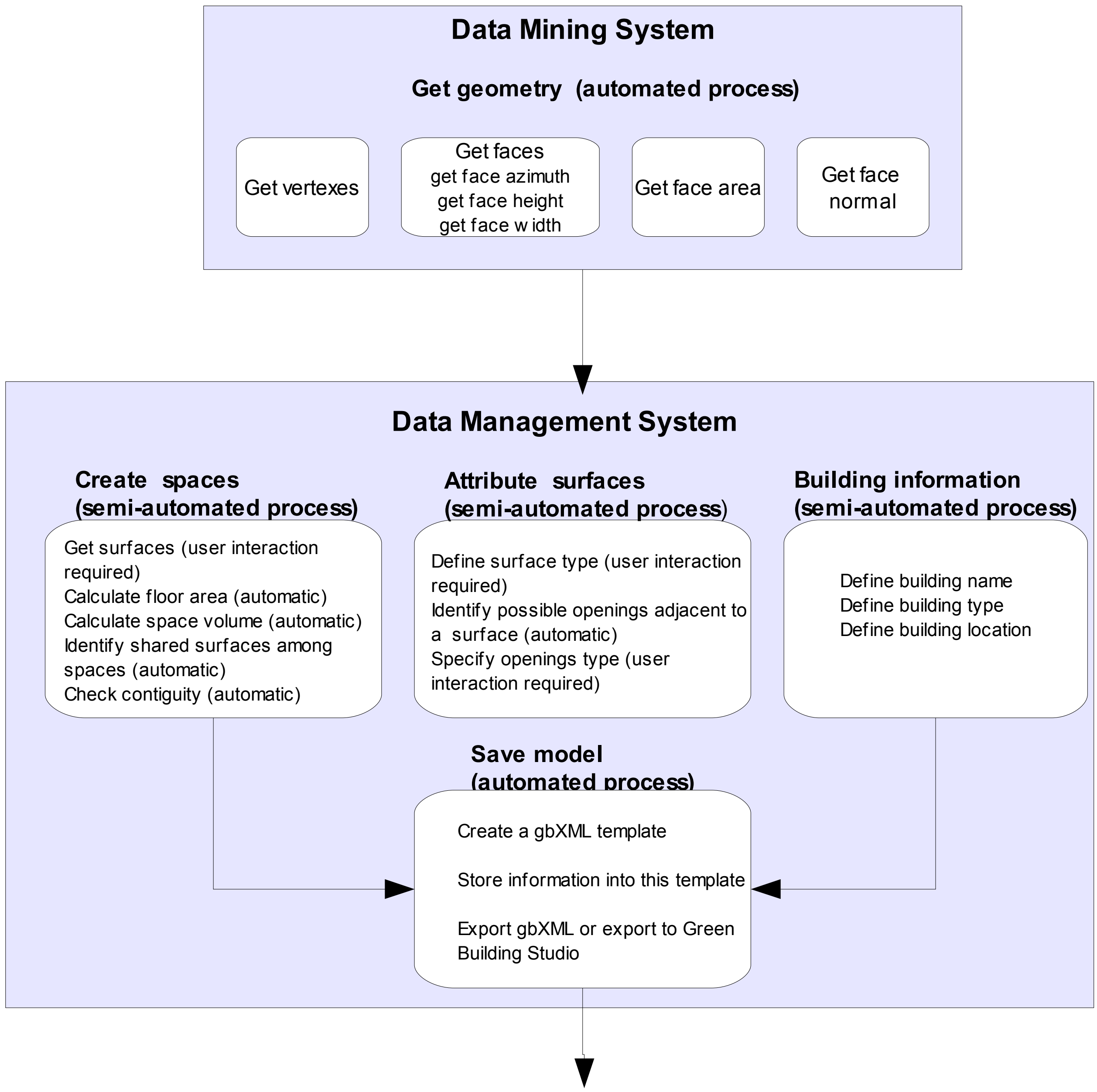

Figure 4.4 Data Mining and Data Management system concept

In the DMM plug-in, when referring to an Automated Process (AP), a process supported only by algorithms is meant. These algorithms ensure that there is no need for user interaction. Hence, the "get geometry" function is an AP since the user does not insert vertexes, faces and edges manually (however, the user still performs certain tasks while using the Sketching environment). Subsequently, the "Building information" function prompts the user to specify the building type and the location of the building, making it a procedure that requires user interaction (sAP). A function that consists of Automated Processes (AP) and semi-Automated Processes (sAP) is considered to be a semi-Automated Process (sAP). A detailed description of which function performs which task is provided at the following paragraphs.

“Get Geometry“

The “Get geometry” function is responsible for “mining” the geometrical data from Google's SketchUp. It was meant to be an AP since the user does not interact with the related information (vertexes, edges, faces, etc.) necessary to represent a geometrical object in the sketching environment. Using this functionality information regarding the vertexes and the edges consisting a particular surface are extracted. Furthermore, essential information to define a simulation model such as surface tilt, azimuth, height, width and area are also extracted. Additionally, the surface normal is extracted since it is an essential for the “space volume” calculation function.

“Create Space”

The “Create space” function belongs to the DMaS and is responsible for creating geometrically accurate “spaces” within the model. The terminology “space” is identical with “zone” which is a commonly found entity among state-of-the-art simulation tools. This function is a sAP because it requires some level of user interaction. The user will have to “click” all the surfaces that he/she understands that form a space. During the development of the DMM tool, it was found as necessary that both SketchUp and DMM plug-in should allow the user to interact with the graphical environment and instantly get the entity information by simply clicking a particular surface or space. After clicking all the surfaces that form a particular space, the DMaS will automatically check weather the space is contiguous or not, and group all the information related to this space as a sketchUp component. The user then follows the same procedure to group all surfaces in the model. A significant advantage of implementing such an approach to modelling is that the DMaS can identify whether a particular surface is shared between two spaces (i.e. interior wall).

“Attribute Surfaces”

A particular space which is grouped as a SketchUp component, can be called back in order to assign attributes to the surfaces consisting the space or the space itself. This is handled by the “attribute surfaces” functionality. In this process the user by interacting with the graphical environment can specify the type and the name of the surface. In addition, the DMaS can identify whether there is an opening attached to the surface selected and prompt the user to specify its type.

"Building Information"

An important element of the method proposed in the beginning of this chapter is the use of default databases and IDD. In the "Building Information" functionality, the user specifies the name, the type and the location of the model. This information will be stored into a gbXML format where the Energy Analysis Module (EAM) will use it to load local environmental data, occupancy types and several other necessary for a simulation data.

"Save Model"

The "Save Model" function is responsible for ensuring that information about the model conforms with the gbXML schema. Then the model can be extracted in a gbXML. The user has two options, either get the gbXML file so that he/she can import the model into a highly advanced simulation engine to continue with a more detailed model definition (in terms of HVAC configuration, ventilation strategies, internal gains, etc.), or send the model into Green Building Studio's web-based platform and get a quick feedback about the energy and environmental performance of the model.

4.4 System architecture and Implementation

4.4.1 Introduction

This section of the chapter initially presents the classes introduced in the structure of the DMM plug-in in order to perform the desired functionality. Following this, it describes how the higher-level components collaborate with each other in order to achieve the required results, and presents a high-level Entity (class)-Relationship model for the DMM plug-in. It is not the the intentions of the Author to provide too much about the individual components themselves. The main purpose is to provide a general understanding of how the individual parts work together to achieve the desired functionality.

The SketchUp geometry contains a set of faces, edges and vertices. The geometry file (*.skp* format) is very simple and only contains what is necessary to display it in the 3D GUI of SketchUp. It does not provide neither the structure to export the data into a gbXML format, nor the basis on which to build a DMaS.

4.4.2 System classes-entities

In object-oriented programming, a class is a programming language construct used to group related instance variables and functions. A function[6] is a set of instructions specific to a class. A class may indicate either specifically or abstractly what methods exist when the program executes. Functions exist within classes, but classes may also exist within classes[7]. After a short introduction to the basic terminology of object-oriented programming fundamentals, the following paragraphs present the classes behind the DMM plug-in as this were implemented within the scope of this MSc project.

SketchUp represents a model as a collection of entities (faces, edges and vertices). These are extended into the core of the DMM plug-in representing two different classes: the **SketchUp::entity** and the **SketchUp::face**. These two classes represent the DMiS in the DMM plug-in. They are primarily responsible for sending information about faces, edges and vertexes to the plug-in. They are defined within SketchUp and extended in the DMM structure to provide easier access to attributes and other classes (to calculate various properties).

The DMaS is implemented using several classes and sub-classes, each performing different tasks using different functions. These are briefly discussed in the next paragraphs following the class diagram (*figure 4.6*).

DMM-main.rb class

This is the parent class of all sub-classes implemented in the DMM tool and is run when SketchUp is loaded. It creates the plug-ins menu and includes all classes. In addition, as this will be presented in section 4.6, it provides the initiation of an instance of the DMM plugin's GUI.

DMM-Model.rb class

The DMM-Model.rb class has several sub-classes. Each of these sub-classes include specific functions that perform specific tasks. The following table (*table 4.1*) outlines these sub-classes and gives a short description for each. In addition, the class includes the "space", "surface" and "openings" entities (classes without functions). The DMM-model.rb is the heart of the plug-in since it contains the most sub-classes and functions. Figure 4.5 represents a class diagram indicating the type of relationship between the sub-classes.

6 A function is also called "method" is some programming languages

7 When a class is within another class , then the former refers as a sub-class.

Sub-class name	Description of functions
gbXMLentity	A space can contain multiple surfaces and a surface can contain multiple openings. A surface is created along with a list of faces representing possible openings. The surface then creates Opening classes from these faces and classifies them into adjacent and inner openings.
Model	● This class creates and stores all the Space objects based on the SketchUp's entities in the model. The entities contain attributes describing their name, type, space usage, etc. ● Openings are automatically identified by using the appropriate geometrical functions. Using this information, the Space/Surface/Opening hierarchy can be constructed as needed whenever the model changes. ● Each zone and surface is given a unique ID. Thus, each opening within an individual surface is given a consecutive ID relative to that surface. ● If the two spaces contain the same surface (in the case of an interior wall), then the surface object is created once and added to both surfaces. ● Prompt the user to define the building name, type and postcode
ModelUtil	This class contains various instance methods such as finding or selecting all faces or classifying openings.
Observer[8]	This class handles calls from a Sketchup observer so it knows whenever the model changes. It can notify a class when the selection and/or entities change. This is used to the information shown in the user interface when the user selects a different object or adds some faces.

Table 4.1 sub-classes included in the DMM-Model.rb class

8 In information theory, an observer is any system which receives information from an object.

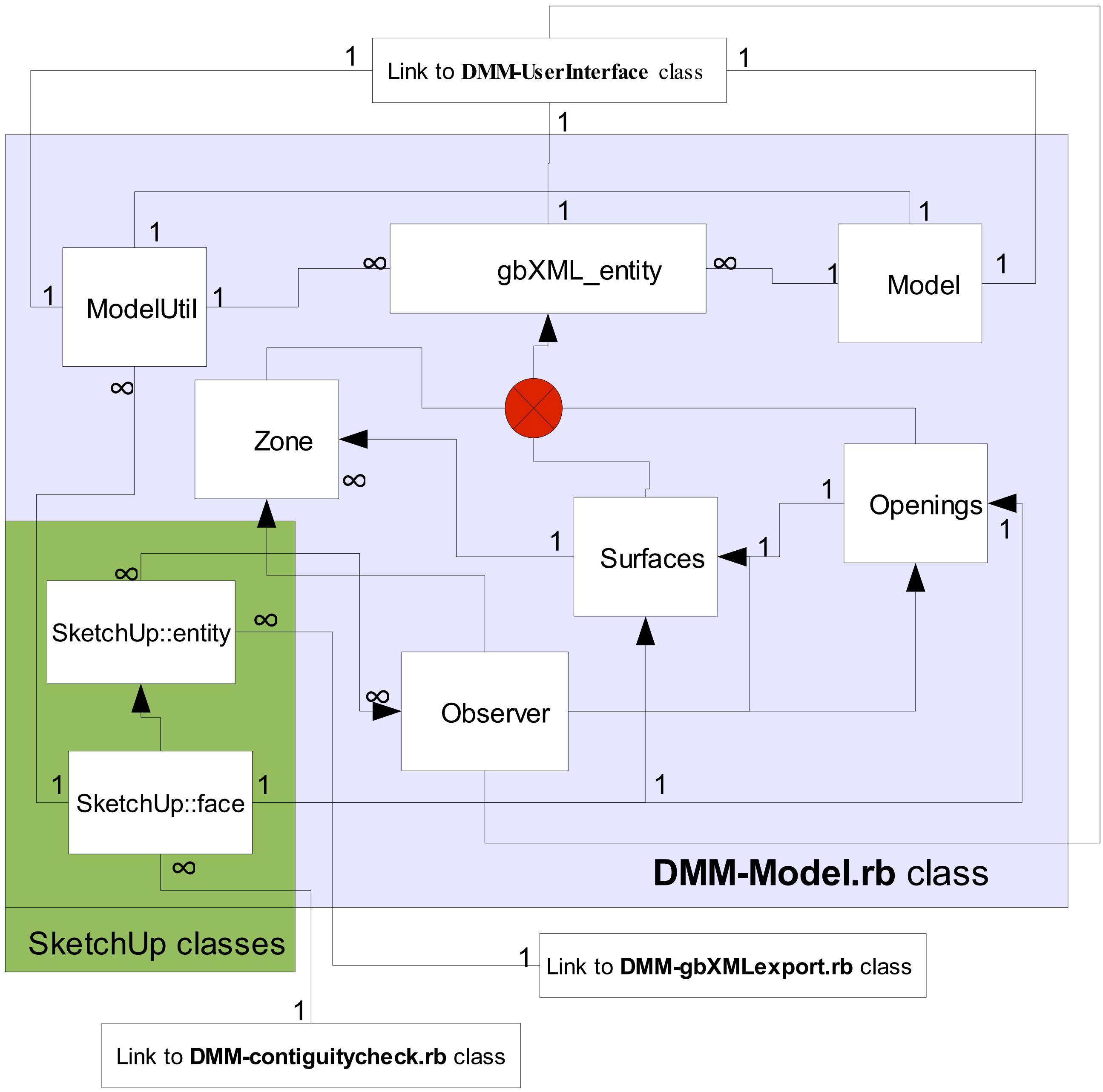

*Figure 4.5 Class diagram for the **DMM-Model.rb** class*

DMM-contiguitycheck.rb class

The contiguity checker take an array of surfaces/faces and returns whether they form a contiguous space or which faces are non-contiguous. This is used when creating or editing a space to prevent the user from creating an invalid space.

DMM-UserInterface class

This creates a window containing the Flex Graphical User Interface (see section 4.5). It sends Flex the information it needs about the model and receives user actions from Flex. It manipulates the model in response to user actions and send any changes back.

DMM-gbXMLexport.rb class

This is a class that takes the model and saves it in gbXML format in an XML file. It opens a dialogue to get the filename from the user and returns the path if it was successfully exported. Most of the information needed is accessible through the *Model* sub-class located in the DMM-model.rb class.

DMM-tools.rb class

Contains functions that enable the user to use SketchUp's tools directly from the GUI of the DMM plug-in. These functions were introduced to enhance user functionality. It contains two tools: the *face type* tool and the *SectionPlane* tool. The later is called directly from SketchUp, while the former was developed from scratch so that the user can "paint" multiple surfaces the same type.

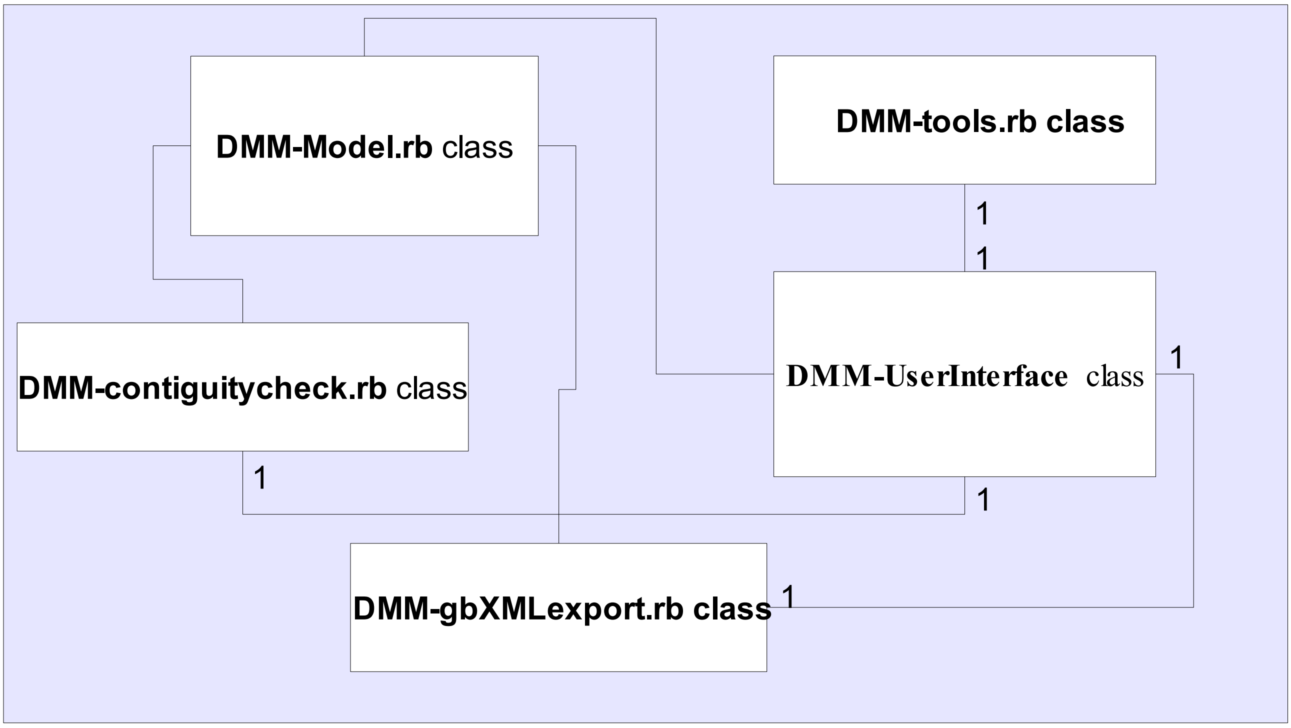

Figure 4.6 The class-relationship diagram of the DMM plug-in

4.5 Graphical User Interface

4.5.1 Introduction

The development of the Graphical Use interface of the DMM plug-in is one of the most essential parts of the project. As mentioned in section 1.7.6, the most energy savings can be achieved if simulation is applied at the early stages of design, where architects predominate. Thus, given the lack of modelling knowledge (in terms of energy) among Conceptual designers, the GUI of the DMM plug-in should be based on ease of use. The lack of ease of use will reject the use of the plug-in from the users. A simple, well-defined interface design that is clearly and accurately represented in the user interface, makes it easier for users to learn and use the tool.

In this section of the chapter, the GUI of the DMM plug-in is presented. A definition of essential parameters such as central concept and requirements is given. This is followed by the specifications of the GUI, where the user's objective model and the user's activity diagram are defined and presented. Finally, general information regarding how the specifications were implemented is given. It is beyond the scope of this MSc project to define the architecture of the GUI, as this includes programs written in complex programming languages (FLEX, Ruby, Javascript, etc) and implemented by the software development team that supported this project.

4.5.2 Requirements

The design of the GUI of the plug-in is different from its engineering-structural design. The later specifies architectural and programming details of how the tool is implemented while the former involves the translation of requirements into operating tasks [I*nterface Concept 2007*]. The process begins by getting at the structure of the tool, the central concept, and proceed by organizing functionality from the user's point of view.

The central concept of the plug-in is to enable a non expert in building energy modelling to define certain properties of a simulation model. This includes four sets of information: geometry, spaces, location and building type. The plug-in is not meant to provide the neither the simulation engine nor the graphical representation of the model (these tasks are handled by Green Building Studio and SketchUp respectively). Furthermore the manipulation of the model using IDD and support databases is not done in the DMM plug-in (tasks performed in Green Building Studio). The plug-in should require the minimum user interaction and the interface should be as simple as possible to avoid confusion and hence rejection from the user. Communication between the interface of the plug-in and the interface of the Sketching environment should be synchronized, thus enhancing user functionality. Furthermore, the interface should provide the user with the appropriate tools so that components of the model can be easily grouped and highlighted in the sketching environment any time the user selects them from the plugin's interface. The user should be able to define the model without the need to spend too much time and effort so that he/she can concentrate in developing the optimum geometry configuration for the model. Spontaneity should not be blocked in the sake of building energy modelling. In addition, all the components defined by the user should be presented in a simple and coherent way. The following figure (*figure 4.7*) presents the user interaction diagram of the DMM plug-in.

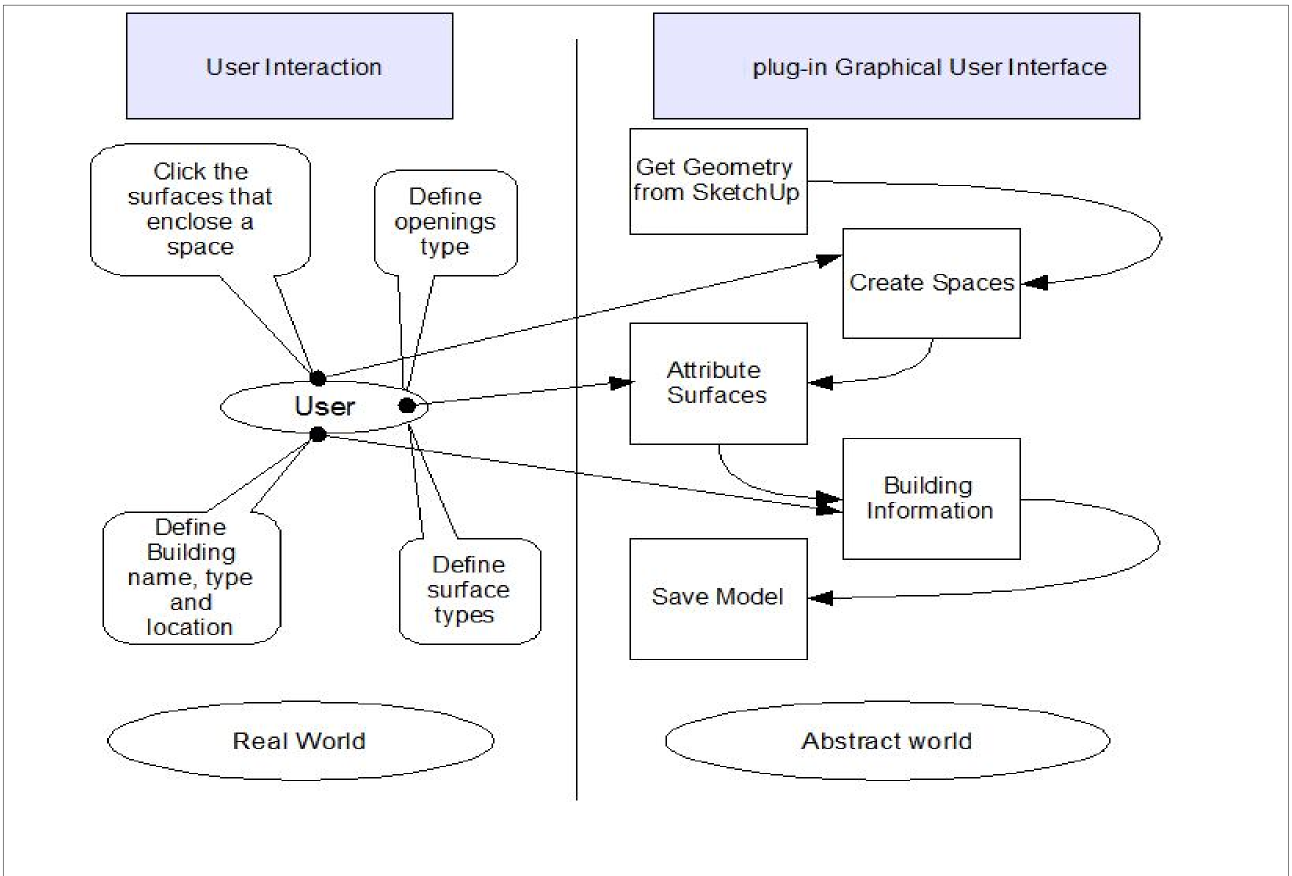

Figure 4.7 User interaction diagram

The user objectives model indicates the relationship between all the users needs and the related entities, actions and classes. This is a very important step when developing the specifications of a software interface from a users point of view (explicit interface design). Through this approach the interface is designed by using the "how easy can be defined" approach rather than the "what needs to be defined" approach. The result is a more friendly to user interface. However, it is quite common in software developed by engineers for engineers to adopt the "what needs to be defined" approach throughout the development of the tool (software core and interface). However, this approach is appropriate only for the first part of the process (software core development) [*Interface Concepts 2007*].

The User Objectives Model (UOM) of the DMM plug-in is presented in table 4.2.

User needs	Related entities	Related classes and functions
Select the surfaces that enclose a space	Vertexes, edges, faces	• The *observer* sub-class receive calls from the Sketchup observer through the *SketchUp::entity* class. • The *observer* sub-class informs the *surface, opening* and thus the *Space* entities in the plugin's *DMM-model.rb* class.
Provide a name for the created space	n/a	• The *DMM-UserInterface* class sends the space name to the *model* sub-class
Check if the space is contiguous	Faces, edges	• The *CheckContiguity.rb* class checks the contiguity of the space (automated process). If not, the system informs the user that the space is not contiguous • The *ModelUtil* sub-class highlights the non contiguous surface
Select all the surfaces that consist a particular space by clicking the space just created	Space, surfaces, faces, edges	• The *Model* sub-class sends all the surfaces to the *observer* sub-class • The *observer* sub-class informs SketchUp to highlight the required surfaces
Present a list of the surfaces that consist this space	Space, surface, surface type, opening, opening type and name	• This function is supported by the GUI's classes (see section 4.5.1)
Select a surface and highlight it in the sketching environment	Space, surface, face	• The *Model* sub-class sends the surface ID to the *observer* sub-class • The *observer* sub-class informs SketchUp to highlight the required surfaces
Define a surface type for this surface	Space, model, surface	• The *DMM-UserInterface* class sends the surface type to the *model* sub-class
Define an opening type and name	Space, model, surface, opening	• The *DMM-UserInterface* class sends the opening type to the *model* sub-class and informs the *Surface* entity
Define building name type and location	n/a	• The *DMM-UserInterface* class sends the building name, building type and post code to the *model* sub-class.

Table 4.2 The User Objectives Model (UOM) of the DMM plug-in

4.5.3 Interface Specifications

The UOM of the DMM plug-in is used in the definition of the specifications of the interface. Since all the user needs and the processes that relate to user are reported in a structured way, an activity diagram can be created. The activity diagram represents the operational work flows of components and user interaction in the system..

The interface consists of several "modules". The concept of modules was introduced in order to help the user to understand the philosophy behind the tool (so that he/she can use it) as well as for referencing reasons. Four modules were implemented in the GUI: The "Space definition module", the "Surface and Openings definition module", the "Building information module" and the "Green Building Studio or gbXML file export module" These are described in the following paragraphs.

"Space definition module"

In "Surface definition module" the user specifies the surfaces that enclose a space and give a name for this space. As mentioned earlier, the user specifies the surfaces by simply clicking each. The system automatically checks if the space is contiguous and assign the selected surfaces to this space. Figure 4.8 represents the activity diagram for this module.

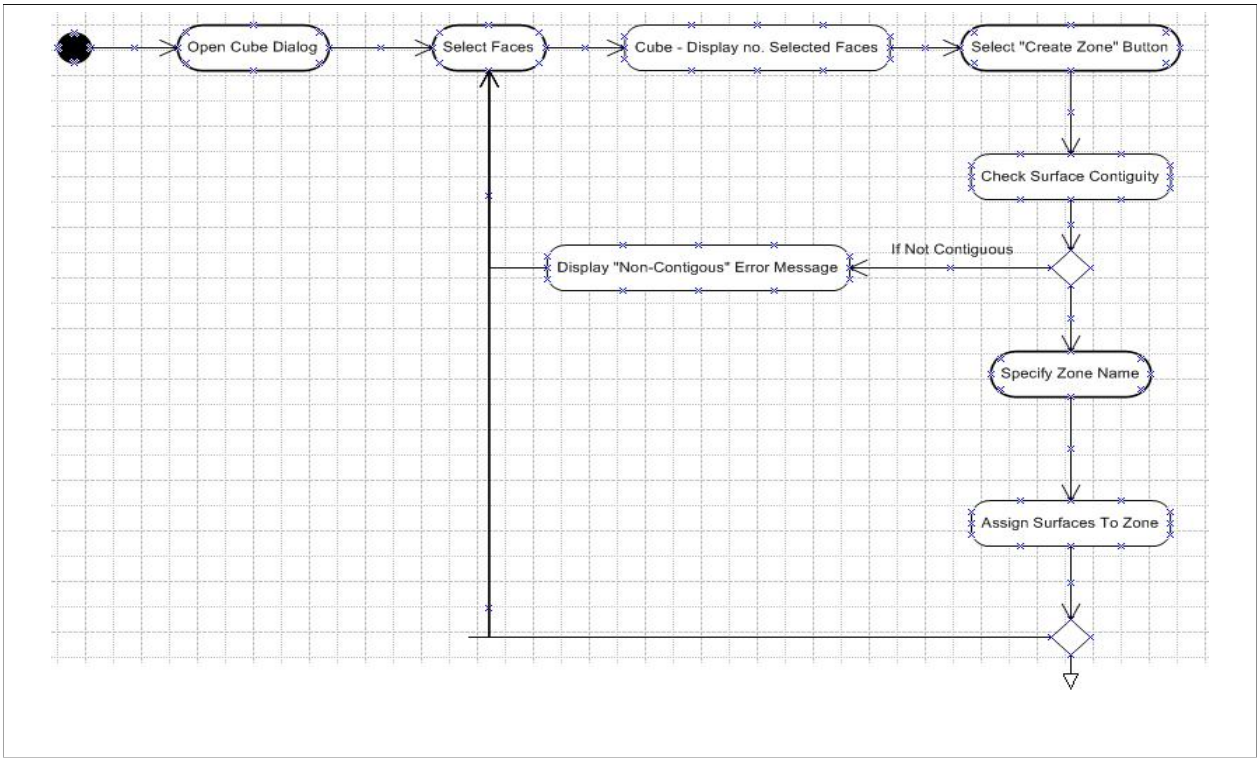

Figure 4.8 space definition module

“Surface and Openings definition module“

In the “Surface and Openings definition module” the user specifies the name and type of each surface (and if there are any openings then specifies the opening name and type). The GUI displays the surfaces and openings of a particular space in a data tree. The concept of the data tree was introduced because this way of displaying the relationship between parent-and-child entities (space-surfaces, surfaces-openings) is common among state-of-the-art CAD or BIM tools (the user is likely to be very familiar with these tools). The activity diagram (continued from the previous) is presented in figure 4.9.

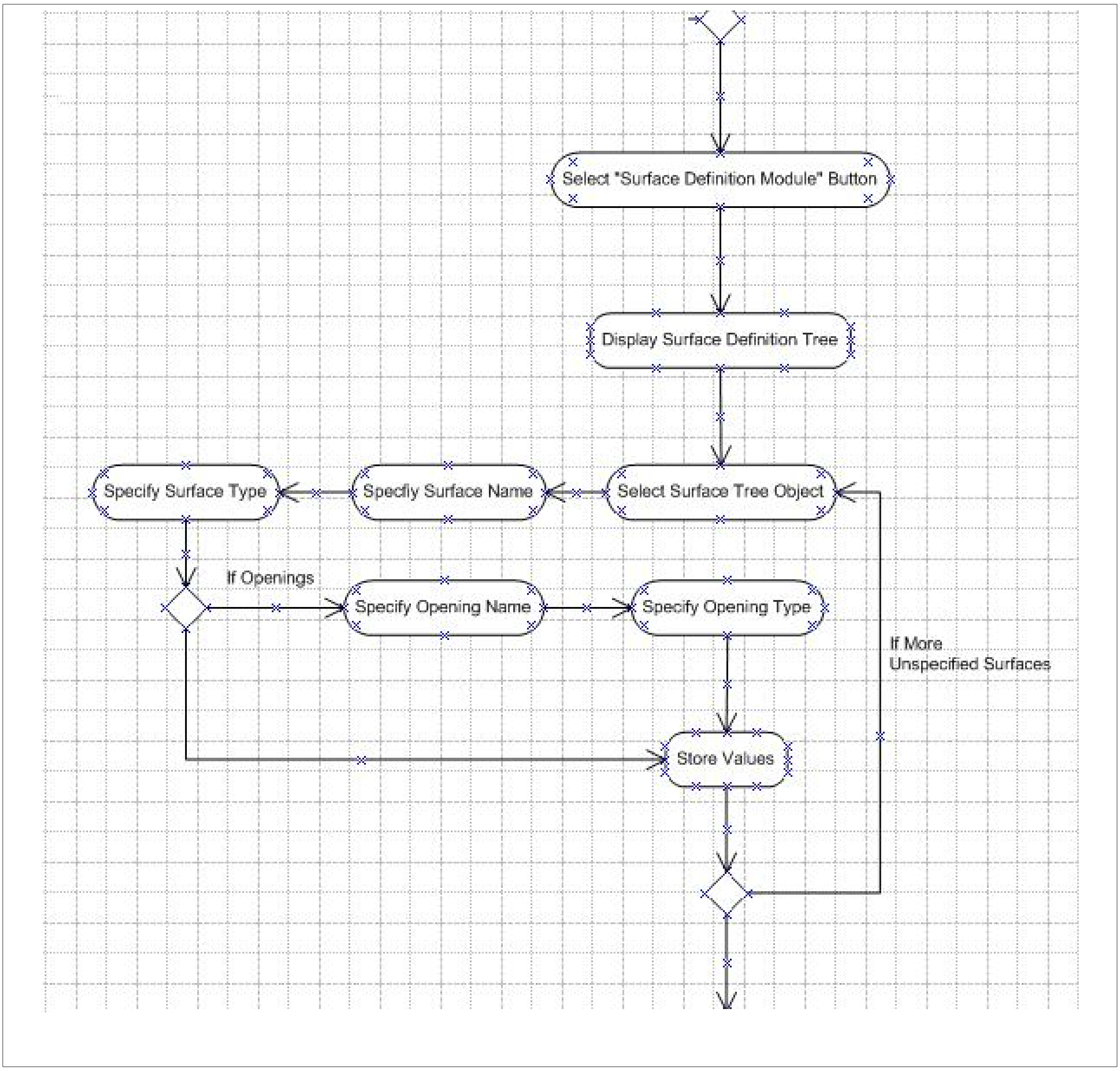

Figure 4.9 Surface and Opening definition module

"Building information module"

The "Building information module" is responsible for prompting the user to specify the name, type and postcode of the building. These are essential information for using the web-based service provided by Green Building Studio. The gbXML file containing these information can provide GBS with the right reference to obtain the local weather file and the appropriate support database to define a ready for DOE simulation model. The activity diagram is presented in figure 4.10.

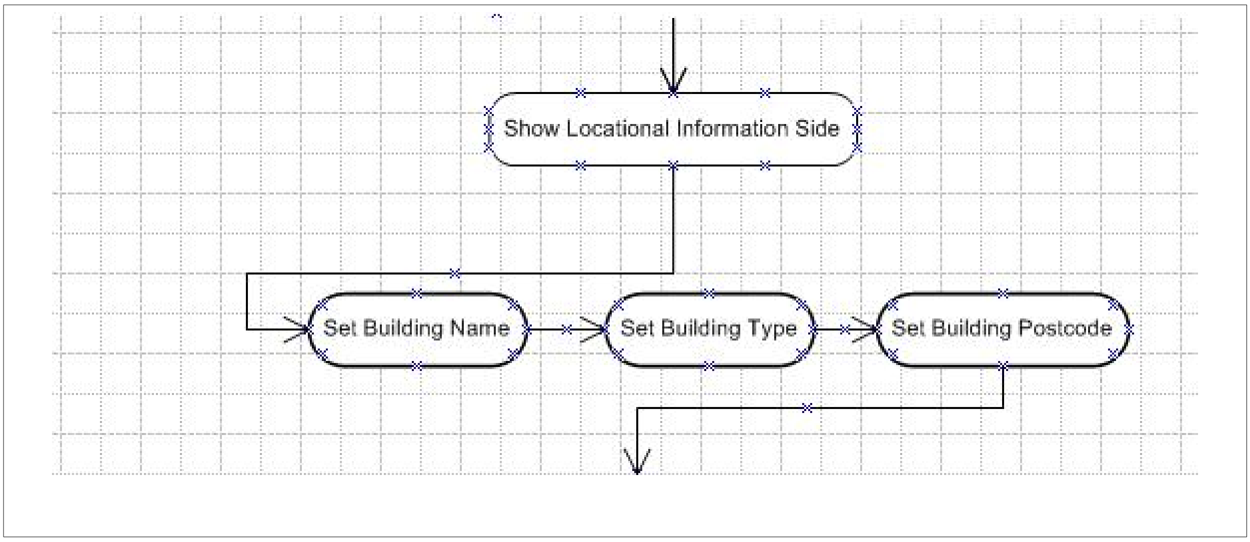

Figure 4.10 Building information module

"GBS or gbXML export module"

In the "GBS or gbXML export module" the user chooses either to export the model in a gbXML format or export the model directly to GBS when an internet connection is established. By exporting the model into a gbXML format the user can import the model in a highly advanced simulation engine (gbXML compatible) and continue to a more detailed attribution of the model. If the user choose to export the model directly into GBS, then the model is "sent" to GBS and a web-browser displays the results (see section 4.2.3). Figure 4.11 presents the activity diagram of this module.

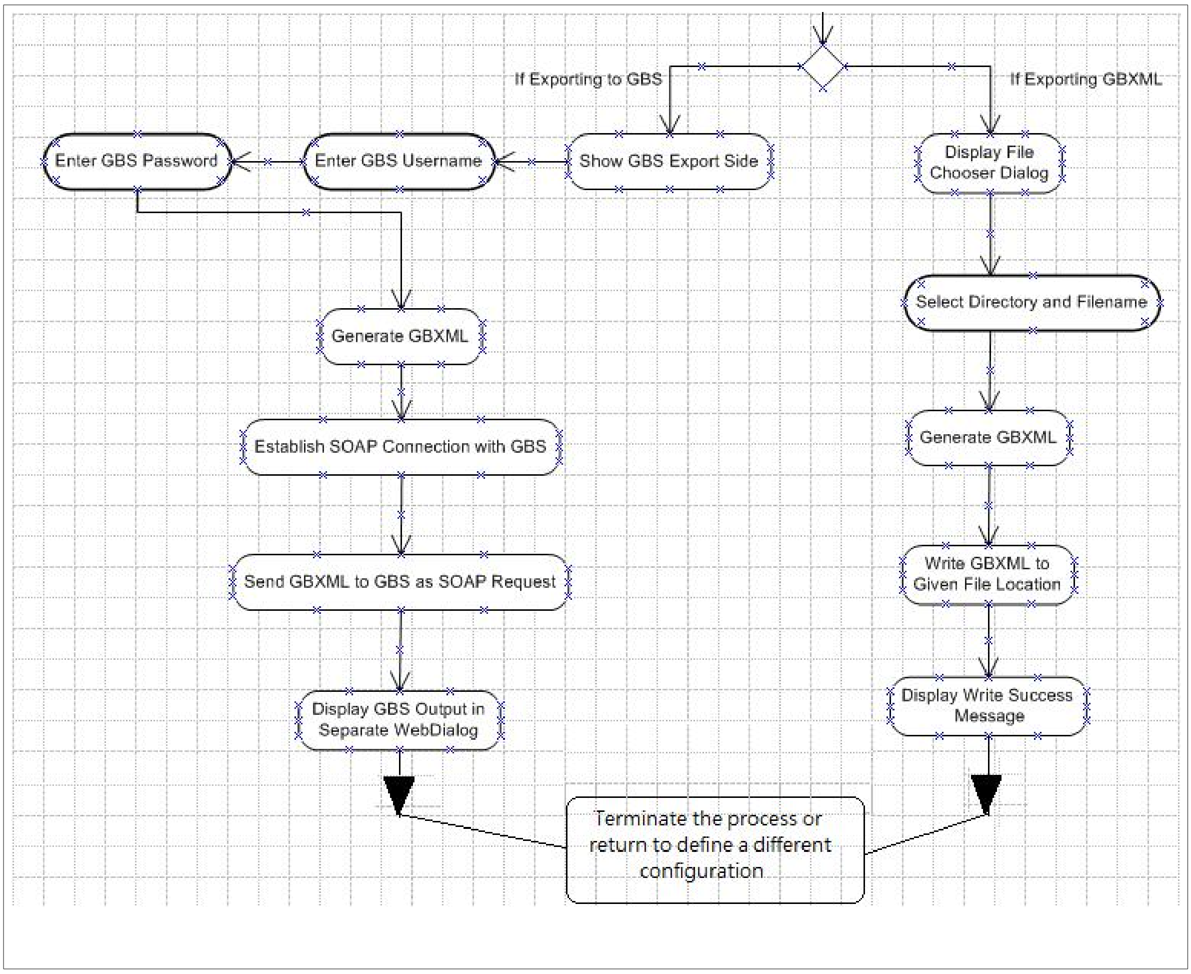

Figure 4.11 GBS or gbXML export

4.5.4 Interface implementation

As stated in section 4.5.1 general information regarding how the interface specifications were implemented is given, following some screen shots of the interface. It is beyond the scope of this MSc project to define the architecture of the GUI, as this includes programs written in complex programming languages (FLEX, Ruby, Javascript, etc.) and implemented by the software development team that supported this project.

The main concept in the GUI of the DMM plug-in is to present all the necessary information that will assist the user though the basics of building energy modelling. The interface functionality was broken down into four modules each given a simple name referring to the task it performs. Thus, the user does not have to be familiar with "building energy modelling" terminology to perform each task. Another reason the interface was decomposed into four modules is to "educate" and "familiarize" the user with the steps of using the plug-in.

The interaction with the user is handled using a Flex program. This provides a user interface based on Flash and runs within a window under SketchUp's control. This window loads an HTML file which references the Flex program along with a JavaScript file. The plug-in can send text to this program to notify it of any changes in the model or anything that the user has selected. SketchUp takes the text from the plug-in and calls a JavaScript function. Calling JavaScript functions is a method provided by the SketchUp API.

In order to reduce the amount of data presented to the user while navigating through the modules (especially when dealing with large models) the concept of a "cube" GUI was introduced. The "Cube interface" enables each side of the cube to represent a different module. Emphasis has been paid to the transition between different faces of the cube by implementing features based on Rich Internet Application[9] built on FLEX. The Flex program contains different panels representing each side of a cube. Each side responds to events sent from the Ruby plug-in and can send events back to the plug-in in a similar way. Thus, the Ruby plug-in could start by sending a list of surfaces to the Flex program. Each surface would then be added to a list of surfaces from within Flex.

After the user has selected a surface and changed its name, the Flex program would send the ID of the surface along with the new name back to Ruby which would update the model accordingly. The two programs store data independently but keep synchronised through this communication. Figures 4.12 and 4.13 present different faces of the cube (i.e. different modules) and figure 4.14 presents the interface in real practice. It is worth mentioning that the DMM plug-in was renamed into "DEMETER-The SketchUp Green building extension" when the first phase of its development was completed.

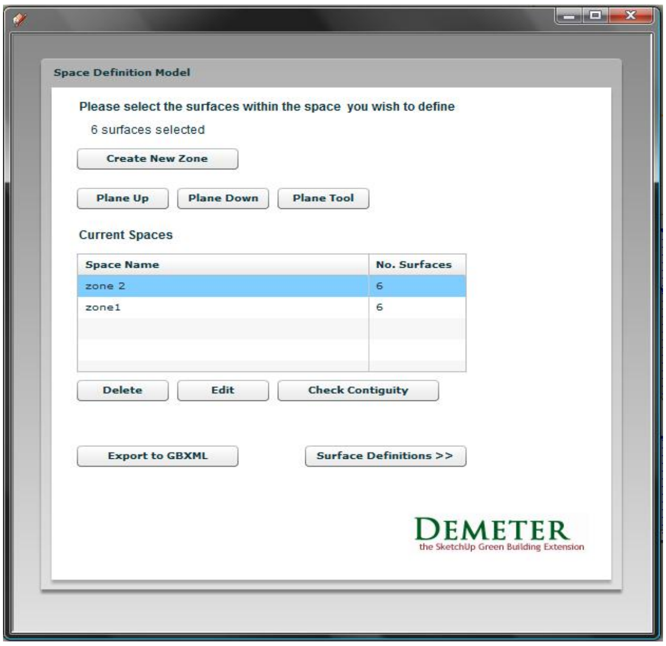

Figure 4.12 The space definition module face of the "Cube"

9 Rich Internet applications (RIA) are applications that have the features and functionality of traditional desktop applications. RIAs typically transfer the processing necessary for the user interface to the FLEX client but keep the bulk of the data back on the application software.

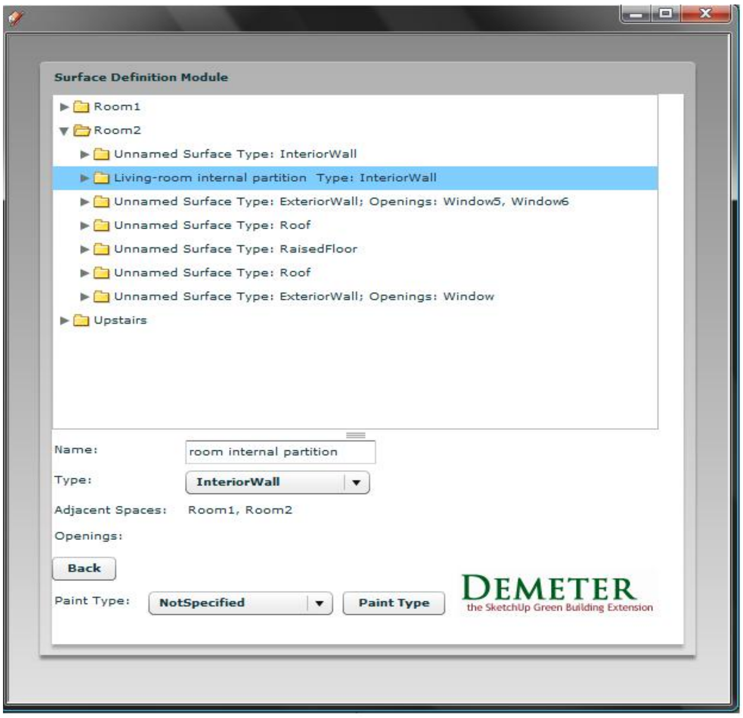

Figure 4.13 The Surface and Openings definition module face of the "Cube"

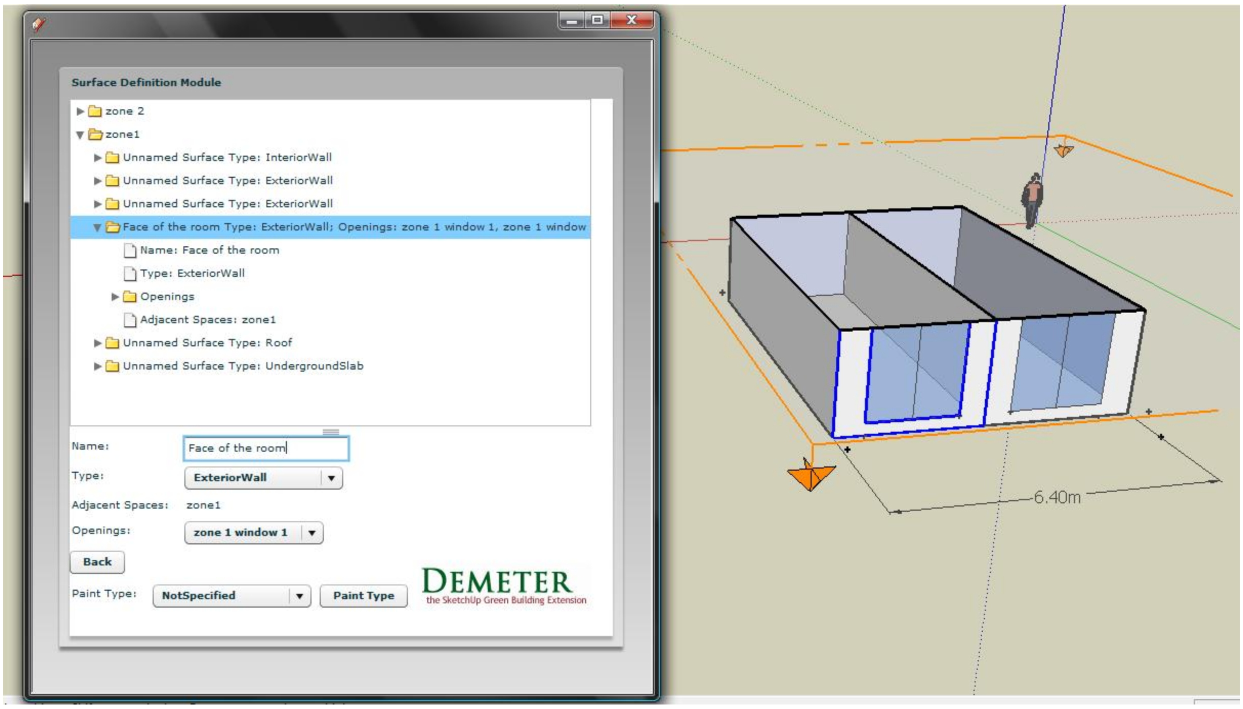

Figure 4.14 The GUI of the DMM plug-in in real practice

4.6 Closing remarks

This chapter initially described how the method proposed in the previous chapter was implemented through the scope of this MSc project. The tools selected for each step of the method reflect a structured approach to addressing the most significant reasons for the small uptake of simulation within the conceptual design process of a building. The approach includes CAD integration, ease of use and interoperability. The popularity of SketchUp, its free entry price and intuitive design makes it ideal for the method. Green Building Studio was selected to provide the web-based energy simulation and manipulation tool since its ability to accept gbXML files, manipulate them by applying IDD and quickly define design alternatives in terms of orientation, material use, HVAC configuration and lighting device efficiency, makes it ideal for the method. In addition, the simulation is handled by a DOE 2.2 e engine running on the back-end of the application. Despite the fact that DOE 2.2 cannot handle with daylight simulation, the results with regards to the energy and environmental performance of the model are presented in an annual basis. Thus, the conceptual designer can have a quick indication about the energy consumption of a particular design proposal and test some design alternatives by using the "Design Alternatives" function directly from GBS.

The chapter also deals with the specifications and the architecture of the DMM plug-in, indicating the classes and the functions necessary to perform the required tasks. Not all of the specifications mentioned in previous chapter where implemented in the DMM plug-in. This can be partially attributed to the complexity of building advanced functions into the plug-in which exceeds the scope of this MSc project. In addition, the implementation of the tool carried out during only the last two months of the placement. Hence, the team focused on implementing some basic features mainly for demonstration purposes. These features are related to the definition of the geometry of the model, type of surfaces and sub-surfaces, building type and location.

The specifications of the DMM tool were defined through the use of the Data Mining System (DMiS) and the data management system (DMaS). This dissociation was made so that the development team and future developers can decompose what information is entering the system (mining) and what is processed by the system (management). The general concept behind the development of this plug-in was user functionality. Thus the majority of the processes are automated while a few require some level of user interaction.

The model created in SketchUp contains a set of faces, edges and vertices. By letting the faces represent surfaces and identifying to which spaces they belong, the basic gbXML structure is created. The gbXML structure is built on a Ruby environment and contains spaces, surfaces, poly-loops, rectangular and planar geometries (all essential elements of the gbXML schema). This structure is stored in a group of classes within Ruby so that it can be easily accessed and modified from different parts of the software.

The central concept in the development of the interface of the plug-in is to enable a non expert in building energy modelling to define certain properties of a simulation model. Hence, a considerable amount of effort was made to develop a “user objectives” model and a “user interaction” diagram. These were used to design a user friendly interface. The specifications of the interface are presented in an activity diagram where both automated and semi-automated processes are included. The interface consists of several “modules”. The concept of modules was introduced in order to help the user to understand the philosophy behind the tool. Four modules were implemented in the GUI: The “Space definition module”, the “Surface and Openings definition module”, the “Building information module” and the “Green Building Studio or gbXML file export module”. In addition, the concept of a cube GUI was introduced. The “Cube interface” enables each side of the cube to represent a different module.

After the completion of the first phase of development of the DMM plug-in, it was named as “Demeter”. This reflects the aspirations of the development team to expand the capabilities of the plug-in and test it within an actual architectural practice.

Chapter 5:

Further developments and Discussion

5.1 Introduction

In the previous chapter a detailed presentation of each component of the method was given. In addition, the specifications and the architecture of the DMM plug-in were analysed and discussed. This chapter provides general guidelines for future development of the proposed method and the DMM plug-in. These guidelines are influenced by discussions with an architectural practice, academia and personal views of the Author. Further development suggestions are presented with regards to the method components and the functionality of the DMM plug-in. Furthermore, the chapter gives an indication about additional uses of both, and discusses how these can be implemented in practice. Finally, the applicability of the method and the DMM plug-in in real practice is discussed and conclusions are made with regards to the final outcome of the project.

5.2 Feedback sources

The DMM plugin's functionality was not tested among the practitioners of the architectural practice, due to time limitations. However. the particular architectural practice proved to be ideal for getting feedback about the concept of the method. In more detail, the majority of the architects interviewed stated that they would be very interested if a tool (or a sequence of tools) can provide them with an indication of the energy rating of a particular design option. In addition, they all agreed that the particular method has several advantages. However, as this will be indicated in section 5.5, applying this method to real practice will not be an easy task.

The particular company does not have an in house energy modelling group. It collaborates with an engineering firm so that the models are worked in greater detail (in terms of materials, orientation, thermal mass, glazing area, etc.) in the conceptual design stage. Thus, building energy simulation is not an in-house part of the design process. As a result, delays in deciding the optimum design option are common since the engineering analysis often contradicts with the original design option. Thus, the company's designers had to modify (and some times re-design) the building design, slowing the delivery of the preferred design proposal.

Discussions with practitioners provided the Author with a better understanding about the functionality the Conceptual designers would like to see from the DMM plug-in. In addition to the “architectural” feedback, the specifications for further development were also influenced by the Author's experience as a user of building energy simulation tools. Nevertheless, the method and the plug-in was used and tested by all members of the development team and external stakeholders[1]

5.3 Comments about further development in the simulation engine

5.3.1 Introduction

The method, as it was implemented through the scope of this MSc project, uses DOE 2.2 e as the simulation engine. Despite the fact that the engine is powerful [*DOE 2007*], it can not take into an account several essential for the conceptual design stage parameters, such as creation of optimized shading devices, shading device transmittance, Bi-directional shading devices, solar radiation passing through interior windows (i.e. Sun-spaces), natural ventilation modelling and many more [*Crawley et al 2005*]. However, as this was found in literature (chapter 2) and justified within the architectural practice, shading design and control is an important aspect of conceptual design. Ina addition, architects are aware of the visual implications of shading into their designs. Thus, they have begun to consider shading as an important aspect in their designs [*ARTI 2002*].

By introducing a more detailed simulation engine at the back-end of the method (such as ESP-r or EnergyPlus), several benefits can be drawn. It is not in the intentions of this dissertation to provide details about these benefits. However, some of the drawbacks of DOE engine with regards to the conceptual design stage are outlined in the Appendix *(Table F).*

5.3.2 Suggestions

In the previous section it was made clear that DOE engine lacks functionality in certain aspects of design decisions taken at early stages of design. Thus, a new simulation engine should be incorporated in the web-services of the “energy simulation and model manipulation” tool. As mentioned in section 4.2.2, the structure of the EAM is of such that once enabled, alternative simulation engines can be called. However, any new simulation engines hooked to EAM should full fill certain criteria. These criteria refer to the fact that EAM is entirely centred around gbXML. Thus, the new simulation engine should have its entities dictionary mapped to gbXML entities dictionary. EAM's model then allows the new engine to be hooked into the system and the input file generated from gbXML transform is run through this engine. In addition, the code will need to be re-written to parse the results from the new engine's run and populate the originating gbXML file

1 External stakeholders were people who had interest in the development of the plug-in, including the CEO of GeoPraxis.

with results (results are also stored in database). Even if the new engine has functionalities not defined in the gbXML schema specifications, the gbXML definitions can be re-written[2].

Incorporating a detailed simulation engine into the EAM's structure will allow the web-service to move away from strategic early stage design and move into a full energy simulation functionality from a web browser. This, in conjunction with modern programming languages (FLEX, Java, etc.) and a detailed interface design practice, can result in a user-friendly energy simulation software package. Thus, several issues related to the ease of use of simulation tools can be addressed without the need to sacrifice functionality. An ambitious solution to the interface will be the "User conceptualization" idea, which was initially proposed by Clarke and Mac Randal [*Clarke et al 1993*]. According to this idea, the interface of a simulation engine will be able to modify its functionality depending on the background of the user since different designers have vastly different knowledge of energy and environmental modelling. In addition, the interface can be automatically adjusted to provide functionality relevant to the needs of an experienced user (modelling expert).

5.3.3 Additional uses of the method

Additional uses of the method can also take place. That is because particular components of the method allow the quick geneation of a preliminary simulation model using a 3D CAD-Sketching tool.

Currently SketchUp is used in several architectural schools as a stand-alone sketching tool or as a part of CAD or BIM tools. In more detail, it is used for training into design workshops which aim to familiarise the students with 3D Sketching tools [*University of Liverpool 2007*]. The introduction of the a method that helps a non simulation expert to run an energy simulation and get some feedback, will contribute to further student training with regards to energy consumption and assessment. This feedback won't be accurate enough to be used for later use by architects though (issue discussed at the conclusions section in this chapter). However, it can provide an indication about how certain aspects of design (such as orientation, material use, glazing areas, etc.) can affect the energy and environmental performance of a building.

5.4 Comments about further development of the DMM plug-in

2 Since gbXML schema is a XML schema, it can easily be re-written to include additional functionality

The DMM plug-in has reached the end of its first phase of development. The outcome of this phase is a full working version of the DMM plug-in (which is now called "Demeter") with certain functionality as this was presented in chapter four. This section of the chapter deals with future functionality of the DMM plug-in where indications, with regards to where development should turn to, are discussed.

5.4.1 De-bugging

The DMM plug-in is a new software and thus, it requires a considerable amount of time to be spend on de-bugging. This was found necessary throughout the development of the plug-in. If the DMM plug-in is to be launched in the market as a supplementary tool to Green Building Studio, the development team should must be sure that everything works smoothly so that user confusion and frustration (and thus rejection) can be avoided.

An efficient way to proceed to the debugging process is to allow selected users within architectural and engineering practice to use the beta version of the plug-in. A "bug tracking system" such as Bugzilla[3] will allow the development team to keep track of defects and bugs.

5.4.2 Further testing

One of the visions of the development team of the DMM plug-in is to turn a powerful 3D sketching tool into a medium for defining geometry (and several other aspects of building energy modelling) for energy simulation tools. To achieve this the DMM plug-in must pass certain validation, verification and testing procedures so that an accurate model definition is ensured. SketchUp is a tool of which capabilities can only be limited by the user's imagination[4]. The DMM plug-in must be able to ensure that the entities created by SketchUp can be modelled for the needs of an energy simulation, ensuring contiguity and consistency so that predictions correspond to the the actual behaviour of the building. These checks should be based on a variety of geometry issues. In addition, since the DMM plugin's Interface (Cube interface) is a very important part of the functionality of the tool, it should be tested among practitioners to identify whether it responds to users needs adequately or not (usability testing).

3 Bugzilla is one of the most widely recognised bug-tracking software. Vendors such as Eclipse, Open Office, Linux and several others are using it to track defects of their software.

4 According to the Author's and several users opinion

5.4.3 Quality Assurance reports (QA)

As mentioned in the previous section, performance predictions need to correspond to the actual behaviour of the building. This check check can be carried out as a combined verification and validation exercise. Verification deals with correct attribution of the simulation model and need to be performed by a person familiar with the aspects and considerations about the purpose of the simulation exercise. However, since this is not the case for the common user of the DMM plug-in, algorithms that ensure model integrity and space contiguity should be further developed and tested.

Except the importance of verification and validation, the documentation of a simulation model should also form an important part of the model definition process. One way of documenting the model in the DMM plug-in is by summarizing its data information into a report. Initially this report will contain information about floor areas, spaces volume, openings area, wall area, wall and glazing area by orientation, etc. The designer would probably be familiar with these and thus the report will provide an additional check that the model is defied as appropriate. In a future version of the DMM plug-in, where more model definition functions will be supported, the QA report should include all relative to the model information.

5.4.4 Construction types and material databases

Currently material and construction types are assigned to the model by the Green Building Studio's Intelligent Default Data (IDD) system. As mentioned in section 4.2.2, this system uses the user-provided information to attribute the preliminary simulation model using defaults based on the building practices and codes based on UK standards. However, this does not enable the user to test his/her own combination of materials and construction type.

A new class should be introduced to the main structure of the DMM plug-in so that the definition of materials and construction type of each surface can be supported. It was found among literature [*ARTI 2002*] and architectural practice that Conceptual designers are more familiar with describing construction according to their U-values. Thus, the new class should include a list of different construction types based on their U-values.

With regards to the interface adjustments required to implement the “Define the construction type” function, a new face in the cube Interface should be added. Initially typical constructions can be included in the construction type database which reflects UK standards. However, each user should be able to define its own construction types according to company's preferences or construction material provider.

5.4.5 Automatic space and surface type definition

Currently the user of the DMM plug-in can define the surfaces consisting a particular space by simply clicking them through the SketchUp graphical environment. Despite the fact that this task is relatively easy and within the knowledge of the user, the development team has identified the need to simplify this process even more. An algorithm can be developed so that it can identify relative, to the particular space, surfaces and match them to define an enclosed space. Another function can contribute to the ease of use of the DMM plug-in by simplifying the surface type definition process even more. An algorithm can have access to the tilt, azimuth and orientation of a particular surface as well as the surrounding surfaces, so that it can make logical conclusions about the type of the surface. However, both algorithms are based in computing combinations which can dramatically slow down the functionality of the system and will require advanced computing platforms

5.4.6 gbXML import to SketchUp

During the development period of the DMM plug-in all the efforts of the team were focused on creating the appropriate dictionary mapping between SketchUp's geometry data to gbXML. This was the primary functionality required from a tool such as the DMM plug-in. However, the opposite process (gbXML into SketchUp) should be considered. By developing the appropriate scripts that allow a gbXML file to be imported in SketchUp, functionality is increased.

5.4.7 Guided input process and link to cost calculations

As mentioned in section 3.4.2, introducing conceptual design wizards into the model's creation process can assist the designer in the model definition. However, compiling a wizard for the conceptual design stage is not a trivial task and requires extended research among practitioners.

Data exchange between cost estimation tools and the DMM plug-in will be based on the usage of a reference database that can be updated. The consistency of this database must be ensured so that accurate costing is achieved. In addition. the system should be designed according to what kind of functionality the user is familiar with (similar to the approach of this MSc project about the CAD-Sketching integration). With regards to the interface of the plug-in, a new face should be added. The ease of use of this addition to the cube interface should reflect the functionality of costing tools that the conceptual designer is familiar with.

Introducing costing functions to the DMM plug-in will not be an easy task. Costing exercises are based on the concept of zones and surfaces [*Morbizer 2003*]. Despite the fact that basic definition requirements can be easily carried out through the DMM plug-in, the difficulty will be to link the functionality with a well established coherent set of data.

5.4.8 Design alternatives

One of the main advantages of Green Building Studio is its ability to allow the user to define design alternatives (orientation, lighting devices control and efficiency, construction types varying with the orientation of the walls, roof construction type, HVAC configuration and glazing type). However, the accuracy of these transformations can be the outcome of another research since the functions that currently support these features are not clear enough[5]. However, this functionality can be transferred into the DMM plugin's main structure and interface. Hence, the user can have the "design alternatives" functionality of GBS within SketchUp. With regards to the interface of the plug-in, the additional functionality can be represented as an extra face in the cube interface. The user should be able to specify a series of design alternatives (orientation, construction type, glazing areas, etc.) and then store these preferences into a different gbXML file for each alternative. When the user chooses to upload the model(s) to GBS platform he/she can get feedback for the original model and the design alternatives.

5.4.9 Support several format imports and exports

Several state-of-the-art simulation tools support certain types of geometry file format (see section 2.5). However, these tools lack CAD integration from a conceptual designer's point of view. Developing modules that support the transformation from gbXML to IFC (or any other format) and vice versa, will provide an even more stronger link between building energy simulation tools and CAD-Sketching tools. In addition, all the information related to the zone and surface attribution made while using the DMM plug-in can be imported into a wider[6] variety of simulation tools. The same feature can be used by engineers while the building is at the Scheme and Detailed design stage, reducing the amount of time required to define the geometry of the simulation model.

5 This conclusion is made from the Author's personal experience. However, investigating the functions that support these transformations is beyond the scope of this MSc project.

6 Currently IES (virtual environment), EnergySave, Loadsoft, HAP, Energy-10 and Trace® 700 can import gbXML files

Several benefits derive from the opposite process (other format types to gbXML). If geometry files created in any CAD or BIM tool can be imported to SketchUp, processed by the DMM plug-in and then exported to GBS or to a more advanced simulation tool, the terminology between architecture and engineering is a step forward to merging. However, this is not likely to occur without sacrificing some functionality. GbXML schema was originally developed as a language that enables data exchange between CAD-BIM and energy simulation tools, However, it is a relatively new schema and thus should be used with cautiousness.

5.5 Discussion about the DMM plug-in and the method

When the Author had the opportunity to present and discuss the use of the DMM plug-in and the method to the architectural practice, a functional version of the tool was completed. As mentioned earlier in this chapter the method was not tested among practitioners. However, the Author had enough time to present the method (and the DMM plug-in in particular) and discuss its functionality among potential users.

The DMM plug-in was originally developed without having the knowledge of how SketchUp is used among conceptual designers. The idea of representing a single surface as a wall proved to be not very functional when the plug-in was introduced to practitioners of the architectural practice. Architects are used to representing a wall with its associated thickness in a CAD environment. This kind of visual representation is uncommon among energy modelling and simulation practitioners (a wall is usually represented as a single surface). However, when the building is still in the conceptual design process, visualization is an important issue for architects. The 3D CAD tools are mainly used for providing a visual representation of the building as this will be delivered to the client.

The SketchUp models presented to the Author by the conceptual designers of the architectural practice, contained high level visual representation of the building (wall and roof finishes, window fittings, shading devices, etc). A test, undertaken from the development team, of whether or not the DMM plug-in can handle with these SketchUp models, indicated that the building can still be modelled using the DMM plugin's functionality but not without sacrificing part of its ease of use. It was found that modelling (in terms of energy) a detailed visual representation of a building in SketchUp[7] required special skills[8] and thus, increasing the complexity of the modelling exercise and reducing the likelihood of adoption by designers.

7 As this will be generated from a conceptual designer
8 However, according to the Author's opinion, these skills can be easily obtained.

Another important issue deriving from the “visualization priority” among architects, is that of an accurate model geometry definition. The DMM plug-in requires a 100% accurate geometric definition of the model in SketchUp. This fact somehow contradicts to the normal use of 3D in CAD, where the aim is to produce a visual representation of the building as this will be delivered to the client. In the visual representation of a building, drawing inaccuracies are acceptable as long as they do not impact on the visual quality of the drawing.

It is a general fact that designers will not take energy performance into a deep consideration if it weren't for the building regulations. Nowadays, the regulations impose an environmental friendly and thus, energy efficient way of designing. However, as this has been found in literature and proved within the architectural practice, compliance is the most desired outcome of an energy analysis.

The overall objective of this MSc project is the development of a tool that enables the user to get a quick energy and environmental performance prediction analysis. The approach taken to address this issue is made by a series of assumptions so that the process is as simplified as possible. This generates questions about the accuracy of the results of the method (i.e. does the default occupancy type assigned by Green Building Studio accurately represents the actual use of building by occupants?). Thus, the use of the method, as implemented through the scope of this MSc project, can not be used for checking compliance with building regulations. The Green Building Studio's features, as these were implemented in the method proposal, can not be used for compliance check. This is because the complete model attribution is made using “default” values for building components that can dramatically effect energy performance (and thus compliance). The main focus of the proposed method is to provide the conceptual designer with an indication of whether a particular design is on the right path to achieve compliance or not.

The use of “default” values should be reconsidered and carefully analysed when developing a conceptual design tool to be used for compliance check (*Morbitzer 2003*). The accuracy of the “default” values assigned from Green Building Studio should be further tested to find out whether or not can create design guidelines, as well as up to what extent reality is represented. Thus the method can have a more strategic purpose. However, validating the accuracy of the predictions is a complex issue and paucity of consensus about “defaults” is the main reason for this.

There are also several other issues deriving from the accuracy of the prediction analysis provided by Green Building studio. These can be mainly attributed to the simulation engine located in the back-end of the process. DOE 2.2 cannot take into an account several parameters that can affect energy performance in a building and has limited modelling capabilities compared to other simulation tools. These are outlined[9] in table G in the Appendix, for referencing reasons. In the same table, the capabilities of a more advanced energy simulation tool (ESP-r), are contrasted. A full report about the capabilities of each the tool, as well as several other simulation tools, can be found in literature [*Crawley et al 2005*].

5.6 Conclusions

In the last two chapters of this dissertation, a detailed description of a method was given. The main objective of this method is to provide Conceptual designers with strategic advice about certain aspects of conceptual design. The method consists of a sequence of two tools and three steps (figure 5.1) and aims to address some of the most significant barriers to the adoption of simulation into the conceptual design stage: CAD integration, ease of use and interoperability.

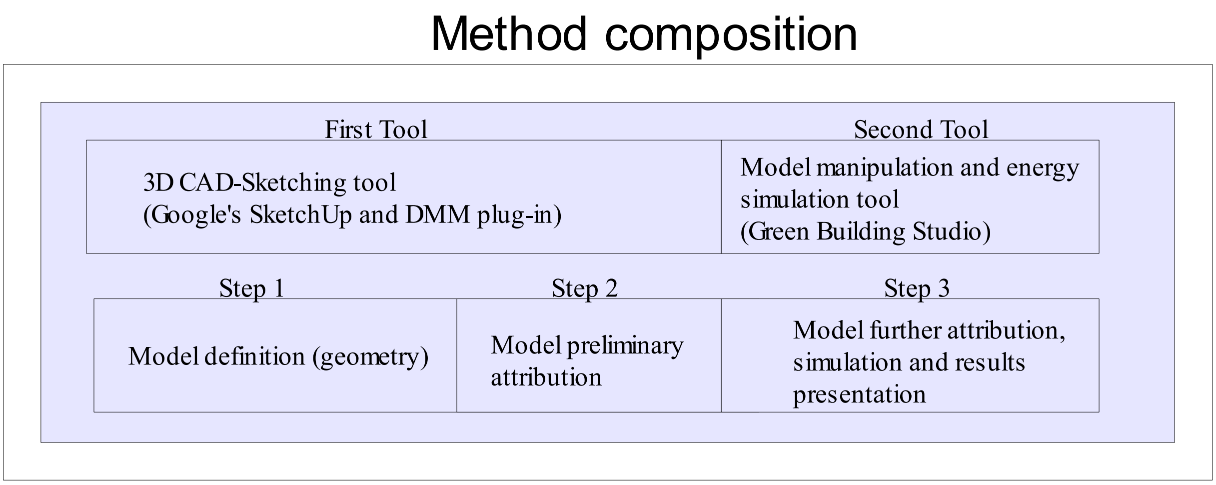

Figure 5.1 Method composition

The use of SketchUp for the CAD integration was made considering three essential parameters: its ease of use, its 3D sketching capabilities and the fact that it is the most popular 3D sketching tool among designers [*Vanguard 2006*]. For the needs of this method, a Data Mining and Management plug-in to SketchUp was developed. Among the plugin's main responsibilities is to “extract” information about the geometry of the model created within SketchUp and manage them so that an accurate preliminary simulation model is created. The preliminary model is then uploaded to the Green Building's web-based platform for further manipulation, by using Intelligent Default Data (IDD) so that a complete for simulation model is created. Then a simulation is undertaken by DOE 2.2 engine and the results are “sent” to the user and presented in a web-browser.

9 The modelling capabilities of DOE 2.1 (a similar to DOE 2.2 engine) are presented in this table.

The method, and thus the DMM plug-in, were originally developed with the aspiration to provide strategic design advice to conceptual designers about certain aspect of design relative to early design stage. However, the first two steps of the method can be used to define a geometry model using the flexibility and the ease of use of SketchUp, to attribute the model in terms of spaces, surfaces and openings by using the attribution functions of the DMM plug-in and finally, to export the model into a gbXML format. Thus, the model can be inserted into an advanced simulation engine (gbXML compatible) for further attribution and simulation.

The user input requirements of the DMM plug-in are related to space definition and surface attribution. Also, the user is required to provide the use and location of the building. However, future versions of the DMM plug-in will probably require more user inputs to provide more strategic design decision support. Emphasis has been paid to simplifying the process by using assumptions based on the current user interactions. Thus, a detailed study has been carried out so that specific user requirements are translated into operating tasks. In addition, the development of the user interface was developed according to development team's conceptualization about ease of use.

The strategic design decision support is provided by the web-services of Green Building Studio. According to these services, the user by defining the "post code" of the building can inform Green Building Studio as to which weather file to use for the simulation. The model is further attributed in terms of occupancy type, occupancy level, internal heat gains, HVAC configuration and air change rates, according to the building use specified by the user. Green building Studio uses these user-provided information to assign "defaults" based on building practices and codes for the UK. However, this generates questions about the accuracy of the results of the method (i.e. does the default internal heat gains or HVAC configuration assigned by Green Building Studio accurately represents the building?). Thus, the use of the method, as this was implemented through the scope of this MSc project, can not be used for checking compliance with building regulations. Nevertheless, if a relative consensus among researches is achieved with regards to "defaults", then the method can provide more "accurate" strategic design decision to the end user. In addition to the issues with the "defaults", questions are also raised regarding the simulation engine. For example, DOE engine cannot handle with time steps less than an hour. However, in order to accurately represent the effect of a particular HVAC configuration, time steps of less than an hour must be taken into an account.

Currently the method can provide the user with strategic design decision advice about the following design aspects:

- ➔ Orientation
- ➔ HVAC configuration (choose among a variety of systems)
- ➔ Lighting efficiency
- ➔ Lighting control
- ➔ Roof construction type
- ➔ Northern façade (choose from a variety of construction type, glassing type and glazing/wall ratio)
- ➔ Southern façade (choose from a variety of construction type, glassing type, glazing/wall ratio)
- ➔ Eastern façade (choose from a variety of construction type, glassing type, glazing/wall ratio)
- ➔ Western façade (choose from a variety of construction type, glassing type, glazing/wall ratio)

These changes are operated by the “design alternatives” functions of GBS. The design alternatives are based on certain kind of transformations undertaken by the GBS' web platform. According to the Authors opinion, the functionality provided to the end user is considerable and can represent some of the needs and priorities of Conceptual designers. However, the functions supporting these transformations should be the centre of extended research so that accuracy is ensured.

As this was mentioned in section 2.4 and proved among architectural practice (section 5.5), ease of use can be eclipsed provided “visual representation” priorities among conceptual designers. In addition, any model drawing inaccuracies in the sake of visual quality, are common among conceptual designers. The DMM plug-in requires 100% accurate geometry definition. However, the DMM plug-in can still handle complex geometries and detailed models generated in SketchUp. The model can be attributed in the DMM plug-in, as this was investigated among the development team, but it will take more time and effort, and require some guidance (at the beginning). Thus the tool is more likely to be rejected among practitioners.

Another use of the DMM plug-in is also promising from a user perspective. The plug-in can be used in conjunction with SketchUp to easily define the geometry of a model and assign attributes to it, in terms of space definition, surface and openings type and construction types. These information can be saved in a gbXML format and exported into an advanced simulation tool for further attribution by a simulation expert. Thus the time required to define a simulation model is reduced and the same geometry model is used throughout all the design stages (Conceptual-Scheme-Detailed)

According to the Author's point of view, this project addresses some of the major problems responsible for the small uptake of simulation into the conceptual design stage by proving a link between a powerful 3D sketching tool and building energy simulation tools. The benefits can be found among conceptual designers, since a strategic Design Decision Support System is provided, as well as other stakeholders, since the generation of a simulation model (in terms of geometry and certain attribution) is supported by an easy to use but still powerful 3D sketching tool.

The final outcome of this MSc project, is the development of plug-in that enables different level of experienced users to take advantage of its capabilities and reduce the time required to perform certain aspects of building energy modelling. The plug-in is currently under further development to support more functionality and thus become even more useful among designers. Verification and testing are still under way to ensure that the model is generated as accurately as possible according to building energy modelling techniques. In addition, several other issues, such as the use of "defaults", transformation functions in "design alternatives" and incorporation of more advanced simulation engines, will also addressed in the foreseeable future.

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APPENDIX

Table A

Work Stage	Description
A: Inception	Discuss the client's requirements including timescale and financial limits; assess these and give general advice on how to proceed
B: Feasibility	Carry out a study to determine the feasibility of the client's requirements.
C: Outline	Analyse the client's requirements; prepare outline proposal and an approximation of the construction cost.
D: Scheme	Develop a scheme design sufficiently accurate to illustrate special arrangements, materials and appearance.
E: Detail	Detailed definition of design.
F and G: Production and Bills	Prepare production information (drawings, materials, workmanship); prepare bills of quantities.
H: Tender	Invite tenders.
J: Project Planning	Appointment of contractor.
K: Operation on site	Administer construction operations on site.
L: Completion	Guidance to maintenance, provide drawings to client, including service installations.
M: Feedback	Occupiers evaluate building.

Table B

Practitioner design tools
CAD environments
Lighting design tools
Architectural visualization tools
Fenestration selection tools
Shading/ solar angle tools
Code compliance tools
Single-zone load tools
Multi-zone HVAC system load tools
Duct sizing/ layout tools
Cost estimating tools

Integrated design suites
HVAC product selection and configuration tools
Engineers 'Toolbox'
Pipping analysis and Pump sizing tools
IAQ/ standard 62 compliance tools
Psychometric tools
Refrigeration load tools
Coil selection tools
Geothermal HP loop sizing tools
Acoustic analysis tools
Solar DHW/ PV system design tools
Weather tools and utilities

Table C

Whole building energy analysis tools
Simplified energy analysis models (DD, bin analysis, day profile per month)
Basic hourly simulation models (calculator engines)
General hourly simulation models
Special purpose simulation models
Screening tools

Table D

Economic and Environmental tools
General life cycle tools
Technology screening/assessment tools
Environmental impact assessment tools

Table E

Specialized analyses tools
Daylight / Illumination tools models
Fenestration models
Infiltration / pollutant / Pressurization models
2D and 3D heat and moisture transfer models
Computational fluid dynamics models
Equation based solvers
General component-based mechanical models

Refrigeration systems (hardware-based) models
Refrigeration system (performance-based) models

Table F

Space temperature based on loads-systems feedback feature not supported
Number of surfaces, zones, systems and equipment limited
Human thermal comfort function not supported
Beam solar radiation reflection from outside and inside window reveals feature not supported
Solar gains through blinds feature not implemented
Solar gains and daylighting calculations for inner reflections form external buildings feature not supported
Creation of optimized shading devices feature not supported
Shading surface transmittance feature not supported
Beam solar radiation passes through interior windows (double-envelope) feature not supported
Track insolation losses (outside of other zones)
Electrochromic glazings feature not supported
Thermochromic glazing feature not supported
Inside radiation view factors feature not supported
Geometrically and optically complex fenestrations systems using bidirectional transmittance feature not supported
Daylighting devices feature not supported
Airflow windows feature not supported
Phase change materials feature not supported

Table F
Conceptual design variables not supported by DOE engine [full report available from Crawley et al 2005]

Table G

Modelling approach	**DOE 2.1 E**	**ESP-r**
Simulation solution		
Simultaneous loads, systems and plant solution	n	y
Coupled loads, systems and plant solution	n	y
Time step approach		
Variable time intervals for zone air/HVAC system calculation	n	y
Less than an hour	n	y
Interior surface convection		
Dependent on temperature	n	y

Dependent on air flow	n	y
Dependent on CFD surface heat coefficient	n	y
Dependent on temperature	n	y
Human thermal comfort	n	y
Automatic design day sizing calculations	n	y
Solar analysis		
Beam radiation from outside and inside window reveals	n	y
Solar gain and daylighting calculations account for inner reflections from external buildings	n	y
Creation of optimized shading devices	n	y
Insolation analysis		
Distribution calculated at each time step (less than an hour)	n	y
Beam solar radiation passing through interior windows (i.e. sunspaces)	n	y
Advanced fenestration		
Electrocromic-thermocromic glazing	n	y
WINDOW 5 calculations	n	y
Window blind model	n	y
User specified daylight control	n	y
General envelope calculations		
Outside surface convection algorithm	DOE-2	MoWiTT (among others)
Inside view factors	n	y
Radiation-to-air component separate from detailed convection (exterior)	n	y
Air emissivity/radiation coupling	n	y
Air flow windows	n	y
Natural ventilation	n	y
Hybrid ventilation	n	y
Window opening for natural ventilation controllable	n	y
Displacement ventilation	n	y
Renewable energy systems	Only Trombe wall	Several technologies
Economic evaluation		
Energy costs	y	Limited
Life cycle costs	y	Limited

Table G Capabilities of DOE 2.1 and ESP-r contrasted [After Crawley et al 2005]