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THE UTILISATION OF GAMES TECHNOLOGY FOR ENVIRONMENTAL DESIGN EDUCATION

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I lovingly dedicate this thesis to my wife Eman,
for her endless love, support, and encouragement

Abstract

In recent years, the architectural design process has witnessed a mounting demand for qualified practitioners who can resolve the highly complex social, cultural, technological, and economical issues associated with the notion of 'Sustainability'. This was clearly reflected in a dramatic shift in the design paradigm to incorporate the whole new set of variables and criteria evolving from the introduction of this notion. Designers are thus faced with wider pallet of challenges, developing their conceptual ideas whilst trying to make the design itself realisable from a sustainability perspective. There is subsequently an increasing pressure on educational institutions to prepare new generations of architects that are well accustomed to the environmental design concepts and parameters, aiming to reduce the impact of the designed buildings on the environment and minimise the reliance on valuable natural resources to bring the building's interior environment to comfortable living conditions. However, architectural education has been notably slow to respond effectively to the new set of criteria and requirements introduced by sustainability to the design process. Evidently there are a number of pedagogical challenges that clearly impede the consistent endorsement of sustainability in the design curricula and thus hinder any potential values, benefits, and opportunities that can result from its effective integration.

This research project presents taxonomy of these challenges and investigates more into their nature and attributes. Based on this investigation, the research proposes a method - with its related tool- that endeavours to overcome the noted challenge and attempts to improve the design students' motivation and acceptance to incorporate sustainability measures in their design projects. In essence, the method proposed by this research aims to mould the technical nature of Building Performance Simulation (BPS) applications (as a means for integrating sustainability) into the cognitive design process. In order to achieve this, the proposed method utilizes 3D games technology, and expands the scope of this technology with incorporating Multi-Agent System (MAS) and Data Mining (DM) techniques, attempting to assist design students in achieving higher levels of motivation, engagement, and comprehension of the environmental design concepts. The research discusses the rationale for electing the employed technologies and discusses the methodology for developing the proposed tool. Following the development process, the tool is presented -in

user trial sessions- to number of stakeholders (students and instructors) for evaluating the pedagogical and conceptual basis that this tool was built upon. The recorded results and the provided feedback from these sessions are presented and discussed within the body of this thesis, aiming to assess the feasibility and effectiveness of implementing this method as a means for improving design students' understanding of the various aspects, concepts, and measures surrounding environmental design and sustainability.

List of Publications

- Sarhan, A; Rutherford, P (2011) "*Environmental Design eTutor: Utilizing Games Technology for Environmental Design Education*", RESPECTING FRAGILE PLACES [29th eCAADe Conference Proceedings / ISBN 978-9-4912070-1-3], University of Ljubljana, Faculty of Architecture (Slovenia) 21-24 September 2011, pp.699-708
http://cumincad.scix.net/cgi-bin/works/Show?ecaade2011_125

- Sarhan, A; Rutherford, P (2009) "*Embodied Game Agents in Environmental Design Education*", Computation: The New Realm of Architectural Design [27th eCAADe Conference Proceedings / ISBN 978-0-9541183-8-9] Istanbul (Turkey) 16-19 September 2009, pp. 795-802
http://cumincad.scix.net/cgi-bin/works/Show?ecaade2009_052

- Sarhan, A and Rutherford P (2009) "*EDVIS-Game: A framework for utilizing game engine reporting agents for environmental design education and visualisation*", Digitizing Architecture: Formalization and Content [4th International Conference Proceedings of the Arab Society for Computer Aided Architectural Design (ASCAAD 2009) / ISBN 978-99901-06-77-0], Manama (Kingdom of Bahrain), 11-12 May 2009, pp. 205-214
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List of Acronyms

BIM	....	Building Information Modelling.
BPS	....	Building Performance Simulation.
CAD	....	Computer Aided Drafting.
DLL	....	Dynamic Link Library.
DM	....	Data Mining.
DW	....	Data Warehouse.
DSS	....	Decision Support System.
GUI	....	Graphical User Interface.
HVAC	....	Heating, Ventilation, and Air Conditioning
IPV	....	Integrated Performance View.
KDP	....	Knowledge Discovery Process.
MAS	....	Multi Agent System.
MMORPG	....	Massive Multiplayer Online Role Playing Game.
NPC	....	Non Playing Character.
UML	....	Unified Modelling Language.
VR	....	Virtual Reality.
VE	....	Virtual Environments.

Chapter One:

Introduction

1. Introduction

"Humans may build their societies around consumption of fossil resources long buried in the Earth, but these societies, being based on temporary resources, face the problem of being temporary themselves." (Bowden, 1977)

Over the past few decades, the rapid growth in human population, along with advancements in scientific knowledge and developments to technology have generated a new socio-cultural -and industrial- way of living that has profoundly, swiftly, and extensively altered natural ecological systems, as well as the human's well-being (Nelson, 2005). These have placed significant reliance on natural non-renewable resources, leading to profound environmental impacts in the form of deforestation, pollution and carbon emissions resulting from fossil fuel consumption, and subsequently leading to climate change and 'Global Warming' (Russ, 2010; and Gore, 2006). The past few decades have seen a number of calls attempting to reverse the negative impact of man's actions on the environment. These include conserving resources through environmental awareness and sustainable development, focusing -in particular- on energy efficiency as a solid industry driver, and addressing its potential long-term ecological and economical benefits (Newman et al., 2004). Sustainable development, as presented in WCED (1997), aims to ensure that the future generations would have adequate living conditions, where they can efficiently satisfy their needs and fulfil their requirements. That aim can be achieved via concurrently embracing number of aspects relating to the management of environmental resources and energy use, and reduction of waste and greenhouse gas emissions.

The building and construction industry is one of the main contributors towards energy consumption and carbon emissions (Price et al., 2006). In response, various organisations, governments, and international bodies have highlighted the imperative need to alter conventional and unsustainable approaches to building design and move towards methods that seek to preserve natural resources and in so doing accommodate sustainability and other environmental measures. In order to reduce the impact of buildings and / or building-related activities on the environment, significant responsibility has been placed on the shoulders of the design profession as a whole, and of importance to this thesis, the

architect. As such, the architect is expected to respond in a manner that satisfies many competing demands whilst ensuring that the building minimises its draw on natural resources. This challenge is ultimately reflected upon schools of architecture that are tasked with preparing future generations of architects and associated design professions, requiring in many cases a significant departure from traditional to more environmentally responsive or responsible pedagogies.

The integration of sustainability into architectural design education is not however without its challenges and is a matter that is currently under exploration across the globe. One area that has been identified as offering potential benefits in integrating sustainability is the rapidly developing field of Building Performance Simulation (BPS). Encompassing fields such as lighting, acoustics and thermal design, at their core, BPS systems/applications may be used to assess any given design and its associated sustainability strategies and for the purpose of this thesis, predict their operation, energy efficiency and ultimately carbon emissions. However, there have been noted challenges that surrounded this integration, reflected in pragmatic issues involving the use of BPS applications as part of the design process. These challenges include the highly technical nature and complexity of these applications, the motivation of design students to use them, and the difficulties encountered in interpreting the simulation data into informed design decisions (as will be discussed in more detail in the next chapter).

The research project that forms the basis for this thesis aims to address some of the afore mentioned challenges, in an attempt to facilitate the integration of sustainability into the architectural design curricula. By employing games technology, with Multi-Agent Systems and Data Mining techniques, it seeks to improve the experience of the architectural design student and in so doing enhance their understanding of sustainability and integrated environmental aspects of their design. In order to set the scene for the research, the thesis will begin by outlining the benefits and calls for sustainability in built environment, leading to the rationale and motivation -as well as the scope and context- for this research project. Having made a clear case for the rationale behind the research, the following sections of the chapter will explore the main aim and its related set of objectives, as well as the methodology of research employed to address and satisfy them.

1.1.   Paradigm Shift in Design

"At the dawn of the 21st century we are faced with unique environmental, economic, social, and political challenges, such as global warming, globalization, diminishing natural resources, and aging populations. At the same time we also have at our disposal opportunities such as ubiquitous information technologies, new materials and building practices, new learning methodologies, and a knowledge-based economy. Addressing these challenges and opportunities requires new approaches to education in general, and environmental design education in particular … [Architects] will need to have a better understanding of the impact that diminishing natural resources will have on physical, social, economic, and political environments; the means they can employ when designing new environments; and the new kinds of products they will be asked to design. More importantly, they will need to understand the impact these developments will have on their professions, on the global environment, and on the societies they serve. Faculty and students will have to assume a leadership role in research and design that will direct these developments along social, cultural, and professional values." (Kalay, 2008, pp. 6)

1.1.1.   Sustainability in Building Design

On a global scale, the building sector is considered presently to be responsible for 33% of all the current energy related carbon-emissions (Price et al., 2006). On a global scale, the operation of Heating, Ventilation, and Air-Conditioning (HVAC) systems is believed to constitute over 60% of a typical building's energy consumption (Department of Sustainability and Environment, 2006). It is believed that utilising current and proven technologies and methodologies in environmental design, new and existing buildings' energy consumption could be reduced by 30-50% without incurring any additional costs (UNEP, 2009). In this respect, a number of important strategic development plans have evolved within the last few years, with particular reference to the built environment, like the European Energy Performance in Buildings Directive (EPBD, 2002), the EU Action Plan for Energy Efficiency (Commission of the European Communities, 2006), and IPCC Fourth Assessment Report (IPCC, 2007). The UK government in turn has enforced a set of tightened regulations aiming to push for low-energy architecture that is in line with the European

policy and its set of performance standards. In this context, attaining low-energy architecture is no longer a choice, or just a matter of ethical commitment, but it has been escalated to become a more practical issue that is legally enforced (at the local authority levels in the UK) for building and planning approvals. These facts have resulted in increasing calls for more effective performance-based design strategies that can integrate architecture and service engineering in order to comply with the new laws and regulations, which are falling under the banner of 'sustainable' or 'green' architecture.

The ASHRAE GreenGuide (2006) defines the notion of sustainable/environmental/green design as the type of design that is developed based on a high level of awareness and respect towards natural resources. As such, it seeks to minimise human impact on the natural environment, this impact is directly correlated to energy consumption (and its resultant carbon emissions), resource and materials usage, etc. (Grumman, 2003). Based on this definition, approaches to building design should clearly consider the building as a complex integrated system that aims to fulfil multiple requirements. In partial response, green building ratings and certification systems have evolved significantly over the past two decades, providing designers with clear objectives that should be met by any proposed design (Gowri, 2004). Currently, some of the most common rating systems include LEED (Leadership in Energy and Environmental Design)[1], BREEAM (Building Research Establishment Environmental Assessment Method)[2], GreenStar[3], BCA Green Mark[4], and GB Tool (Green Building Challenge Assessment Framework), and CIBCE Guides. Although these certification and accreditation schemes vary internationally in their standards and rating criteria in response to national social, cultural, economic and environmental priorities, they have placed increased pressure on architects and other design professionals to integrate environmental design strategies at key stages in a design's development. Subsequently, such designs are subject to rigorous analysis, where given the complexity and interdependence of the numerous strategies employed, designers are expected to employ specified applications and tools as a means to verify the performance of the resultant designs. This will be discussed in more detail later in this chapter.

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[1] LEED: http://www.usgbc.org/DisplayPage.aspx?CategoryID=19
[2] BREEM: http://www.breeam.org/
[3] Green Building Council Australia: http://www.gbca.org.au/
[4] BCA Green Mark: http://www.bca.gov.sg/greenmark/green_mark_criteria.html

Sustainable environmental design thus aims to strike a careful balance between creativity and design expression, maximising the potential for occupant satisfaction and minimising the energy and resource requirements of the building throughout its entire lifecycle. In this respect, the design shouldn't just be aesthetically, spatially, socially, and culturally pleasing, but should also satisfy the thermal, acoustic, and economic performance parameters (Soebarto, 2005). In contrast, since the rise of the 'Machine Age', architects and the design team as a whole have tended to try to overcome the challenges of creating comfortable, liveable, enjoyable and productive internal and external environments through the design and implementation of building services systems and their associated technologies (Hayles and Holdsworth, 2008, and Altomonte, 2009). All too often, this approach has demanded the use of high grade energy means and valuable resources to meet those needs. Contrary to the expectations of such systems affording high quality living, working and/or play environments, this highly serviced approach has often resulted in significant occupant dissatisfaction with the environments that have been created. It is thus clear that there is a substantial shift in the building design paradigm, where the architecture is informed by a new set of environmental parameters aiming to produce a reasonable, energy-efficient design alternative, that satisfies the indoors occupants' comfort conditions and quality of life (Graham, 2002). It has to be mentioned at this point that, with respect to the scope and context of this research, the term 'sustainability' is focusing mainly on the thermal performance of the proposed building design (including energy consumption and carbon emission, heat gains/losses, ventilation strategies assessment, etc.), and the basic daylight analysis of its zones. Other sustainability aspects (such as acoustics, water conservation, waste management, biodiversity, etc) are not covered within the scope of this research. The research scope is discussed in more detail later in this chapter (section 1.4), and the sustainability aspects noted within this scope are discussed in more detail throughout Chapters Two and Five.

1.1.2.   Coupling Design with Performance

Coupling a building's functional and occupant requirements with the architectural design process is a prerogative matter, but this coupling is associated with an inevitable set of challenges that affects the designers and influences the design decisions made, as discussed

by Wilson et al. (2007). Additionally, such authors note that a fundamental challenge in this coupling is to assess and comprehend how different design decisions can be reflected in terms of achieving an acceptable level of building performance, addressing macro and micro-scale environmental concerns, conserving energy and natural resources, fulfilling the clients' requirements, and catering for and satisfying the occupants' needs. To consummate this coupling and attain successful assessment for the building, designers tend to utilise the ever-growing range of tools, skills, and techniques available in a cyclic iterative design process.

Currently there are number of environmental design support applications and building performance simulation tools that may be employed by architects at various stages of the design process. These tools utilise advanced techniques and processing capabilities to effectively inform the designers/engineers through investigating and simulating several aspects of the building's design, and predicting its projected behaviour and performance. Current BPS tools are thus a testament to sustained multi-disciplinary research and development efforts, and mark one of the significant accomplishments in the contemporary building design process (Wilson et al., 2007). However, recent research (including that carried out by Attia et al., 2009; Bambardekar and Poerschke, 2009; Schmid, 2008; Crawley et al., 2008; and Wilson et al., 2007) suggests that there is great potential and considerable scope for expanding the use and application of these tools within the architectural community, the success of which will rely on overcoming some significant hurdles and challenges.

Some fundamental challenges regarding the nature and design of BPS tools have stood as a barrier towards fully effective integration within the design process. The highly technical nature of the majority of these tools, and the knowledge needed to understand the physical principles that govern their output has resulted in several pragmatic issues that have affected their uptake and use within the architectural community as a whole (as discussed in more detail in the next chapter). Indeed, these issues are particularly salient for the novice architectural student. For example, their perceived complexity may result in students and/or professionals actively avoiding their use (Soebarto, 2005). A lack of knowledge of architectural science and basic building physics may result in incorrect input assumptions

that would impact directly on the 'accuracy' of the simulation overall. Similarly, a lack of awareness, understanding and legibility of the meanings, principles and assumptions behind the output data can result in a misinterpretation of the results from the simulation process. Ultimately, this might impinge on the design decisions that eventually affect the building's performance over its life span. In response, several strategies, methodologies, and tools have been introduced to facilitate integrated thinking and practice within sustainable building (especially in a pedagogical context). Educating the designers –in this respect- aims to assist deepening the principle of designing low-energy buildings, reflected in the integration of three key principles; design, visualisation, and BPS simulation (Hamza and Horne, 2007).

1.1.3. Sustainability in Architectural Design Education

With mounting awareness of resource use (or misuse) and its impact on the natural environment, pressure from governments, demands from international bodies and organisations, and with the introduction of voluntary and compulsory accreditation systems to evaluate buildings' sustainability, emphasis has been placed on schools of architecture to prepare new generations of architects equipped with a wider skills-set that allows them to accommodate sustainability (and sustainable design principles) as an integral part of the architectural design process (Charles and Thomas, 2009). The comprehensive integration of sustainability and its associated principles in the design process, as argued by Altomonte (2009), requires a thorough and substantial revision of the educational process through which qualified practitioners are prepared, which is in turn reflected on the preparation and formulation of the architectural design curricula. It has been noted in many case studies and surveys that there is a number of technical and pedagogical barriers that deter the effective integration of sustainability in architectural education, including the motivation to integrate environmental principles in the design project, complexity in the utilisation of the supporting BPS application, and the ability to interpret simulation data outcomes into informed design decisions (the taxonomy of these barriers and challenges -with respect to the notes case studies, frameworks, and surveys- is discussed in more detail in Chapter Two, section 2.4, and summarised in Figure 2.2). However, there are potentially pioneering opportunities that can contribute in transforming sustainability measures from the current

supplementary position to a more central role. For example, a number of European and international bodies, organisations, and actions (like the European Commission funded Environmental Design in University Curricula and Architectural Training in Europe, EDUCATE action) have developed several sets of directives and principles for effective integration of sustainability into architectural design education (these discussed in more detail in Chapter Two).

Many studies, research projects, and frameworks have also been developed to improve approaches to integrating and teaching environmental design, producing a set of recommendations and guidelines to follow in designing and implementing an integrated learning methodology. Rutherford and Wilson (2006), for example, argue that it is essential to implement a user/student-centred approach to accommodate the integration of sustainability within architectural design curricula. Such approach should focus on the nature of the students, their capabilities, background, expectation, and more importantly the way they think and approach a design problem. In essence, the required pedagogical approach should match the pattern of practice, and mould the technical problem-focused strategy of sustainability into the cognitive creative solution-focused strategy of design, allowing the application of knowledge to be carried out in a creative manner that develops the students' 'Cognitive Schemata'. This should be done in a manner that can aid design activities, inform the students (uncovering knowledge that could be missed with conventional means), and act as a basic-yet-effective Decision Support System (DSS). The effective implementation of such an approach can ensure better integration and a higher level of students' comprehension, engagement, and motivation.

1.2. Research Rationale

Reflecting on the aspects mentioned to this point, the rationale and motivation behind the research proposed within this thesis is threefold:

1. The research seeks to facilitate the process of integrating sustainability into the design curriculum, with particular emphasis on the use and application of both BPS tools and games technology.

2. In so doing, the second driver for the research is to improve, incentivise or motivate design students, thereby increasing their engagement with environmental aspects of building design.

3. These culminate in the third driver; that is to assist the design students throughout their environmental design process aiming to assist them to make robust and informed design decisions.

To achieve the rationale, this research places emphasis on the pedagogical and technical challenges that design students encounter during their experience of integrating sustainability aspects into the design studios (through the use of BPS application as a means to support this integration). Having outlined these challenges, the research presents a proposed interactive narrative learning support method -with its related tools- that aims to utilise state-of-the-art techniques to address and attempt to resolve the noted challenges. Ultimately, the research seeks to support the students' utilisation and knowledge gained from using the BPS tools, and thus to improve the efficiency of integrating sustainability into the design curriculum. The remainder of this chapter therefore discusses the different aims and objectives related to this research project, along with the structure and methodology of research.

1.3.   Research Aim and Objectives

This research project is based on the hypothesis that "Utilising 3D games technology, including advanced knowledge extraction and information representation techniques, could have a significant impact on the design students' motivation to accommodate sustainability, and their general perception of environmental design concepts". In this respect the hypothesis can be reflected in the research aim and its derived set of objectives, as depicted in Figure 1.1.

Develop a method to facilitate integrating sustainability in design education, & enhance students' motivation & perception.

Chapter Two

A — Identify *challenges* related to integrating sustainability
- Potentials of Utilising BPS in design process
- Technical & Pedagogical challenges
- Attempts, surveys, & case studies
- Develop conceptual requirements

Chapter Three

B — Probe effectiveness of *3D Games* as a Virtual Learning Environment
- Potentials of 3D interactive narrative VLEs.
- Games as host for the 3D VLE
- Games and 'play' in education
- Serious games and architectural design education.

Chapter Four

C — Utilising *MAS & DM* for Knowledge extraction & Representation
- Benefits & potentials of MAS in the scope of the research aim
- MAS as a technology & narrative support.
- DM techniques suitable to extract BPS data knowledge
- Coupling MAS & DM

Chapter Five

D — Develop a *tool/Game* to combine discussed theories & technologies
- Present methodology for the tool's development
- Implement MAS & DM techniques as separate module to game engine
- Review pedagogical reflection in the tool's features.

Chapter Six

E — *Test* the proposed method & *evaluate* its potentials.
- Compare proposed method with conventional means.
- Evaluate the tool as a learning methodology & DSS
- Assess the feasibility & potentials for utilising the method in design education.

Figure 1.1: The research main aim and its derived objectives, along with a representation on how these are addressed throughout the chapters of this research's thesis.

The main research aim revolved around utilising games technology for developing an educational support method –and its related tool- (Environmental Design eTutor), that seeks to facilitate integrating sustainability principles into the architectural design curricula, and in so doing, enhance the students' motivation to incorporate these principles into their design process, and their overall perception and understanding of the environmental design process. This aim is reflected into five more specified key objectives, which aspire to:

A. Identify the current pedagogical and technical challenges and pragmatic issues -as well as potentials and opportunities- for integrating sustainability and environmental parameters in architectural design curricula.

B. Investigate the effectiveness of exploiting interactive narrative virtual environments as a method and context for learning in general, and for environmental design education in particular, and probe the utilisation of "3D Games" as the potential hosting medium for this method.

C. Investigate the utilisation and integration of Multi Agent Systems (MAS) and Data Mining (DM) techniques -within the game engine's technology- as potential mechanisms for BPS information analysis, knowledge extraction, and data representation.

D. Develop an interactive narrative virtual learning environment (a game) that acts as a proof of concept for integrating the theories and technologies (covered throughout the research literature review) and for later evaluating the main research aim. This game/tool collates all the recommendations and requirement specifications generated from previous objectives and interprets them into features and functionalities that envision to satisfy any pedagogical and technical requirements.

E. Test the proposed method (throughout its tool) among a number of stakeholders (undergraduate students, tutors, lecturers, researchers, etc.), and evaluate the potential feasibility and effectiveness of such method within architectural design education.

The main objectives of the research are addressed throughout this thesis (as depicted in Figure 1.1), and also reflected within the associated proposed method and tools. For effective management and handling of the project's objectives, they are divided into a number of key sub-objectives/tasks. The following maps the main objectives and their related tasks as they relate to key chapters.

Chapter two marks the starting point for the research, and in so doing, addresses the first objective [A]. As such, it seeks to investigate the challenges associated with sustainability and its integration within architecture curricula, looking at the problem from both pedagogical and technical perspectives. To address this aim, the following tasks are undertaken, namely:

A.1. Investigate the current pedagogical approaches that seek to integrate environmental design measures into architectural curricula, and review if/how these suit the design students' method of thinking and approach to problem solving.

A.2. Identify the motivational challenges that design students encounter when integrating sustainability through the utilisation of BPS applications. Also identify the challenges that relate to the level of detail required and input information needed to ensure effective simulations, and the challenges that relate to the analysis and correlation of BPS outcome data, and in so doing, review the current means in which data are represented and visualised and how such analysis is exploited when helping to inform design decisions.

A.3. Review current and recent attempts to overcome the noted challenges, and mould sustainability into the design process in general, and -with specific reference to education- reflect upon and evaluate such approaches with a view to formulating recommendations and basic requirements for the proposed tool's development.

Chapter two finishes with a discussion and concluding remarks, these focusing on the importance of engaging and motivating design students into integrating environmental measures into their design process. This will include recommending technical and

pedagogical approaches to follow to eliminate any challenges encountered and satisfy effective motivation and understanding.

Chapter three builds upon one of the technical approaches recommended in chapter two, which is the utilisation of interactive narrative virtual environments as a potentially effective medium for moulding the notions of design and BPS simulation (objective [B]). The derived tasks for this objective are:

B.1. Investigate the benefits and opportunities of using interactive narrative 3D virtual environments as a learning medium.

B.2. Probe whether '3D Games' are an effective medium for design visualisation, as well as a viable means to represent knowledge extracted from BPS data.

B.3. Investigate the efficiency of the current proliferation and utilisation of games in educational in general, and in architectural design education in particular, and review the potentials and challenges that surround this approach.

B.4. Present a set of recommendations for electing an appropriate 'Game Engine' to accommodate the proposed tool, and the specification required to extend the features and functionalities of this engine to transform it into an effective environmental design educational game.

Chapter four builds upon the recommendations and concluding remarks discussed in chapters two and three, presenting state-of-the-art technologies that can potentially expand the capabilities of the game engine (elected for this project), and accommodate communication and interactive interrogation routines between the students and the system, as part of their learning experience, conceptual perception, and decision making process. Chapter four thus addresses objective [C] in the form of these tasks:

C.1. Undertake a comprehensive review of the benefit and opportunities associated with utilising Multi Agent Systems (MAS) technology in general, and its relevance and prospect within this research project in particular

C.2. Investigate the use of MASs as an individual separate module within the adopted games engine, the role that the MAS may play as the director of the game's narrative, as well as the communicator (and reporter) that passes information to and from the users.

C.3. Probe the use of Data Mining (DM) techniques as a potential mechanism to collect and analyse the BPS data outcomes, therefore aiming to extract 'knowledge' that is relevant to the users experience and preferences in a manner that can guide them to understand performance problems, causalities, and decisions implications, and guide them through effective strategies to improve their design and building performance.

C.4. Review relevant specified DM techniques that can be utilised to serve the aims of this research, the 'rules' that associate these techniques, and their role within the knowledge discovery and extraction process.

C.5. Investigate the potential of coupling MAS with DM techniques to create a 'dialogue' with the game's users, and how this can be reflected and integrated within this project's associated tool.

Chapter five collates all the knowledge, findings, recommendations, and requirements discussed thus far with the view to present the development process of the proposed associated environmental design learning support tool (eTutor). This chapter addresses objective [D], and seeks to address the challenges encountered and discussed within chapter two, and utilise the technology, philosophy, and logistics discussed within chapters three and four. In this respect, these tasks were outlined:

D.1. Present the elements that were chosen as part of the proposed method, which include the elected games engine, BPS application, and building design case study, and the rationale behind choosing each of them.

D.2. Present the methodology for the proposed tool's development and discuss those factors that were applicable during the various stages of its development, including

requirement specifications, conceptualisation, formulation of the proposed system architecture, and system implementation.

D.3. Implement the MAS with its different agents' typologies and define the role and scope of knowledge and service embedded within each of them. This also includes setting the relationships and integration between the agents and the other aspects of the system.

D.4. Implement the elected DM techniques within the game engine's source code, and present the methods for linking these techniques to the simulation process data outcomes. This includes implementing specified means to gather, filter and store data into relevant repositories for further analysis and knowledge extraction.

D.5. Implement in-game features and functionalities within the proposed tool, therefore aiming to create a dialogue with the students to better inform them (based on the knowledge gained and gathered by the system). These features should address the pedagogical and technical challenges -along with the requirements- set and discussed in earlier chapters.

D.6. Reflect on how the game with its proposed scope, architecture, features, and functionalities addresses the noted requirements, and how it can facilitate and improve the students' overall learning experience. This includes reflection on the pedagogical approaches to design and sustainability integration discussed in chapter two.

Chapter six of this research project investigates the feasibility and effectiveness of the proposed tool within the context of the architectural design education process, as well as the acceptance of relevant stakeholders to such an approach. This is done via means that reflect upon the main pedagogical directives set for this research project that can feed-back into modifications and iterations in the proposed tool development process, as well as recommendations for further development and extended scale of implementation. In essence, chapter six addresses objective [E] with this set of tasks:

E.1. Compare the proposed method with conventional environmental design means. This comparison is based on the stakeholders' opinions of how the tool can inform the design students, guide and support their decisions throughout different design iterations with means that are not available in other methods. It is important to note that the comparison here is not with current BPS applications, but with the means that students use to interpret the simulation outcomes to make further informed decisions.

E.2. Evaluate the proposed tool as a learning methodology, as well as a decision support system, based on the comparison set in the previous objective. This is done through assessing the suitability of the proposed method to the architectural design educational domain (design studios for example). The evaluation is directed to measure students' motivation and willingness to integrate the proposed game into their design iterations, as well as examining how the proposed approach suits the architects' method of thinking, and approaches to problem definition and decision making.

E.3. Assess the feasibility and effectiveness of the implemented features of the proposed tool, and their suitability to support and improve the students' comprehension and guide them to improve their design with consideration for sustainability concepts.

E.4. Carry out a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis of the proposed system, identifying its fundamental advantages and disadvantages and potential for improvement and further development.

Chapter seven builds upon the results and feedback obtained from chapter six, and presents a reflection upon the whole research project in terms of revisiting the set aims and objectives. It also discusses the technical and pedagogical shortcomings and limitations (conceptual, functional, and usability) relating to the proposed tool. The chapter presents a set of recommendations for addressing any weaknesses and challenges noted with the proposed approach, as well as any suggestions to improve the students' comprehension,

motivation, and overall learning experience. Chapter seven also presents overall concluding remarks about the research project in general and the different notions and aspects that were discussed within its documentation.

1.4.   Research Scope
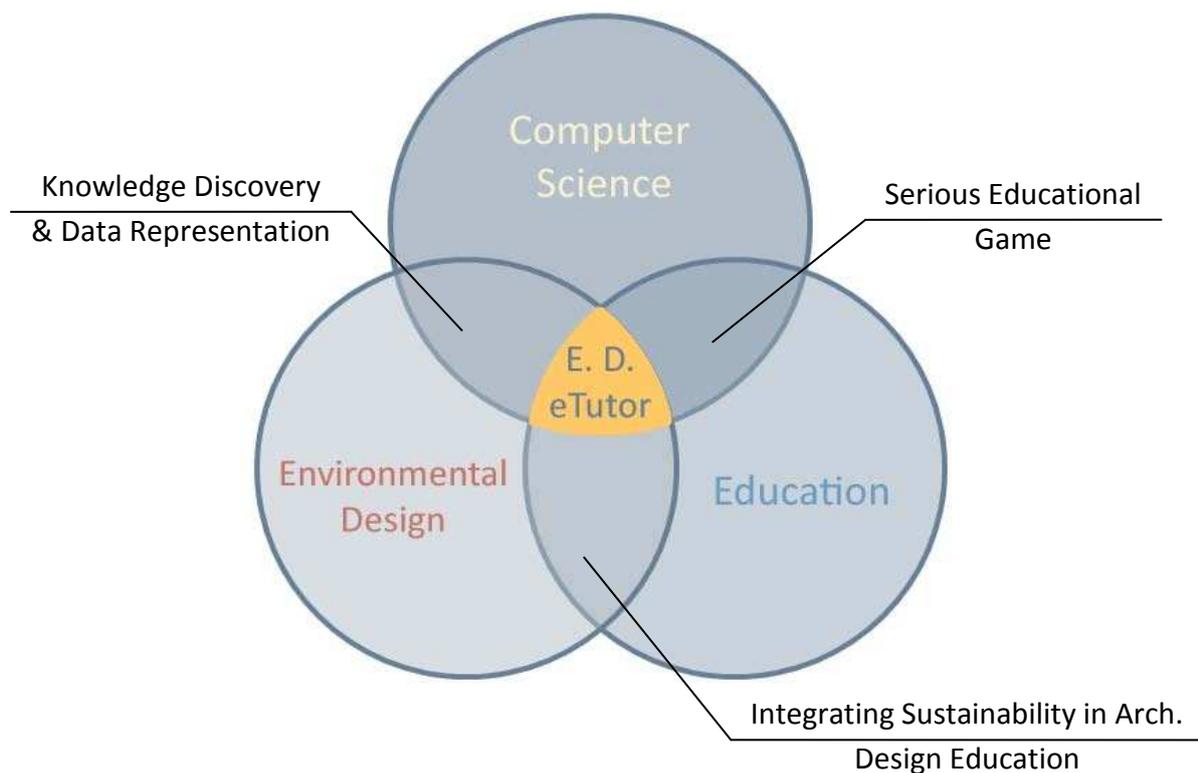
Figure 1.2: The research scope, combining three disciplines; Computer Science, Environmental design, and Education

The scope of the research combines three distinct yet inter-dependable disciplines; these are Environmental Design, Computer Science, and Education (as represented in Figure 1.2). These are combined together to develop the "Environmental Design eTutor" (Sarhan and Rutherford, 2011), which addresses the main aim of the research, along with its derived objectives. Figure 1.2 also depicts how the areas of intersection within these disciplines are reflected within the scope of this research:

- Combining Environmental Design and Education within the scope of this research to review the current potentials and opportunities, along with the barriers and

challenges that face the effective integration of sustainability in the architectural design curricula.

▪ Combining Computer Science and Education to stand upon the state-of-the-art learning technologies, and with respect to this research, the utilisation of 'games' (as a philosophy and a technology) to promote effective education and deep/active learning.

▪ Combining Computer Science and Environmental Design to investigate the potentials of utilising Multi-Agent Systems (MAS) and Data Mining (DM) technologies, in order to support the design students in the process of information extraction, knowledge discovery, and data representation (with respect to the BPS simulation process outcomes).
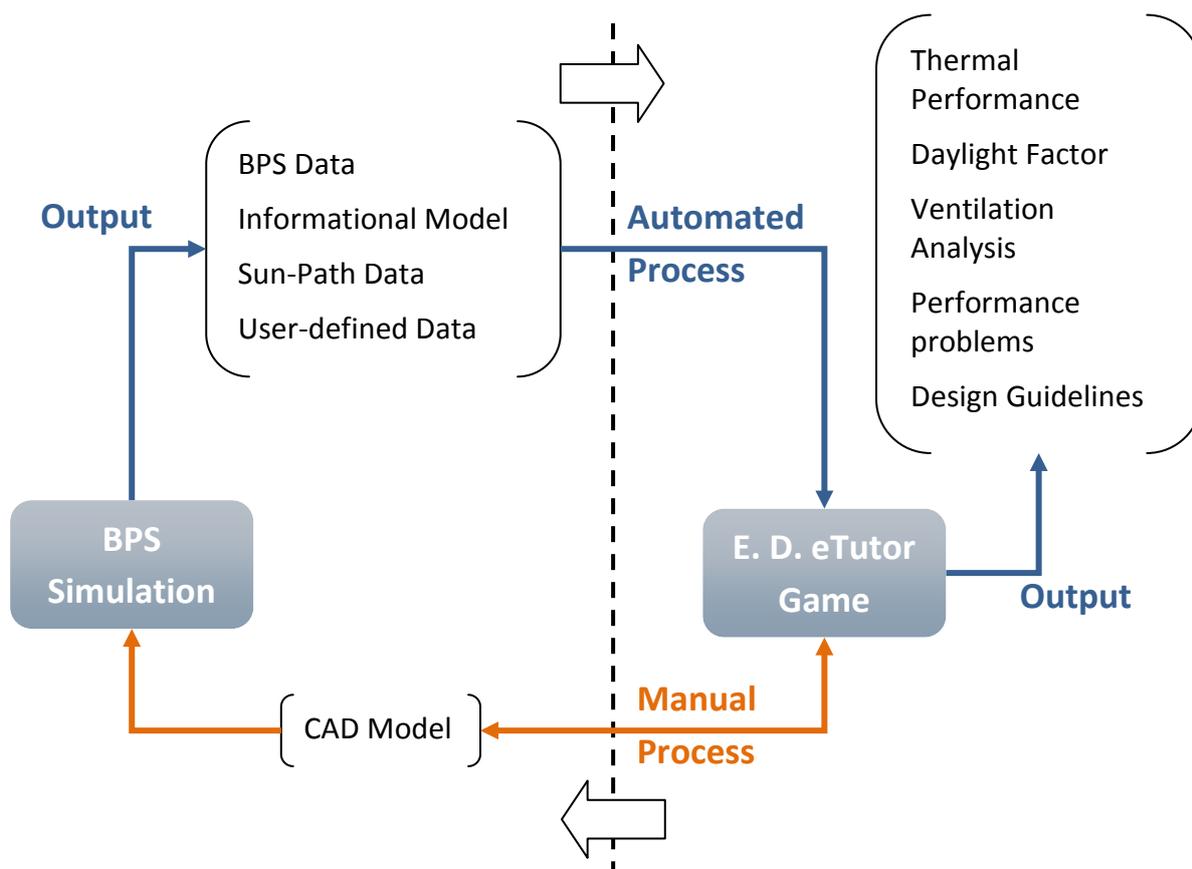
Figure 1.3: Abstract illustration for the proposed method, depicting the outputs of each key node (simulation and ED Game), as well as the processes/tasks that are automatically performed, and those that require manual update/intervention from the students.

It is important, when discussing the scope of this research, to present a general outline of the proposed method, including its benefits and outputs, and a general overview of how it is integrated within a design cycle (Figure 1.3). The proposed method seeks to automate the process of data simulation and extraction, as well as building an informational model for the proposed design. These will be carried (along with any other relevant information like weather data, sun-path diagram, Psychrometric chart, etc) and stored within the proposed tool/game, to act as a referral point during the student's virtual learning experience. The proposed method envision to present feedback and reports to the students regarding their overall design's thermal performance and basic daylight analysis, along with assessment of the strategies followed by the students to improve the performance. The feedback presented to the students also includes reporting on any performance problems and possible causalities, as well as guidelines for improving the general thermal performance of the building. The alteration to the design (including updating the CAD model and that for the BPS application) has to be carried out manually by the students (as illustrated in Figure 1.3), and any modification to the input information required before running the simulation also has to be carried out manually. Students will need to re-import the updated 3D CAD model back to the game engine's editor before running the game.

It has to be mentioned also within the discussion of the research scope the boundaries and conceptual limitations for the proposed method. These can be summarised in the following points:

- The proposed tool/game is a proof of concept, and cannot be considered a final/version implementation.

- The proposed method is not an independent entity, as it is still dependant on an existing BPS application for generating the simulation data, as well as CAD modelling software for building the design model to be imported into the game.

- The interaction with the method's 3D game is limited to exploring (within an interactive walkthrough) the proposed geometric design elements, as well as interacting through communicating with the system's reporting agent (explained in

more detail in Chapters Three and Five) to get feedback and reports on their design performance. In this respect, the tool doesn't incorporate any run-time modifications to the design geometry or simultaneous re-runs of the simulation process. Indeed the proposed method relies on manual updates carried out by the students, as explained earlier in this section, and in Figure 1.3.

- The proposed method focuses only on analysing the thermal performance of the proposed building design, as well as basis daylight factor analysis.

- The feedback provided within the testing and evaluation sessions (covered throughout Chapter Six), and its supplementary analysis is only indicative and by all means not conclusive. Further detailed evaluation on a larger cohort of students, researchers, studio tutors, and lecturers is required for validating the initial (indicative) findings and results.

- Design students –as well as involved instructors- are expected to learn (or be trained) to use the proposed tool's interface in order to be able to repeatedly import their design's CAD models, and run the game effectively.

1.5.   Methodology of Research


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                    ┌──────────────────────┐
                    │  Research Motivation  │
                    │     and Rationale     │
                    └──────────────────────┘
                               │
                    ┌──────────────────────┐
                    │  Research's Aim and   │
                    │      Objectives       │
                    └──────────────────────┘

┌──────────────────┐  ┌──────────────────────┐
│ Literature Review │  │ Preliminary Interviews│
└──────────────────┘  └──────────────────────┘

        ┌──────────────────────┐     ┌──────────────────────┐
        │  Discussion of initial│◄────│ Research into Technology│
        │   Research Findings   │     │   (Games, MAS, DM)     │
        └──────────────────────┘     └──────────────────────┘

              ┌──────────────────────┐
              │     Requirement       │◄───
              │     specification     │
              └──────────────────────┘

              ┌──────────────────────┐
 Feedback     │ Proposed Tool's System│
              │     Development       │
              └──────────────────────┘

              ┌──────────────────────┐
              │  Preliminary Testing  │
              │    (Pilot sessions)   │
              └──────────────────────┘

    ┌──────────────────────┐   ┌──────────────────────┐
    │  Testing & Evaluation │──►│ Conclusion and Further│
    │ (Detailed Questionnaire│   │     Development       │
    │    and Interviews)    │   └──────────────────────┘
    └──────────────────────┘
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Figure 1.4: The research project's methodology of work and development

The general methodology followed in this research project (illustrated in Figure 1.1), involves number of phases which are mostly in linear progression. However, in other phases there are nodes for reflection and iteration, leading to revisiting and updating previous

phases. The initial phase is concerned with presenting the rationale and motivation behind carrying out this research, and the contribution that it could offer to the design education community. The second phase is to identify and set key aims and objectives, upon which the rest of the phases will reflect and examine. The following phase involves setting the philosophical and theoretical basis for the research. This is established upon an examination and review of current and recent research frameworks, case studies, surveys, and proposed methods and applications, to stand upon the challenges and potentials for integrating sustainability within architectural design. This review is coupled with initial semi-structured interviews carried out by the researcher, involving undergraduate students, researchers, lecturers and design tutors, to gather their views and experiences on the potentials and challenges of integrating sustainability, as defined within the scope of research. The initial research phase also comprises the research into the philosophy and technical aspects of the technologies elected to serve the purpose of this research (this includes games technology, MAS, and DM techniques). The theoretical, pedagogical, and technical research will later yield a set of requirement specifications that constitute a referral point in the development of this research's associated tool.

The next phase in the research involves the development of the proposed tool, and the implementation of its various functionalities to serve the base aims and objectives represented as fundamental requirements of development. The research tool is repeatedly examined and evaluated via interim testing and evaluation trial sessions, to maintain a user-centred approach for development. The feedback gained from these interim trials is used to update the set of requirements and implement additional concept, features, and functionalities within the tool. After a number of iterations, the system is evaluated using a detailed questionnaire employing semi-structured interview techniques aimed at ascertaining the users' views on the tool (as set in the objectives discussed earlier in this chapter). These views feed into the final phase of research which involves a critical reflection on the research (with revisiting its aims and objectives), and presents recommendations for further development of this research and its associated tools.

Chapter Two:

Integrating Sustainability

in Design

2. Integrating Sustainability in Design

2.1. Introduction

Chapter one presented the rationale and scope of this research project, discussing briefly its context and motivation. It also introduced the projected aims and objectives for the research and the methodology employed to attain these objectives. This chapter addresses the first aim set for this research, and builds upon the relevant notions outlined in the introductory section of the previous chapter. In so doing, it investigates the potentials, opportunities, and challenges regarding the integration of sustainable measures (in terms of thermal performance and basic daylight analysis) into the design curricula -reflected in the utilisation of BPS applications. The chapter starts by extending the discussion of the benefits and calls for the use of BPS tools in the design process, and examines how the integration is introduced and handled within the educational context.

Following on from this, the chapter also investigates the architect's methodology of thinking, learning, design formulation, and problem solving, and drafts a comparison between this methodology and that introduced/imposed by integrating the environmental design parameters. The chapter subsequently investigates and presents -primarily from the perspective of architectural design students- a taxonomy of the pragmatic issues encountered when using BPS tools to support the design development and decision making process, and evaluate or validate the proposed design strategies. Finally, the chapter concludes with a discussion on how these pragmatic issues can be addressed to reduce some of the highlighted negative effects -on both the students and the design process. In this respect, a set of conceptual requirements are outlined, which will later constitute the base specification of the development of this research's supporting tool, and the basic rationale for the technology employed within this tool.

2.2. Environmental Design Education

Integrating sustainability measures has driven the evolution of the conventional architectural design process, to introduce a multitude of new variables and equations that the proposed design should consider and resolve to become acceptable. The technical and performance aspects of design -which involve these new variables- have more often than not been left to the services engineer to resolve (Maassen et al., 2003). Given that passive environmental design is a core objective to the design process itself, many of these aspects have now fallen on the shoulders of the architect, leading in turn to a strong paradigm shift in the way in which design needs to be tackled. Design students are thus faced with wider pallet of challenges, developing their conceptual ideas whilst trying to make the design itself realisable from a sustainability perspective. It could be argued therefore that the shift is one whereby students must demonstrate holistic design abilities that have a strong sustainability/performative bias and to achieve this must attain a solid understanding of the implications that sustainability brings to the design and the forces that foster or impede it (Fien, 2000). The challenge subsequently falls on the schools of architecture to prepare new generations of designers that are capable of integrating sustainability with the multiple sets of design variables (visual, social, economic, cultural, morphological, urban, etc.), with high level of comprehension, and solid approach to problem solving and decision making (Kalay, 2008).

2.2.1. Principles and Objectives for Sustainable Development in Education

The United Nations instigated a new 'Decade of Education for Sustainable Development' back in 2005, as noted by Yan and Liu (2007), stating that "*Universities must function as places of research and learning for sustainable development*"[5]. The notion of 'Education for Sustainable Development' aims to educate and prepare a new generation of young professionals (including architects), to shape a society with reduced energy needs and an attitude towards the preservation of natural resources. This is achieved in part through developing well-structured curricula that clearly identify the different aspects of the sustainability problem, and offer approaches to address these aspects using integrated

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[5] DESD Draft International Implementation Scheme (IIS). UNESCO, 2004.

interactive methods for education and training. The University of Nottingham led the EDUCATE project (2009), for example, with a mission objective of fostering the skill-sets and knowledge base required to integrate sustainability into all stages of architectural education. This project, comprising numerous European partners drafted its agenda for sustainable architectural education in its Budapest meeting (EDUCATE, 2010), which adopted a set of pedagogical principles. Some of the EDUCATE principles and directives focused on these aspects:

- Sustainable environmental design must be seen as a '*priority*' in educating design professionals, from the early stages of their studies

- Academic institutions, students and professional bodies should be '*committed*' to this educational priority.

- Design students should be '*enthused*' and '*inspired*' by the adopted approaches for sustainability education, in order to rigorously and creatively address contemporary design challenges.

- A '*Direct Experiential Learning*' (Kolb, 1984) approach should be promoted by educators, adopting the appropriate and necessary tools, methodologies and techniques.

- The approach utilised for sustainable environmental education should promote '*Critical Awareness*', '*Responsibility*', and '*Reflection*' (Schon, 1983) of the various interdependencies within the design process.

- Educators and professionals should recurrently improve and develop the '*Knowledge Base*' for sustainable environmental design through exemplar research and architectural practice.

- The knowledge base should be 'disseminated' to the students, educators, professionals, and the general public, in a simple and comprehensible manner/format.

These directives can be considered as an emerging imperative that represents a major shift in the paradigm and conceptualisation of education and tutoring to accommodate sustainability as a 'priority' (HEA, 2005). The 'commitment' of academic institutions to sustainability was a chief objective within the Sustainable Development Action Plan for Education and Skills[6], setting out the required pathways for academic bodies as well as organisations and agencies like the Learning and Skills Council (LSC) and the Higher Education Funding Council for England (HEFCE) for assuring the implementation of a more sustainable paradigm within a diverse range of professions and domains. In this respect, pedagogical methodologies should shift and drift away from the 'reductionist' concept to embrace critical and holistic thinking and promote life-long learning and inter-disciplinary dialogue and investigation between conventional cognitive domains (Warburton, 2003). Such methodologies could in fact contribute to achieving an effective level of 'Deep Learning', and improve the students' conceptualisation and approach to problem handling and solving.

Some of the keywords that can be derived from these listed principles include:

- *Experiential Learning*: which is based on making sense/meaning of the presented learning materials through direct experience without any direct intervention from any instructor/teacher; i.e. through reflection in and on action (as explained in the next point). The experiential learning theory, according to Kolb (1984), highlights four factors that can effectively support deeper levels of learning, and promotes critical thinking and evaluation; these are "*concrete experience, reflective observation, abstract conceptualisation, and active experimentation*" (as cited in Altomonte, 2009).

- *Reflection*: which is an iterative process of reviewing actions and their qualities. Boud et al. (1985) describe reflection as "*an important human activity in which people recapture their experience, think about it, mull it over and evaluate it*" (pp. 19). Schon (1983) describes the practitioner's (student in this context) behaviour in the process of reflection in that he/she "*allows himself/herself to experience*

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[6] Published by the Department for Education and Skills (DfES) in 2003.

surprise, puzzlement, or confusion in a situation which he finds uncertain or unique. He/She reflects on the phenomenon before him/her, and on the prior understandings which have been implicit in his behaviour. He/She carries out an experiment which serves to generate both a new understanding of the phenomenon and a change in the situation" (pp.68). Schon (1983) presents two types of refection that can support effective learning methodologies:

- o *Reflection in Action*: This type of reflection occurs when the students are able to evaluate their work/decisions, and make subsequent changes during/within the action/process. In this respect, it is reflection on a smaller (low-level) scale.

- o *Reflection on Action*: This type of reflection differs from the first, in that it makes the students instigate a more generic evaluation on their work after the actions have been complete; i.e. reflect on already made decisions. In this respect, it is a more generalised type of reflection on a high-level scale.

- *'enthused' and 'inspired' (i.e. Motivation)*: Which can be attained through promoting 'active learning'. Tyler (1949) argued that the key ingredient for effective learning is the learners' autonomy/independence and 'Active Behaviour'. Meyers and Jones (1993), –among many others- supported promoting an active approach of learning, highlighting its effectiveness and significance for the students' learning experience. An active learning approach incorporates a learner's autonomy strategy, as in this approach, the students are offered a higher degree of freedom within an autonomous medium where they are active participants who make decisions, rather than passive members who are solely receiving instructions. The Learner's autonomy -encompassed within an active learning approach- involves the adoption of a 'learner-centred' strategy focusing on higher levels of students' engagement, as well as fulfilling the needs (learning objectives) and expectations of the students, which in turn keeps the students enthusiastic, committed, and motivated. This approach also have great potential to promote *'Critical Awareness'* and '*Responsibility*'.

- *'Simple and comprehensible manner/format'*: This is a factor that can also greatly affect students' motivation and approach to attain deeper levels of learning. Complex overwhelming information can be confusing and off-putting for students, thus a simplified hierarchical approach can be more effective and offer more comprehension and motivation (this is particularly important in the case of highly technical simulation data).

However, a sustainable approach for design, as argued by Altomonte (2009), needs to extend beyond the technical notions of energy and resource preservation and carbon emission reduction, to embrace the aesthetical, socio-cultural, and economical values. He adds that in order to effectively promote sustainability in the design of built environment, its targets and principles should be adequately embraced and moulded within the creative realm of the design process.   For this integration to be fruitful –from a pedagogical perspective- it is important to understand the architects' approach to learning and design development, in an initial step to mould sustainability within the other aspects of design, rather than compromising the whole process by enforcing it.

2.2.2.   Architects' Learning and Problem-Solving Approach

Architects in general, as argued by Rutherford and Wilson (2006), approach the design development with a solution-focused strategy, rather than a problem-focused one. Gelernter (1988) described the architect's solution-focused approach as a 'Cognitive Schemata' methodology for problem solving, explaining that the "*designer faced with a new problem selects a solution type (cognitive schemata) from his or her existing repertoire of design ideas, imposes this idea on the problem, and then tests it to see how well it satisfies the problem's requirements. If the designer is lucky, and the problem matches exactly the solution type which is initially employed … then in Piaget's terms the designer has assimilated the problem to an existing solution type. More likely, though, the solution type first proposed will not sit comfortably on the problem in every aspect, and so the designer begins to adjust the schema to the problem through a cyclical process of modifying the schema, testing it against the problem, modifying the schema again, and so on, until the original schema has been transformed into a new one which resolves the design problem's*

requirements. In Piaget's terms the solution type has been accommodated to the new problem, and in the process the designer has added a new solution type to a personal repertoire which may be used as the starting point for addressing future problems."

The architects' cognitive schemata, as argued by Altomonte (2009), is thus derived from the iterative approach to problem solving, where students build upon their knowledge through a sequence of design exercises and criticism, in which the process is *"mostly focused on the solution they put forward rather than the methodology they apply"*. Based on this analysis, the students' approach will mostly concentrate on proposing a solution that satisfies the design preconceptions and achieve the desired outcomes (Rutherford and Wilson, 2006), rather than adopting an analytical methodology where they analyse the complexity of the problem and perform critical investigation that feeds into the solution (Altomonte, 2009).

Introducing sustainability with its technical, analytical, and quantitative nature to the architectural cognitive methodology of learning could be quite challenging and problematic. Hillier et al. (1984) (within Genlernter, 1988) discussed an integrative learning process that can accommodate both the cognitive and analytical aspects of the design problem; the 'Conjecture Analysis' learning process. They explain that this is a dual mode process that embraces 'conjecture', where the design students utilise "*extra-rational and artistic procedures of analogy, metaphor, sudden flashes of insight, and displacement of concepts to create new ideas*", and build upon their existing cognitive schemata. In the second 'Analysis' mode, designers relies more on the rationale and thorough scientific assessment of different aspects and entities of the problem, aiding them to analyse the technical consequences of their design ideas with regards to the philosophy and theories surrounding the problem and its requirements.

The 'Conjecture Analysis' learning process generates a set of critical requirements for the development of the proposed environmental design learning-support tool. These requirements are parallel to Warburton's (2003) outlined principles for effective integration of sustainability within design education, which included:

- The learning process should develop the students' cognitive schemata in a robust '*graphic*' manner that allows analysis, reflection, and enquiry of the key problem concepts. This analysis should be clearly visualised to support profound decisions and feed the design iteration process.

- The learning process should be staged as 'revelatory' activities that allow the development of students' knowledge and awareness. This will allow the students to formulate and ask better sets of questions that can effectively feed into their learning process, rather than riskily assume that solving the problem is defined within a definite set of answers. This is particularly a fundamental requirement, as it feeds directly to the student's knowledge by involving them practically to frame the right set of questions, and thus seek informed answers (within the simulation process) to these questions.

One of the fundamental pedagogical aspects -highlighted in the EDUCATE principles- is promoting '*Reflective analysis*', which can be reflected in two terms; 'reflection in action', and 'reflection on action' (Schon, 1983). Reflection in action is when students can reflect upon multiple aspects of their design as it is evolving. The success and effectiveness of this term depends upon the knowledge, awareness, and experience maintained by the student at the time, and thus this term can be considered as a subset of 'conjecture analysis'. 'Reflection on Action', on the other hand, is based on the review of an action after its completion; in other words, students finish a task (or set of tasks) in their design process, and then reflect upon their quality and effectiveness. It is important to consider both aspects of 'reflection' in the development of the conceptual requirements of the proposed method to enrich the sense of self assessment and analytical evaluation. With reference to the approaches being explored in this thesis, the tool should help nurture the students' skills with reflection on action, and build upon their knowledge. The tool should also promote reflection on action, based on the completed tasks that the students have accomplished, for example, the students have designed and simulated, and now reflect on those two tasks with the evaluation using the tool. The interpretation of these principles, directives, and requirements within the proposed tool's implementation is discussed in more detail in chapter five.

2.2.3.   Architectural Approach for Sustainable Development Education

Integrating sustainability into the architectural design process comprises dealing with and embracing a new set of criteria, which are reflected into a set of new variables that should be considered in the design process. The noted criteria are those introduced to the design process in order to meet specified standards set by governments, international organisations, and accreditation bodies, and include thermal performance and energy consumption, daylight analysis, ventilation strategies, waste management, etc. Architectural education, for many years, has been slow to respond effectively to these criteria, tending to assume that these measures are out of the designers' scope and are solely the role of the engineering profession (Rutherford and Wilson, 2006). Hamza and Horne (2007a) also explained that architectural schools incorporate environmental analysis in the design curriculum only in response to the "Triangle of Influences"; governmental and organisational policies, employers' expectations, and pedagogical expectations of higher education. However, in recent years, the mounting awareness of global warming and necessity to preserve energy and natural resources has resulted in an escalating moral motivation to design for sustainability (Russ, 2010).

Only in recent years have the schools of architecture in the UK adjusted their educational agendas to adopt the sustainability concepts and principles, and change their approach to addressing and integrating environmental measures of design. A key motivational factor for this shift is the pressure to reinforce the sustainability measures in architectural curricula posed by a number of architectural organisations and professional bodies, including the RIBA (Royal Institute of British Architects) and Architects Registration Board (ARB). They have introduced a set of measures that need to be addressed by schools and thoroughly assessed and fulfilled in order to obtain the required validation and/or accreditation. These measures should address the following principles/aspects in the design students (ARB, 2011; and EDUCATE, 2010):

- *Knowledge*: ARB (2011) explained that design students should be able to demonstrate '*with coherent architectural design and academic portfolio*' their aptitude to accommodate and integrate the knowledge and principles of building

technology, environmental design, and construction. This encompasses the familiarity with the facts, theories, rules, methods, processes, and settings that are integral parts of the sustainability principles.

- *Understanding*: this involves the assimilation and comprehension of the presented or gained information (knowledge), and the ability to correlate this knowledge to other cases or problems with effective practical application.

- *Skills*: this involves the ability of students to relate specified knowledge and understanding to the accomplishment of given tasks, and definition of solutions to specific problems.

In this respect, the schools of architecture are required to alter their educational agendas and methodology to accommodate the theoretical aspect of environmental design -through presenting the theories and principles beyond the underlying building physics- as well as accommodating the technical perspective through the utilisation of advanced technology to simulate different aspects of building performance. The latter concept may be achieved via the utilisation of BPS applications within design courses. Charles and Thomas (2009) argued that an effective integrated teaching setup, that incorporates environmental analysis and building performance simulation with the design process, could contribute to the preparation of bright future professionals that have the capacity to develop conceptually and aesthetically pleasing building designs, based on a reasonable understanding of how these buildings would operate and perform. However, a number of researchers -including among many others Soebarto (2005), Hamza and Horne (2007a), Rutherford and Wilson (2006), Delbin et al. (2007), Bambardekar and Poerschke (2009) and Altomonte (2009)- noted some issues and challenges regarding the practical integration of sustainability within the architectural learning domain, which can be summarised as follows (and detailed later in section 2.4 of this chapter):

- Motivation to use BPS applications, in terms of the suitability to the cognitive creative nature of the design process, suitability to early design stages, and the general preference of architects on their experience and guidebooks.

- Complexity of the BPS application in terms of the learning curve for adapting to its interface, as well as linking the building physics to reasonable procedure (reflected into reasonable input information).

- The ability to understand and correlate the simulation data outcomes, and translate this into informed design decisions to improve the proposed design performance.

These challenges, as argued by Rutherford and Wilson (2006) form a clear gap and missing links between the concepts of underlying building physics introduced in the course lectures, and their application in the design studios within the students' subsequent projects. The challenges constitute an integral part of the research, and directly address the main research question. They form a basis to which the proposed method can refer to in answering the research question and its aims and objectives (in terms of students' motivation and general perception to the environmental design aspects, as discussed in the research hypothesis in Chapter One, section 1.3).

The next section of this chapter focuses on discussing the application of BPS tools in architectural education, presenting an overview of these tools with their strengths, weaknesses, potential opportunities, and threats of their application. This discussion will pour into a set of requirement specifications that forms the core component in the development of this research's proposed tool.

2.3. Building Performance Simulation (BPS) Applications

There is currently a wide variety of scientifically validated BPS tools that are available for use within a diverse range of professions (Attia et al., 2009). Building performance prediction, analysis and calculation, according to Prazers (2006), gained a higher level of attention in the 1970's due to the 'oil crisis'. In this respect, a number of organisations and governmental bodies, as well as the academic community, were pushed into exploring new methods for energy conservation, particularly in the building sector. Though the origin of building performance prediction relied mainly on manual calculation techniques backed up by extensive research in the area of building physics, the rapid advance in computing and

processing power, availability of physical data, and the advancement of computational algorithms, evolved the whole prediction process to become a 'simulation'. As such, the process afforded the ability to simultaneously compute complex data, handle higher levels of detail and allow exploration on multiple time-scales, therefore yielding sophisticated and advanced building performance assessments which are fortified by a solid philosophy for building simulation, as argued by Morbitzer (2003). He adds that this philosophy creates a virtual building that can hold detailed parameters of different entities affecting the performance, resulting in an advanced, integrated, inter-related, and near-real performance prediction that has the capacity to simultaneously carry out combined assessment for multiple physical phenomena.

Nowadays, BPS applications can have the capacity to assess and analyse building design proposals, and to generate solid assessment models for several environmental factors including heating/cooling, lighting, ventilation, and acoustics. This level of analysis attempts to deliver a highly detailed picture to the designers and engineers on the building's behaviour once built. Furnished with this, they may make design modifications and iterate the process to reach a solution that will allow for high occupant comfort levels, optimum building performance, and ultimately responsible resource conservation. If properly utilised, BPS tools can help develop more energy efficient designs that in turn can result in a 50-75% reduction in the overall building's energy consumption (Clarke, 2001). Besides reducing the cost and maintaining resources, the eventual occupants can also benefit from achieving vast improvements in indoor air quality, as well as thermal, visual, and acoustics comfort levels, as argued by Prazeres (2006). This level of competence in building performance can be attained at conceptual/early stages of design through the appropriate integration of BPS applications and assessment methods into the design process. This can be greatly beneficial as argued by Chown (2003), as it assists in validating the proposed design decisions -from a performance point of view- and confirms any technical assumptions that the designer based his/her decisions upon.

Besides their potential for being effective design validation tools, BPS applications have great potential for being powerful decision support systems, as argued by Hensen (2004), as they are highly interactive, providing sophisticated analysis and methodical evaluation of

anticipated design-specific performances. In the architectural community, BPS applications offer architects novel frontiers to investigate new dimensions of their designs. The new dimensions extend far beyond the aesthetical qualitative nature of design concepts, to introduce new basis for design alternatives evaluation, based on the expected building performance and anticipated energy requirements. Charles and Thomas (2009) added that BPS applications can offer design students a chance to broaden their perspective and skill set, and gain constructive analysis proficiency with regards to complex building physics phenomena. The analytical evaluating nature of simulation software, as argued by Bambardekar and Poerschke (2009), is particularly suitable for the iterative nature of the architectural design process, where the repeated gradual refinement of design entities and details can be reflected in its anticipated performance.

It is thus quite clear that integrating sustainability and utilising BPS applications within the architectural design community has its extensive merits, and may afford significant opportunities to the design process. This integration process was facilitated and fortified in particular in the last decade, not only due to the compelling calls raised by governments and international bodies (as explained earlier), but also due to the utilisation of advanced computing processing capabilities and algorithms to develop a number of sophisticated BPS tools to support the construction and engineering disciplines. Some of the most common BPS tools currently utilised by the architectural community are Ecotect[7], EnergyPlus[8], IES-VE[9], ESP-r[10], HEED[11], eQuest[12], DOE-2[13], Green Building Studio (GBS)[14], Design Builder (DB)[15], and Envest II[16]. A Number of case studies, research projects, and surveys have been carried out in recent years to assess and evaluate these tools in terms of suitability and appropriateness within the architectural design community, with significant focus on the educational aspects (Attia et al., 2009; Bambardekar and Poerschke, 2009; Crawley et al.,

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[7] Autodesk Ecotect Analysis: http://usa.autodesk.com/adsk/servlet/pc/index?siteID=123112&id=12602821
[8] EnergyPlus Energy Simulation Software: http://apps1.eere.energy.gov/buildings/energyplus/
[9] IES - Integrated Environmental Solutions: http://www.iesve.com/
[10] ESP-r: http://www.esru.strath.ac.uk/Programs/ESP-r.htm
[11] Home Energy Efficient Design: http://www.energy-design-tools.aud.ucla.edu/heed/
[12] Energy Design Resources: http://www.energydesignresources.com/resources/software-tools/equest.aspx
[13] U.S. Department of Energy - DOE-2: http://www.doe2.com/
[14] Autodesk Green Building Studio:
http://usa.autodesk.com/adsk/servlet/pc/index?id=11179508&siteID=123112
[15] Design Builder: http://www.designbuilder.co.uk/
[16] Envest 2: http://envest2.bre.co.uk/

2008; Soebarto, 2005; Delbin et al., 2007; Schmid, 2008; Hensen et al., 2004; Reinhart and Fitz, 2006; Hopfe, 2005; and Hamza and Horne, 2007). These studies mainly adopted some key criteria for assessment that fall into two categories; the first being the usability and information management of the BPS application interfaces (including building or importing the design model, and supplying all required information to initialise the simulation); and the second being the suitability to act as a design decision knowledge base (including the interpretation of simulation data outcomes to formulate relevant design decisions). These categories will be the basis for the evaluation and review of the usage of BPS applications throughout the rest of this chapter. The studies were aiming to:

- Distinguish the basic norms for effectively developing BPS applications that can potentially act as a decision support system for architects and designers.

- List, highlight, and compare the potential pragmatic issues and challenges encountered during the use of current BPS tools in the design and education context, and investigate opportunities and propose pathways and frameworks to tackle these issues and resolve them.

- Understand and document the architects and designers' expectation for using BPS applications, and their current perceptions about the existing tools. This is an important aim as it employs a user-centred approach in investigation.

In this respect, these studies and surveys helped to pin-point the major shortcomings and concerns for the application of these tools in design exercises, providing opportunities and opening avenues to bridge the gap. The outcomes from these studies form starting points for the development of newer versions (and even more novel approaches) that adopt a more *'Architect Friendly'* approach for simulation and analysis (Attia et al., 2009). Figure 2.1 represents four criteria for developing an architect-friendly BPS application, showing that within the architectural community, the highest priority for a BPS application is to integrate a knowledge base and act as an effective decision support system.
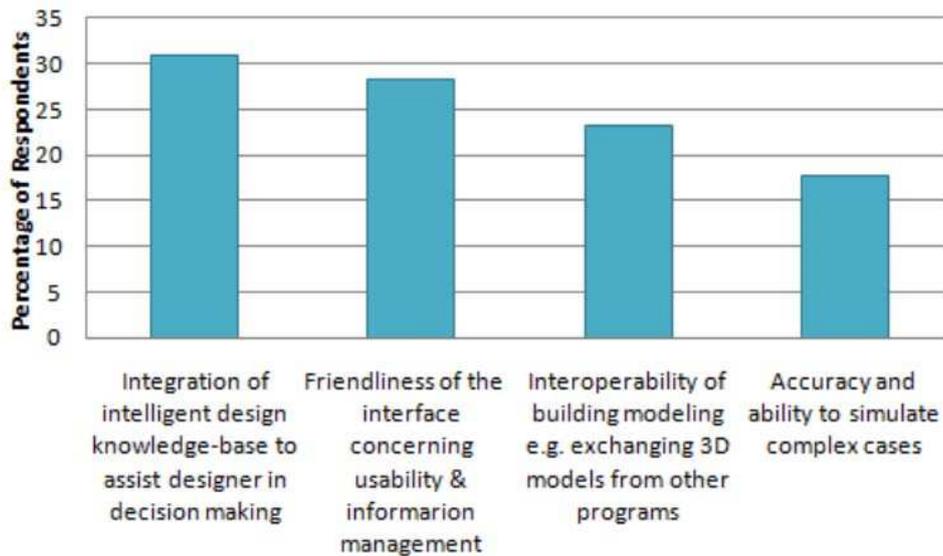
Figure 2.1: Criteria for the ranking of 'Architect Friendly' tools. Image from
the survey carried out by Attia et al. (2009).

Having discussed the strengths, potentials, benefits and opportunities offered by the utilisation of BPS applications in the architectural profession, the next section of this chapter presents a pedagogical review of the current state regarding the integration of sustainability in the architectural design education. This is followed later by a critique of using the BPS applications within the architectural realm, aiming to highlight any weaknesses, threats, difficulties, hindrances, or pragmatic issues that design students encounter with their experience of the BPS tools, and later discussing how these issues have been and/or can be addressed.

2.4.   Pragmatic Issues with BPS tools in Architectural Design Education

This section discusses the fundamental pragmatic issues that architectural encounter while using BPS applications, as a means for validating and evaluating their design solutions. It reflects on three key questions that define the noted challenges in using BPS tools in the architectural profession and pedagogy (as represented in Figure 2.2). The first question is "Why use BPS tools", which focuses on the factors that affect the motivation for using these tools. The second question is "How to use BPS tools", which highlights the issues encountered due to the complexity of these tools, where design students face the challenge to understand the BPS application interface -in terms of information and data input- and

relate its features and functionalities to the environmental design concepts they have been introduced to. The third question is "What to do with the simulation data", which focuses on issues regarding visualisation and representation of simulation results, and difficulties regarding correlating data, identifying patterns, and defining problems with their possible causalities, and subsequently making informed design decisions.
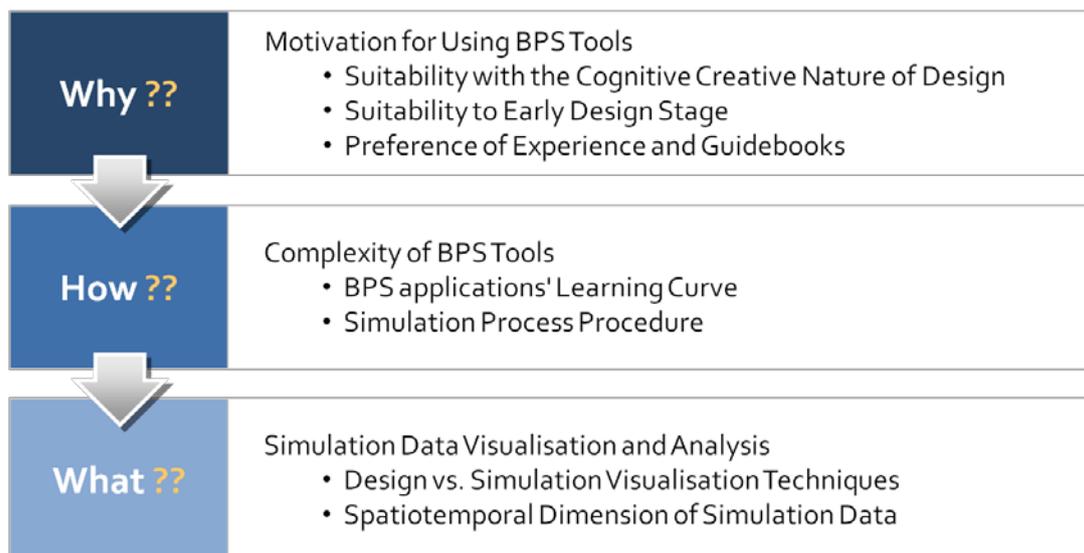
Figure 2.2: A taxonomy of the challenges encountered when utilising BPS applications in architectural design education

This section is not intended in any way to devalue the benefits of building analysis and simulation applications, and does not fail to recognise the value added by these tools to the architecture, engineering and construction professions (as discussed earlier in this chapter). Rather, it intends to highlight the challenges that the architectural design community encounter throughout the simulation and analysis process using BPS tools, and the routes that can be followed in an attempt to overcome, minimise the effect of, or resolve these challenges, which will in-turn improve the outcomes and effectiveness of the experience. This view is later reflected in the development of the research's learning support tool/game, which relies on the simulation and analysis carried out by a BPS application, making the simulation data an integral part in the proposed system architecture, as discussed in more detail within chapter five.

2.4.1. Motivation for Using BPS Tools

"*The mere mention of the words environmental design, architectural science, or building physics to many architectural professionals will guarantee either a very cold, hostile response or see them running for the door*", (Rutherford and Wilson, 2006, pp.261)

This section discusses the motivational aspects for using BPS applications, and raising the question "why" to simulate or use these tools for architects. It investigates the different aspects that affect the keenness of architects and designers to approach and integrate BPS applications as a part of their building design process. It also presents some possible and proposed solutions that can eliminate the negative effect and overcome the problem.

2.4.1.1. Suitability with the Cognitive Creative Nature of Design

In recent years, many factors have contributed in the introduction of environmental design variables to the architectural design process; however, these new variables were not deeply welcomed. Soebarto (2005), Struck and Hensen (2007), and Srivastav et al. (2009) -among many others- argue that most architects in general and architectural design students in particular, place environmental design aspects at a lower priority level in the design process, while the aesthetic aspect of design is -on the other hand- normally assumed to acquire the highest priority. Design students tend to think more about geometries, masses, relations, proportions, as well as social interaction with and within the space. On the other hand, they perceive environmental design as a series of mathematical equations that requires extensive time and effort to resolve, as argued by Rutherford and Wilson (2006). They explain that this is a medium that design students are not naturally accustomed to, that doesn't naturally fit into their solution-focused approach for design and problem solving, and doesn't feed into their 'cognitive schemata'.

In this respect, students are caught in between the conceptual cognitive nature of design, and the technical analytical nature of performance simulation and analysis, and hence setting the priorities, and attaining an appropriate level of control over the simulation exercise through understanding the performance implications of design decisions is vital (Hobbs et al., 2003). For example, students may perceive that a conceptual design priority

would be integrating indoors and outdoors environments, thus creating a sense of continuity and expansion of space. This design decision could impact on other critical environmental aspects, like creating large windowed areas that, whilst may bring in sufficient daylight and solar gain, may risk the overall building energy consumption through increased heat loss or overheating and thus impact on thermal comfort or energy demand. In this sense, many design students develop different interpretation of the 'priorities'. Some may not see the opportunities afforded by an integrated design approach, and thus may perceive the new variables introduced by the environmental and sustainable design approach as being 'unimportant', whereby they could be ignored. Alternatively some students may see them as 'vital' to the extent that they can make unrealistic and / or highly deterministic sustainability-informed changes 'just to make the numbers look good' (Soebarto, 2005). The latter perception of sustainable design variables can have a great effect on the creativity of the designer and the aesthetics of the produced design.

Rutherford and Wilson (2006), argued that there is a growing pressure to re-evaluate the priorities that drive the creative design process, based on the increasing recognition of environmental burdens that were imposed by unsustainable approaches to the design and operation of buildings. While there is no question about the benefit offered by the BPS applications, there still is a clear demand -in a design and sustainability integration learning context- for a method that can assist in understanding and setting the priorities, and identifying the implications of various aspects of the simulation. In this respect, one of the key requirements for the proposed method adapted in this thesis would be employing methods/mechanisms that allow constant interaction and communication between the designer and the tool. The projected communication would thus be based upon the data and information obtained from the BPS applications, and act as a 'walkthrough' for the user (student), guiding him/her through various environmental parameters and notions related to the current state of their design, and highlighting the meaning and implication of each of these parameters. Such an approach might have the capacity to formulate a better understanding of what the effects of specific design decisions would be on the overall building performance and energy consumption. This can be achieved by clearly defining the priorities and allocate decisions in-between the 'unimportant' and the 'vital' spectrum. Understanding the cause-effect relationship and the implications of their decisions, students

may be able to mould -more effectively- the sustainable parameters into their design without compromising the 'creativity' or the simulation data.

2.4.1.2.   Suitability to Early Design Stage

The conceptual/preliminary/early design phase is a fundamental stage within the building design process. Many authors, including Ellis and Mathews (2001) and Hensen (2004), argued that the key decisions made during the earliest stages of design -like the general building form, structure, orientation, etc.- have critical effect on any subsequent derived decisions, and that could have the greatest impact on the energy use and consumption within the building throughout its lifecycle. Maassen et al. (2003) argued that as the design development process progresses in a hierarchical manner, it generates a series of consequent sub-decisions, which makes it increasingly difficult and costly to alter the core early design decisions at any progressing point during the project development. While decisions are crucial in early design stages, it must be noted that most of these decisions are based on intricate and incomplete data, which could possibly be inaccurate (Maassen et al., 2003). Thus, it is highly likely that designers would revisit their earlier decisions and re-iterate the design, based on any updated information provided throughout the design process.

The use of BPS applications by design students in the earlier stages of design, according to Hobbs et al. (2003), have the potential to improve the level of understanding and awareness of the environmental entities surrounding the design problem, and this will lead to better design outcomes. However, Bambardekar and Poerschke (2009) argue that reaching this level of awareness and understanding requires the gathering of an extensive amount of input data and detailed building information just to be able to run the simulation. Much of the information and details required are unavailable and insufficient in the early design stages, as the building's geometry/configuration faces constant updating, revision, and modification. Thus the use of sophisticated BPS applications for performance analysis and validation in the early stages of the design seem to be daunting, frustrating, and to an extent pointless (Bambardekar and Poerschke, 2009). They add that this, in turn, can cause a psychological gap between the two parallel processes of design and analysis. Mahdavi

(2005) supports this argument, adding that designers tend to prepare the required detailed information towards the later stages of the design in order to run the BPS analysis, and most likely, this analysis would be run by specialists (like service engineers) rather than the architects themselves.

Surveys and studies (cited earlier in this chapter) have persuaded BPS developers to implement methodologies and features that directly address the early design concerns. IES-VE, for example attempts to facilitate rapid progression (in terms of information input) for getting quick results for thermal performance analysis at the early stages of design. This is done through the use of templates that assist the quick building of the thermal model with basic information that reduces the amount of effort required before carrying out the simulation. eQuest, as argued by Attia et al. (2009), improves the modelling capabilities for conventional building components as an attempt to facilitate the modifications required in the design iterations during its conceptual stages. Some other BPS tools aim to accommodate the lack of available information during the early design stages. ENERWIN[17], for example, is supported with a built-in database that can generate default data based on the building types (like heating/cooling systems, air-flow rates, and used materials). This was developed in an attempt to help designers use generic initial values that can help initialise the simulation process as early as desired, without the actual data being ready or prepared. However, Soebarto (2005) argues that this approach might prove to be ineffective and quite 'tricky', as students would tend to accept the default values without actually understanding their relevance and their implications on the whole process.

Although many argue that designers may lack the motivation to use BPS tools, it is also arguable that designers are curious to investigate the potential performance influences and impacts of their design decisions, at the earliest possible stages (Marsh, 2006). In order for this to be easily achieved, there is a demand for a smooth and simple flow of information between the design and simulation elements of the process. Currently, the advances in BIM systems facilitate the compilation and structure of an informational model that works in conjunction with the BPS applications (Yan and Liu, 2007; and Attia et al., 2009). BIM systems are constantly opening new frontiers that directly affect "*not only what we make*

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[17] ENER-WIN: Energy Simulation Software, available: http://pages.suddenlink.net/enerwin/

but simultaneously how we make as architects" (pp. 756). Eastman (2008) also argues that BIM systems have great potential in encapsulating the semantics and geometric information, and reusing/migrating this information across multiple domains of specialisation throughout the design development process. In essence, recent years have seen a number of announcements for optimising the relation between CAD -in general and BIM systems in particular- with simulation applications. This optimisation aims to facilitate rapid development and preparation of conceptual design models for simulation and analysis. For example, Google SketchUp[18] plug-in for IES-VE and EnergyPlus, the AutoCAD[19] plug-in for EnergyPlus, and Revit Architecture[20] plug-ins for Ecotect and IES-VE.

It can thus be concluded that an essential requirement for architects -in the environmental design process- is to be able to assess and validate their conceptual design on a performance basis in a quick and accurate manner, with minimum information and without any specialist intervention. This can be achieved through two methods; firstly through dynamically providing any required data using default values (like the case in ENERWIN), while clearly notifying the users to these values and their implications on the initial simulation run. Secondly through simplifying the outcomes of the simulation and presenting results that can be interpreted into further design guidelines (as explained later in this chapter). At this level of development, the accuracy of simulation data is not as important as the general outline and 'reflection' to the conceptual design (Marsh,2004). Implementing these two methods will allow designers and students to be more involved in the primary phases of building analysis, and provide them with a chance to iterate the design and examine a wider range of possibilities to improve both the building design and performance, based on a more solid understanding.

2.4.1.3.   Preference of Experience and Guidebooks

Some authors, including Mahdavi (2005) and Lam et al. (2003), believe that a significant portion of time spent on assessing and validating the design from an environmental perspective (through the use of BPS applications) is directed towards understanding the

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[18] Google SketchUp: http://sketchup.google.com/
[19] Autodesk AutoCAD: http://usa.autodesk.com/autocad/
[20] Autodesk Revit Architecture: http://usa.autodesk.com/revit-architecture/

different aspects and functionalities of these tools, and they can initially run it and eventually get useful design directives. As many could argue this is quite a daunting task, especially for design students at preliminary design stage, which points back to the understanding of the theories and principles of sustainability in building design, as well as the underlying science and building physics that surround the process. Designers tend to be more accepting of -and dependant on- their own experience, beside general design guidebooks. Struck and Hensen (2007) argued that "*Design decisions are often based on experience and intuition, rather than on quantitative prediction of performance indicators such as running costs, thermal comfort and CO$_2$ emissions*" (pp.1434). This statement supports the designers' learning theory and problem solving approach that was discussed earlier in this chapter, and Hillier et al. (1984) description of the design as a cyclic reflective deductive process.

Recearch by Pedrini and Szokolay (2005) concludes that in general, mathematical simulation models were deemed unpopular by architects, ranking BPS tools among the least favoured method within a list of eighteen design decision support techniques. This was basically due to the fact that the technical analytical nature of these tools didn't mould well into the cognitive, reflective, deductive nature of the design process. Their research also concluded that in early design stages, personal experience and intuition are the most popular and preferred methods for decision making, followed by rules-of-thumb, design guidelines, and published design assisting suggestions. Struck and Hensen (2007) also argue that quantitative analysis of performance indicators -like energy consumption and operating costs- pulls the design process towards a rigid technical side at the expense of human interpretation and personal input to the design.

 Pedrini and Szokolay (2005), and Bambardekar and Poerschke (2009) explain that the high tendency for employing guidebooks as an effective reference resource or pointer in the design process can be attributed to their ease-of-use. Since guidebooks are general and not based on certain building specifications, they are easy to navigate, and more importantly, they do not demand comprehensive detailed information about the design at any stage. This deems the design guidebooks relatively more effective in terms of time, cost, and effort. Guidebooks, however, have remarkable shortcomings that could ultimately affect

critical design decisions. The lack of specification in the guidebooks makes them detached from the design process and lack a substantial level of depth and details. Bambardekar and Poerschke (2009) explains that the biggest shortcoming of guidebooks is that they lack the interactive nature where critical building data should be gathered and considered. Guidebooks and guideline applications (like Climate Consultant[21]) are somewhat generic, giving suggestions on what can be done rather than giving effective reflection on what will actually happen in terms of building performance and energy consumption. Guidebooks, as argued by Bleil de Souza and Knight (2007), are not sufficient and cannot be solely relied upon as a decision support tool. Soebarto (2005) also argues that guidebooks lack being zone-specific, or even building-specific, unlike simulation tools that take into consideration the specification, dynamic nature of the building's microclimate, as well as the building operations. In this sense, guidebooks could provide some design suggestions that could, for example, prove effective for one zone, but could eventually affect the overall building performance as it lacks the consideration of different zones' interoperability.

Some BPS applications (like HEED for example) have adopted guidebooks implementation as an interactive case-specific functionality, in the form of a presented set of guidelines. This concept constitutes a fundamental requirement in the proposed tool, which needs to focus on addressing particulars and specifications of the design. This building-specific information should be assessed against a set of standards, algorithms, and building physics laws, to ultimately present formative feedback to the user with specified information and design-oriented guidelines.

2.4.2. Complexity of BPS Tools

The previous section in this chapter discussed the shortcomings of BPS applications usage in the architectural profession, in terms of motivation of use and acceptance for integration within the design process at its various stages. In this respect, it was answering the question 'why' use environmental analysis tools. This section discusses the next set of challenges associated with BPS tools usage, specifically relating to their information input functionality, interface usability, linking with other CAD applications, etc.

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[21] Climate Consultant 4.0 - UCLA: http://www.energy-design-tools.aud.ucla.edu/

Architecture students, according to Schmid (2008), are neither attracted nor keen to use the existing environmental assessment tools, due to their relative complexity and highly technical nature, which doesn't suit the architects' mentality. Soebarto (2005) also argues that "*there is no building simulation program that is easy to use by architecture students (and architects) and gives truly accurate results.*" (pp. 1150). Though many attempts have been made after this statement to make the BPS applications more architect-oriented and attempt to satisfy the designers' expectations, some noted issues have been raised relating to the usability and information management of BPS interfaces (Attia et al., 2009). Bambardekar and Poerschke (2009), for example, argue that with the high level of complexity of BPS applications, there exists very limited software-independent guidance aimed to assisting architects throughout the energy simulation process. Thus, this section is concerned about addressing the concerns raised relating to the question 'how' to use these BPS tools, highlighting various issues and challenges that designers and students encounter while using these tools. It also presents some attempts made to resolve these issues and make the process simpler for students.

2.4.2.1. BPS applications' Learning Curve

Energy simulation applications are -in the main- very powerful, and have supported many professionals in the construction industry in their quest to develop and deliver low-energy sustainable buildings. Many case studies are clear evidence of this claim, including project like 'The Sliding House', 'University of Sheffield campus', 'Heelis, National Trust HQ in Swindon'[22], and many others. However, architects -in general- could be considered fairly new users to these energy simulation tools. For architects to be able to properly use these tools, they initially encounter a relatively steep learning curve (Schmid, 2008). Architects need initially to have some degree of awareness, knowledge or understanding of the underlying theories and building physics related to environmental design, which comprises different concepts and terminologies (like internal gains, solar radiation, stack ventilation, etc.). They also need to understand the different features and functionality of the BPS application that directly (or indirectly) relate to the theories and physics that they were

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[22] The details of these projects (among many other case studies), with the projected design data and the actual operational data can be found within Carbon Buzz website database: http://www.carbonbuzz.org

introduced to. Architects need to relate the terminologies and notions learnt to the functionality implemented in the application interface, and understand how to prepare initial information about their building design (geometric and non-geometric) to be fed into the application in order to prepare for starting the simulation process. Bambardekar and Poerschke (2009) explain that, for designers to be able to carry out an effective simulation, they need "*thorough understanding of the nature of performance based design inquiry, the related performance parameters to be evaluated and the associated simulation task*" (pp. 1311).

Maassen et al. (2003), and Punjabi and Miranda (2005) argue that the interface to most BPS applications (from an architect's point of view) are mostly rather complex, typically cumbersome, highly technical, and difficult to learn and understand. Many researchers added that these tools are more engineering-oriented than being architecture or design-friendly (Attia et al., 2009; and Maasen et al., 2003). This was based on the fact that traditionally BPS applications were used by services engineers at the later stages of development (Marsh, 2004), thus requiring broad technical capabilities and extensive detailed information before the simulation could be performed. Soebarto (2005) argues that highly technical BPS tools that have high accuracy to describe a building are more likely to be difficult to use as they require extensive numerical input, which could be quite a hindrance for architectural design students who naturally tend to work graphically rather than numerically.

More recent research and surveys, however, show that there have been noticeable improvements and developments in some BPS tools' interfaces and usability, paying significant consideration to the architects' background, knowledge, and experience. Ecotect for example, as argued by Praserez (2006), Crawley et al. (2008), and Srivastav et al. (2009), is gaining more popularity among the design community as it has a relatively less complex and more friendly interface, relying on highly visual and interactive modelling and analysis mechanisms. IES-VE and eQuest also attempts to offer higher flexibility and improved interaction, along with easier navigation and control (Attia et al., 2009). In this context, Bambardekar and Poerschke (2009), carried out a test case for using BPS applications within the schools of architecture (Ecotect and IES<VE> in this instance), noting that the interface

itself was much less problematic, and that the main learning curve problems for the students were linking and translating the concepts and building physics introduced in the lectures to meaningful simulation tasks, that can be carried out during the tutorials (which will be discussed in the following section), and also making sense of the simulation outcomes and again translating them back to design decisions (which will be discussed in more detail later in this chapter).

Soebarto (2005) explains that attempts to change the simulation process to be more user-friendly in a design studio are likely to involve a lot of simplifications and assumptions of data in the preliminary design stages. Several attempts were made -in the form of research projects and proposed frameworks- aiming to develop methods that can facilitate the use of BPS tools in design courses, and minimise the time and effort required for understanding the applications before even running the simulation. One of these attempts was introduced by Peters (2009) (Figure 2.3), where he argue that the learning curve for students can be reduced by assigning them simple basic tasks within a much abstracted interface. The simplified interface aimed to walk the students through basic simulation tasks, so that they can only focus on achieving these tasks, while eliminating other unnecessary features. In his experiment, students worked on a simple box model, and changed the basic input parameters in number of iterations until reaching acceptable results and fitting the building within the adaptive comfort zones for most of the year. Peters' proposed interface uses EnergyPlus in the background for performance simulation and analysis, while the users are only subjected to the simplified interface. Peters' concluded that subjecting the students to simplified tasks allowed them to gain confidence to understand the implications of the parameters they used, so that when attempting to design a bigger building, they would be less reluctant and hesitant to deal with input information and parameters, and the learning curve would thus be minimised. This 'simplified tasks' approach was also reflected in the simulation data outcome (as presented within Figure 2.3), where the interface adopted multiple visualisation mechanisms (including 3D, graphs, and tabular/numerical), and the user can control the type of data to be presented, and the period required (daily, monthly, annually, etc.). Although this approach is effective in its 'simplification' and abstraction of the problem, and also effective in its basic user-defined methods of data representation, it still falls short in terms of:

- Addressing problems of a bigger scale (being limited to a single box/zone).

- It is not informing the students about the process being carried out in the background. In other words, they are playing with numbers (on the sliders) and anticipating the effect of these numbers on the simulation data outcomes; making it more of a trial and error process rather than a procedure that is problem focused.

- It stops in giving information (similar to the actual BPS applications, though in a much simplified manner), and doesn't highlight problems and causes, and doesn't suggest solutions and guidelines to follow.

Simplification of the environmental design problem and abstraction of its parameters is deemed to have potential and could be effective in terms of users' perception. In this respect this approach was taken into consideration as a directive and a key requirement in the development of the tool presented within this thesis. This has later affected the tool's system architecture and the decisions to utilise specific techniques (data mining in this instance) to support simplification and presenting knowledge in an abstract format (as discussed later in Chapter Four).
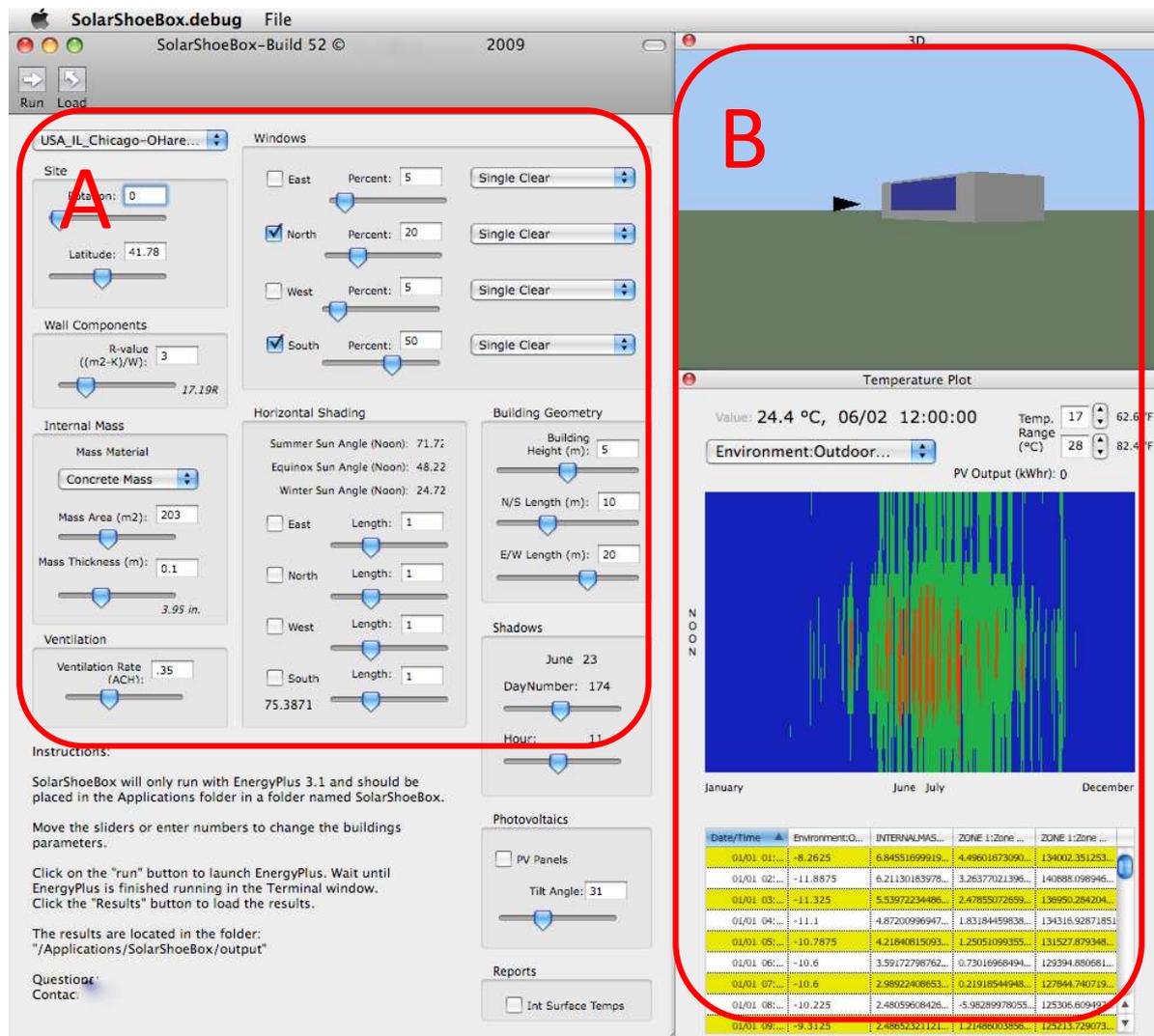
Figure 2.3: A screenshot of the simplified BPS interface developed by Peters (2009), representing the controls and sliders for changing the input information and details, depicted within bordered zone [A], and the representation of the performance outcomes in multiple formats (3D, graphs, and tables), depicted within bordered zone [B].

2.4.2.2.   Simulation Process Procedure

The 'Conjecture Analysis' method of learning -discussed earlier in this chapter- was proposed as a suitable and efficient mean for incorporating sustainability into the architectural design curricula. However, effective implementation of this method, as argued by Warburton's (2003), required incorporating revelatory activities that enables the development of students' knowledge and awareness, through assisting them to 'ask the right questions'. In terms of building simulation, one of the key challenges that design students face, as argued by Bambardekar and Poerschke (2009), is to formulate the right

questions; in other words, translating the knowledge, theories, and concepts they learnt into meaningful and defined set of simulation tasks. They explained that "*Architects are usually familiar with environmental concepts, but often do not clearly understand how to translate the design and performance inquiries into simulation tasks and evaluate them using ESP's [Energy Simulation Programs]*" (pp. 1307). In other words, students may show good comprehension of building physics, but fail to interpret this comprehension into meaningful questions and a procedure they should follow in assessing the performance of their designs using BPS tools (Schmid, 2008). Bleil deSouza and Knight (2007) also argue that designers and students need to possess a good level of knowledge and understanding (of the building physics and the BPS functionalities), to be able to formulate and define a set of criteria and procedures that structure the building simulation and analysis process.

In this respect, design students need to know the type of calculations and assessments required to run in the BPS tool they are employing. This knowledge should be based initially on what they already know, and what they intend to get as outcomes of this simulation. Marsh (2006) explains that even for an experienced BPS application user, planning the simulation model based on a diverse set of requirements that address the analysis process, is still a challenging task that requires careful consideration. He adds that "*a first-time student has no hope*" in getting this right, and in using this simulation to benefit his design process. Thus it is clear that there is a need for methods to bridge the gap between theory and practice, and walk the students through the simulation process thus aiding them to ask the right questions, and ultimately get feedback that will form a solid design decision. Bambardekar and Poerschke (2009) argue that students need extensive support to be able to understand the range of simulation capabilities which will lead to assisting them in formulating a scope that defines suitable simulation process procedure that they can actually benefit from. They add that there are currently very limited sets of guides and/or documentations that could support the students to know what to simulate, and that this support should inevitably come from the class tutors. Bambardekar and Poerschke thus conclude that the lack of simulation procedure, scope, and guidance constitutes another clear burden for students.

A key factor in overcoming this challenge is to understand and comprehend the nature of design inquiries at the earlier stages of the design process, and to feed or mould the performance parameters into this; once again addressing the cognitive schemata of the designers. Bambardekar and Poerschke (2009) explain that designers would be more accepting of a system that incorporates environmental and performance assessment of the design, while offering a high level of flexibility and consideration to the designer's mentality. Ellis and Mathews (2002) also argue that clearly identifying and redefining significant simulation parameters as design-oriented criteria is a key factor in resolving the simulation problem, and obtaining relevant outcomes that can be easily comprehended and dealt with by the architects.

A number of research studies and surveys into the use of BPS applications in the architectural pedagogy -including Bleil de Souza and Knight (2007), Toth et al. (2010), Attia et al. (2009), Crawley et al. (2008), and Bambardekar and Poerschke (2009)- call for an integrated medium that can act as a design knowledge base that facilitates learning. They note that this can be achieved by relating theory into practice by explicit integration of 'what if?' scenarios that correlate to the underlying concepts and theories, as well as the practical aspects and potential impact of different design strategies. This was attempted in some BPS applications through implementing case studies and introducing templates and tutorials for use by the novice (as explained earlier in this chapter). However, this solution is just a starting point, and needs to integrate higher levels of interactivity and specification.

2.4.3. Simulation Data Visualisation and Analysis

Data representation and visualisation is a key aspect in many fields, and has been for a long time. Brown et al. (1995) report that visualisation techniques were employed to read and interpret data using maps and basic diagrams in China from as early as 1137. Data visualisation is a fundamental means for information and knowledge transfer between several parties in a single or multiple disciplines context. Data visualisation in general can be defines as "*the use of computer supported, interactive, visual representations to amplify cognition*" (Card et al., 1999). In this respect, computing is normally utilised to facilitate the methods of allocating, processing, and presenting the data to the users, while interactivity

presents the users with a means to form hypothesis and interpret data on-the-fly, for further testing and reformulation (Moere, 2005). This concept thus mainly focuses on enhancing the human interpretation of data by presenting visual methods that attempt to uncover patterns, underlying principles, and 'knowledge' hidden within available datasets, and subsequently draw conclusions.

There is currently an ever-growing and extensive research into novel and effective methods that support the interpretation, analysis and visualisation of data across several disciples. These disciplines include Clinical and Medical research (Shahar and Cheng, 1999; Blaas et al., 2007; and Gallo et al., 2008), MRI data and Brain Imagery (Zhang et al., 2004; and Robler et al., 2006), Geographical Information Systems (GIS) (Appleton and Lovett, 2003; and Legates, 2005), Geomechanics (Hashash et al., 2003), Computational Fluid Dynamic (CFD) (Laramee et al., 2006), Hydrometric (Kramer and Jozsa, 1998), Remote Sensing data (Schowengerdt, 2007), and online traffic and log data analysis (Hochheiser and Shneiderman, 2001). In the architectural profession, data visualisation techniques have been used extensively as means for interpreting analysis and simulation outcomes (generated from BPS applications for example), as well as a method for communication between different project stakeholders (architects, engineers, clients, project managers, etc.).

One of the most important fields that utilise different visualisation techniques is building performance simulation and analysis. It is quite crucial for BPS tools to be able to communicate analysis outcomes to the designers in an effective manner that they are accustomed to, and that can assist them in comprehending these data, correlating them, and thus making appropriate design decisions accordingly. Tufte (1997) explains that the process of analysing and understanding quantitative data is rather intricate, and demands a good choice of superior visualisation methods in order to reach credible and precise findings. He adds that faulty representation of simulation data could in many cases have significant consequences, especially when relating this analysis to a decision making process. In this context, where it is quite difficult to understand data in its raw numerical format, architects and designers call for effective means of visualisation, thus using 2D diagrams and 3D models, as well as still images and animations. Laiserin (2001) explains that

these visualisation methods play a progressively important role in helping to highlight potential problems in the current design and support decisions to resolve them.

Many researchers, however, believe that although BPS tools utilise highly professional and powerful visualisation techniques, there are still many shortcomings when communicating these data back to architects. Marsh (2006) argues that "*The decision to introduce analysis software in any course is always a tough one. The main problem is invariably the amount of time required for students to gain sufficient proficiency to actually make use of the analysis results*". Srivastav et al. (2009) also argue that using environmental analysis and simulation software in the architectural profession is still not very common, and the main reason for these tools being such an obstacle to designers is their methods of data representation. They add that the main reason for the notable failure of visualisation techniques utilised by BPS tools is the complexity of representation of data and calculations, and thus correlating the data and deriving design decisions from it.

This section presents the challenges associated with the current visualisation techniques employed within BPS applications, with relation to the architectural design community. It investigates why designers and students face a mounting challenge with the increase of the complexity of design concepts. It also discusses the current and proposed methods that can effectively resolve these issues, and facilitates the comprehension and analysis of simulation outcome data.

2.4.3.1. Design vs. Simulation Visualisation Techniques

BPS applications tend to use various means of visualisation that could be arguably very effective, if the user can understand and correlate the results representation. However, in the architectural profession, there is notable extensive utilisation of (and reliance on) CAD drafting and visualisation techniques. The rapid development and advance of CAD tools with their various functionalities and capabilities not only helped in increasing productivity within the design community, but also assisted in the production of highly technical and graphically advanced design visuals, particularly in the 3D context (Srivastav et al., 2009). Design visualisation in general is a reflection of the conceptual model developed by the designer

that relate to and feeds-back into his/her cognitive schemata. The qualitative geometric information about this model is normally represented spatially in a highly visual virtual representation that mimics the actual proposed built environment.

Simulation visualisation techniques, on the other hand, have remarkably different characteristics. The simulation process itself is a highly technical scientific method based on an empirical model, that fails in many cases to "*reconcile the relationship between design actions and performance outcomes*" (Toth et al., 2010, pp.315). Attia et al. (2009) also argue that the current methods and mechanisms employed by BPS applications are incapable of significantly transferring knowledge back to the users and supporting their decision making process. Some of the simulation outcomes of BPS analysis are represented qualitatively (like visualisation for lighting, and auralization for acoustics), however, when it comes to energy and thermal data representation, the simulation outcome is more quantitative, normally through "*alpha-numeric charts, difficult to use and interpret and generally composed of enormous quantities of data*" (Bleil de Souza and Knight, 2007). The general differences in concepts and applications between design and simulation visualisation techniques are presented in Table 2.1.

Design	Simulation
Information Visualization	Scientific Visualization
Qualitative	Quantitative
Sketch/Drawing/Diagram	Graphics/Charts/Tables
Spatial(3D)	Spatiotemporal(4D)
Conceptual	Empirical

Table 2.1: Comparing the nature of design and simulation data
representation and visualisation techniques. (Srivastav et al., 2009)

Graphical representation of BPS simulation data, according to Srivastav et al. (2009), utilises various techniques that range from layering, varying line-thickness, and colour coding, to digital 3D visuals. However, they believe that the full potential of the microclimate analysis

carried out by BPS tools is not being tapped effectively (with respect to the architectural profession), because of the means of data representation and visualisation. Many researchers, including Pilgrim et al. (2003) and Mourshed et al. (2003), argue that the prevailing means of simulation data representation is through 2D graphs, charts, and tables, though some BPS applications utilise some advanced 3D representation techniques (Figure 2.4). They explain that these methods are not well accustomed to dealing with complex data like that derived from simulation analysis, particularly when communicating the analysis outcomes to the less-technical designers. Attia et al. (2009) support this argument, adding that the currently available energy simulation applications do not adequately serve the affiliation of the design process and the performance data outcomes, which jeopardises the simulation analysis' effectiveness as a supporting decision making system. Poor representation of simulation data could compromise the whole process and reduce the richness of the "*integrated simulation*".

It is arguable that the use of BPS analysis tools is yet to see the extensive expansion that was noted with CAD and 3D applications. A key reason for that, according to Srivastav et al. (2009), is the lack of architect-friendly visualisation methodologies in these BPS tools –like those utilised by the CAD and 3D applications- and a lack of data representation techniques that could satisfy the conceptual needs of designers. They add that the visual representation of analytical tasks performed by BPS applications lacks much consideration of the existent norms that are dominant and expected within the design realm. The variation in scope and nature, along with the lack of harmony in visualisation techniques between traditional design and modern simulation has caused many architects to be reluctant in adopting and/or using BPS tools, despite the advantages that can be gained from them.
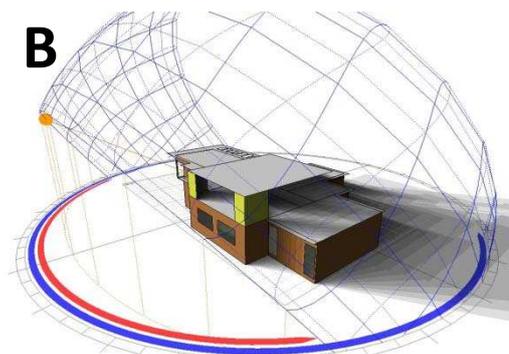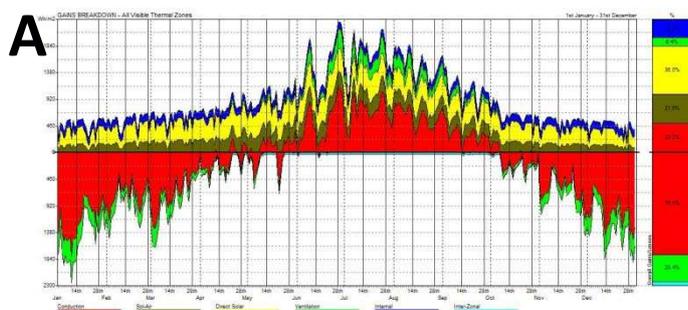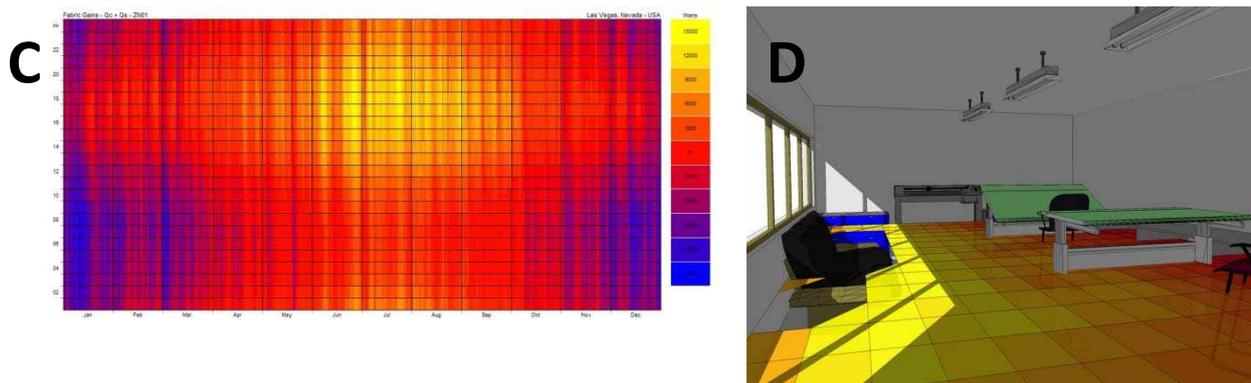
Figure 2.4: Some simulation data representation and visualisation
techniques. Images generated from Ecotect, representing (A) Annual gains
breakdown, (B) Sun-path diagram and shadow path, (C) Annual hourly
fabric gains, and (D) Daylight factor and illuminance levels representation.

2.4.3.1.1.   *Attempts for Improving Simulation Data Representation*

Several studies, attempts and approaches have aimed at improving the communication of simulation results to the BPS users (particularly architects), and bridge the gap between data representation and knowledge transformation. Some of these approaches have targeted the human perception of the presented data (focusing on the arrangement and methods of communicating data with the users -using the same conventional techniques), while others have targeted the base methods of data representation and attempting to introduce more effective and novel means of communicating data. Haberl and Abbas (1998), for example used 'Plot Matrix'[23] techniques for representing simulation outcomes (Figure 2.5). They argue that this technique is comparatively more informative because it collates the available information and presents them in one stance to the users for evaluation and comprehension. They add that the matrix structure can include several properties and can facilitate comparing multiple solutions on a performance basis. However, the plot matrix approach still requires a solid understanding from the users of how to interpret the represented data and form basis for comparing solutions.

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[23] A 'Plot Matrix' represents an aggregation of multiple simulation data output in a grid-like format (matrix). This aims to present the users with as much information as possible at the same stance, where it would allegedly be easier to understand and relate.
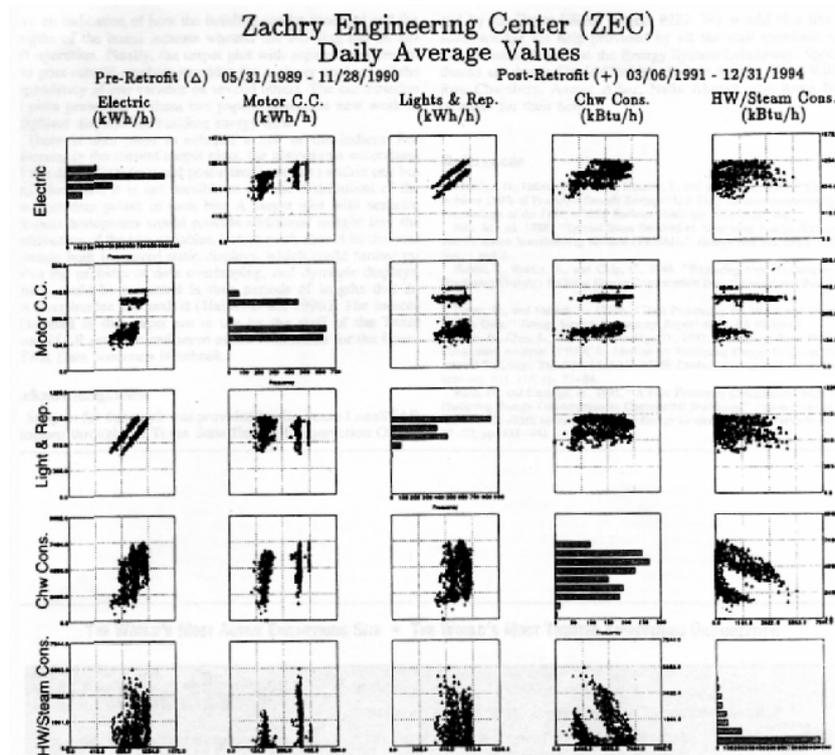
Figure 2.5: Energy consumption plot matrix, from Haberl and Abbas, 1998.

Clarke (2001) developed an "*Integrated Performance View*" (IPV) approach for simulation data representation and visualisation based on the 'plot matrix' approach (Figure 2.5). This approach inter-operates with a BPS application (ESP-r in this case) for running the calculations, the IPV then represents the outcomes in a matrix structure, which includes a standard set of metrics for representing the multi-variant aspects of the proposed building's performance. These metrics include summaries about thermal and visual comfort, energy consumption and performance indicators, and daylight and glare assessment. Although this approach is again a good means for comparing solutions on a performance basis, and did begin to integrate summarised performance reports and 3D means of visualisation, it is still static and didn't offer much interactivity to the users.
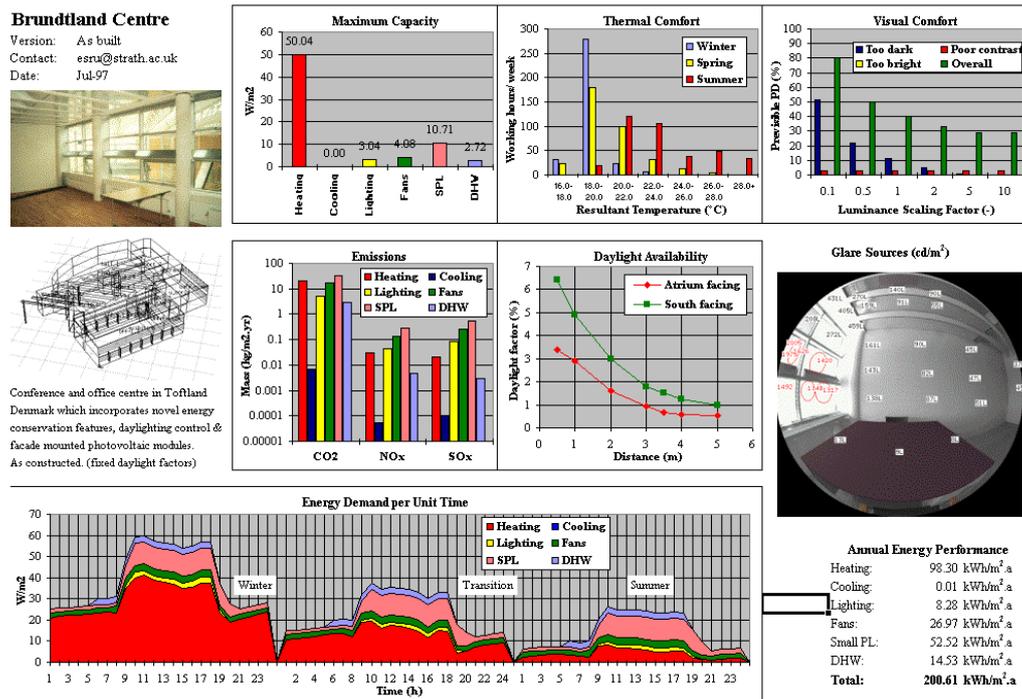
Figure 2.6: Integrated Performance Displays (IPV) approach for
performance data representation (Clarke, 2001)

An advanced version of the IPV was developed later by Prazeres (2006), which integrated
more interactivity and multimedia usage to support the users' interpretation and
comprehension of results (Figure 2.6). The users are offered more interaction with the
model to alter some of the visualisation settings and explore more details and information
at run-time. This IPV included multimedia representation via sound, video, graphical, as well
as the basic alphanumerical formats, along with the implementing basic VR interactivity.
IVPs have contributed to the enhancement of the means of communicating performance
information to the users, particularly those who don't have the extensive knowledge and
experience required to interpret the standard visualisation techniques. Some of the features
and concepts utilised in the IPVs formulated important requirements for the tool proposed
in this thesis, particularly the dynamic nature and the interactivity offered to the users.
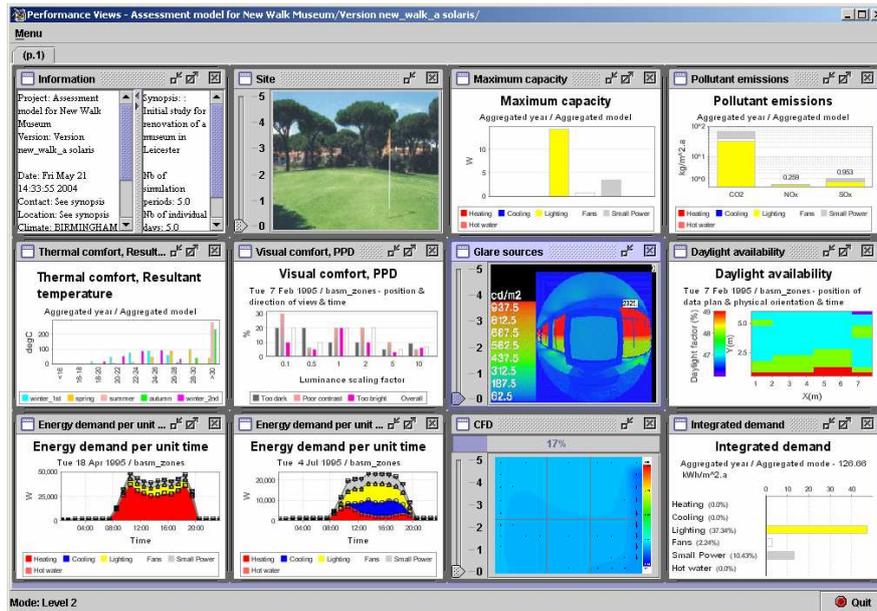
Figure 2.7: Energy consumption plot matrix, from Prazeres, 2006

Other approaches for communicating simulation data have called for the integration of more visual and interactive techniques. Herkel et al. (1999), for example utilised VR technologies to represent thermal comfort and lighting analysis as a colour-coded layer in an interactive 3D virtual experience (Figure 2.7). The concept of 'Layering' was also adopted by Srivastav et al. (2009) but on 2D diagrams/figures, where they suggested integrating multiple levels of information about different environmental design entities in a more visual format. The layers are explored by the user when further details and analysis are required. It is arguable that this technique could be useful, as it prevents the users from being subjected to extensive volumes of simulation data (numbers and graphs), and presents hierarchical levels of detail, which the users can explore interactively and intuitively when needed. The 'layering' and '3D interactivity' concepts were adopted by recent versions of current BPS applications like Ecotect (as can be seen in Figure 2.3[D]).
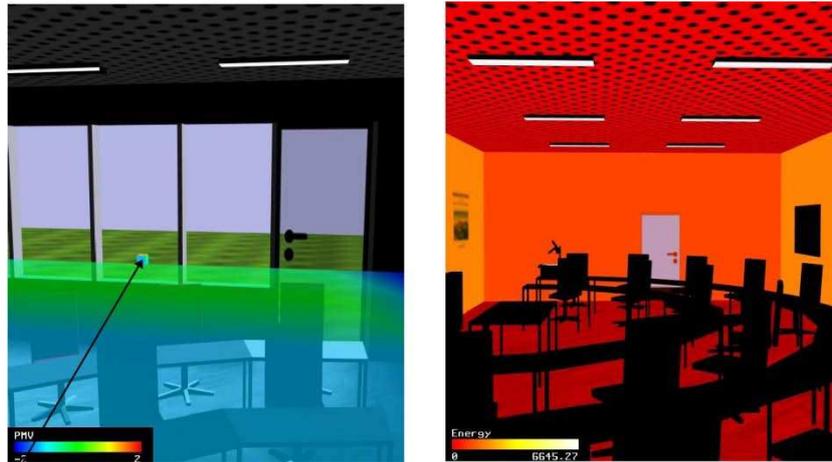
Figure 2.8: Colour-coded layered representation of analysis data in an
interactive 3D environment, from Herkel et al., 1999

2.4.3.1.2. Defining Patterns and Performance Problems

In early design stages, where the conceptual design is constantly updated, effective visual data representation techniques are crucial, as they assist quicker interpretation of data, pattern analysis, problem identification, and definition of possible causes for encountered problems. Bambardekar and Poerschke (2009) explain that the format for the simulation data output, result interpretation, and pattern analysis are decisive aspects in assessing the efficiency and effectiveness of BPS tools as a decision support system. Defining patterns could assist in uncovering problems and flaws in the proposed design, and could aid in pointing to the possible causes of these problems. Morbitzer et al. (2003) argue that architects and designers tend to look for data patterns that can provide answers to key questions they have (like airflow, comfort ranges, ventilation, gains, etc.). These patterns are normally extracted from data presented on multiple tabular or graphical displays. They add that it would be a useful contribution to support the simulation process with further analysis techniques that designers are more comfortable with and accustomed to.

One of the issues raised about the usability of BPS application in the design community, is that it lacks interactivity and that it is process-centred rather than designer-centred. Srivastav et al. (2009) argue that a major shortcoming of BPS tools is that they often skip the computation core of the simulation process to directly present analysis outcomes. This means that the designers may not be fully aware or understanding of the implications of

their design decisions on the generated data. Prazeres and Clarke (2003) also argue that one of the shortcomings of simulation analysis data is its 'static' nature, which relies to a great extent on the designer's experience and perception to understand and relate to the design requirements. They add that in this respect, data visualisation cannot solely be relied upon in deciding on the performance of two design alternatives.

Thus it can be concluded that -from a designer's point of view- the simulation process is like a black box; where the designer has minimum knowledge of the assumptions being made, the methods of calculation, and the entities that contribute to the received outcomes. It can be argued that the simulation process doesn't just lack interactivity, but also lacks a 'narrative structure'. In other words, the process lacks a narrator who can communicate with the students and tell them the story of their design (in terms of geometry, social space, performance and energy requirements, etc). The same narrator can help in reporting the problems, identifying possible causalities, and suggesting methods to resolve them. To be able to do that, this narrator has to utilise a technique that can traverse the simulation data and highlight patterns aiming ultimately to extract abstract useful knowledge. It is argued by number of researchers, including Morbitzer et al. (2003) and Wilson et al. (2007), that 'Data Mining' (DM) techniques are appropriate for pattern definition and knowledge extraction, and that the simulation process can benefit greatly from these techniques. This notion is discussed in more detail in chapter four.

2.4.3.1.3. *Simulation as a Decision Support System*

Despite some of the advances in the visualisation and data representation techniques employed by BPS applications, there is a noted shortcoming in the methods for translating the presented outcomes into meaningful knowledge that can feedback into the design and act as an effective DSS (Bleil de Souza and Knight, 2007). Mahdavi (2005) also argues that the technical nature of data representation leaves a substantial degree of choice for the designer who evaluates the outcomes of the simulation. This means that there is a significant risk of misinterpreting the simulation outcomes, thus leading to uninformed design decisions (Prazeres et al., 2009). A fundamental aspect for confusion and/or making uninformed decisions is the lack of availability of support and guidelines that assist in

understanding and correlating simulation analysis data. Stravoradis and Marsh (2005) argue that understanding all the simulation output data, and processing these data in such a manner that can inform subsequent design decisions, is just as critical as running the simulation process itself, adding that there is no point of carrying out this process if designers can't make sense of the analysis data outcomes. Bambardekar and Poerschke (2009) support this argument, adding that there is an extensive need for guidance that would help architects in understanding the results generated from BPS tools, and incorporating these results to form effective design decisions.

In a learning context, Marsh (2006) argues that the simulation data analysis process has been proven to be quite challenging for most design students, leading to a noticeable struggle in getting any results whatsoever from the simulation, let alone meaningful ones that support further decisions. In the study by Soebarto (2005), where BPS applications were introduced to a design studio, she concluded that even when a highly graphical and more design-oriented tool was introduced to the students (Ecotect), they were still quite uncomfortable approaching and using the program, as they still (beside the graphical representation) have to deal with extensive numerical output. She explained that "*most students found it [BPS applications] less interesting to use and felt rather 'scared' when they had to see so many numbers*" (Soebarto, 2005, pp. 1149). Thus, the problem was the interpretation of these numbers (what do these numbers really mean?), and difficulties in linking these numbers back to further decisions. Towards the end of the design studio, Soebarto noted that students tend to utilise what is available (or what they can find) in the BPS application, and give up some decisions they have made earlier in the design process (like materials and their thermal properties). This can again raise the issue of what the students are expecting from such tools, and what sort of information or data should they be looking for in order to base their future decisions upon, which ultimately leads back into Warburton's (2003) recommendation that the process should be revelatory, allowing the students to ask the right questions, instead of grappling with concepts they are not accustomed to. Knowing and understanding what to ask will clearly lead to knowing what to look for in the output data, leading to a more informed design decision, and a more confident and effective simulation experience for the design students.

2.4.3.2. Spatiotemporal Dimension of Simulation Data

"[The] *Majority of building simulation data is spatiotemporal and the visualization techniques available to us so far are unable to deal with the complexity. There is a need for a visual aid that can represent spatiotemporal data in a way that makes the relationships and patterns of the 4D data comprehensible to the user.*" (Srivastav et al., 2009, pp.1945).

A fundamental characteristic of simulation analysis data, is that it has two core dimensions; spatial and temporal, as explained by Yan and Jiang (2005). The temporal nature of simulation visualisation is adding a new timeline dimension to the –normally 3D featured- process. This spatiotemporal 4D aspect of the analysis data has quite an intricate nature, which it is relatively difficult to represent and visualise. While designers are normally accustomed to the three-dimensional aspect of their design, a fourth (temporal) dimension, like that introduced by the BPS analysis, is likely to cause much confusion and uncertainty to the designers to interpret and build decisions upon. In this respect, it is important to adopt a visualisation mechanism that can simplify the representation and interpretation of the temporal nature of simulation data.

Crawley et al. (2000) and Yan and Jiang (2005) among many others believe that current visualisation techniques utilised by the vast majority of BPS tools have limited capability in supporting the level of complexity generated by the spatiotemporal characteristic of the simulation. Though the nature of simulation data might be perceived initially as a significant burden and an impediment to developing effective visualisation, the spatiotemporal nature of these data has the capacity to create novel powerful techniques that reflect the spatial geometric and non-geometric properties of the design, with respect of the temporal nature of the analysis data.

In discussing the multidimensional nature of simulation data, it is important to distinguish between 'Scientific' and 'Informational' visualisation (Pilgrim, 2003). Scientific visualisation, according to Card et al. (1999), is an analytical physical based representation of the real-world's scientific calculations and computation using specified encoding techniques. Information representation, on the other hand, is an exploratory process of an abstract,

non-physical, and non-numerical based representation of concepts and ideas (like design visualisation). It is clear within an architect's design experience, there is a mixture and often a fusion between informational and scientific visualisation and in the process of reaching effective design decisions, both aspects should be addressed and represented in an integrated context. Some BPS applications (like Ecotect) started improving their methods of simulation data representation to accommodate its multidimensional nature (figure 2.3[B]). It could be argued that IPVs (discussed earlier in this chapter), attempt to address the multidimensional attribute of the simulation data (with both its scientific and informational attributes). The work done by Prazeres and Clarke (2005) for example uses multiple integrated '*interactive*' visualisation mechanisms with consideration to the temporal and spatial aspects of data.

Pilgrim (2003) argues that the key to effective representation of multidimensional data (scientific and informational) is through offering high level of interactivity. Virtual Reality (VR) applications -in the last decade- have become rich media for incorporating high levels of interactivity and effective information representation, as argued by Prazeres and Clarke (2003). They add that VR has the advantage to 'bring alive' the informational domain; by providing effective interaction to investigate and explore various aspects of informational virtual space. From a visualisation and data representation perspective, giving the users the opportunity to navigate with a high level of control and interactivity, can potentially break down the complexity of the imbedded knowledge, and subsequently ensure better comprehension of the presented information. The concept of 4D visualisation using interactive virtual environments has been adopted in many domains and professions, including GIS, medicine, biological sciences, and construction. Computer Aided Design (CAD) construction software (such as Autodesk NavisWorks[24]) integrates temporal data (generated from planning and scheduling applications) into the 3D model development process, so that the 3D visualisation is carried out with an additional temporal dimension, representing - using a clear integrated timeline- the phases of development in the proposed building construction (Figure 2.8). The potential for implementing an interactive virtual environment

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[24] Autodesk NavisWorks: http://usa.autodesk.com/navisworks/

as a means of simulation data visualisation is discussed in more detail later in this chapter, and in chapters three and four.

Thus it is a key requirement to incorporate a method of visualisation that addresses and satisfies the spatial and temporal dimensions of the simulation data, and incorporates the scientific and informational visualisation in a virtual interactive medium. Such visualisation techniques are of huge potential, and would face great acceptance from the design community, as they reflect on the geometric as well as the non-geometric entities of the design.
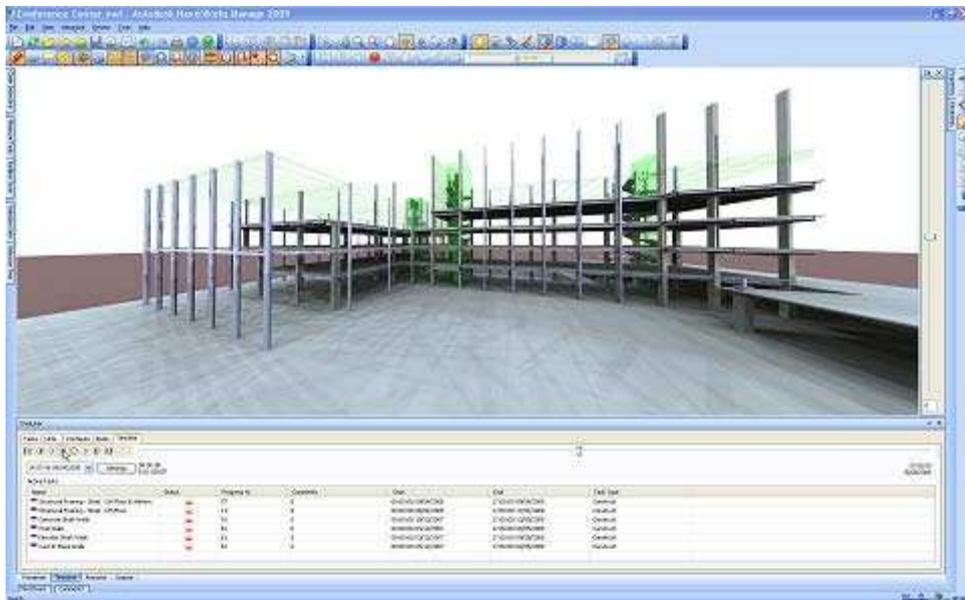
Figure 2.9: Example for spatiotemporal (4D) visualisation in construction
using 3D modelling and progressive timeline. Image retrieved from
Autodesk NavisWorks 2009.

2.5. Chapter Discussion and Summary

"*In simple terms the problem faced appeared to be one of translating the engineering/scientific concepts delivered through the precise language of mathematics for which exact answers to problems are implied, into design work, responding to a flexible brief where, at least in principle, there is an infinite solution set. Expressed slightly, more elegantly, a problem of building a bridge between a pedagogy based on logical positivism to one based on constructivist principles*" (Rutherford and Wilson, 2006, pp.262)

This chapter identified the current pedagogical and technical potentials and challenges for integrating sustainability and environmental parameters in architectural design curricula that is reflected in the use of BPS applications. In so doing, the chapter addressed the first of the main project aims outlined in the previous chapter, and subsequently its derived objectives. It started by discussing the designers' learning methodologies and approaches to problem solving, in an attempt to improve the process of moulding and integrating sustainability in these methodologies. Later on, it presented a taxonomy of the challenges that designers encounter when using BPS application, including those related to motivation, complexity of the interface, required input information, and the interpretation and correlation of the simulation data. In so doing, the chapter presented some case studies, surveys, and research frameworks that attempt to overcome some of the noted challenges, and exploit the potential opportunities for integrating sustainability into the design process. The next section of this chapter will summarise the literature findings into a set of conceptual requirements, constituting the base for the development of the proposed tool.

A key impediment for sustainability integration noted in the research carried out in this chapter -from a pedagogical perspective- is the design students' cognitive creative methodology of learning, which is clearly contradicting and even conflicting with the procedural analytical nature of sustainability. In other words, the analysis of building performance has not effectively been mapped to the design students' learning approach, and clearly doesn't fit with their cognitive schemata, as argued by Rutherford and Wilson (2006). They argue that environmental design lectures are structured linearly, sequentially, and rather technically, and thus they are "*rarely developing imagination, creativity,*

perceptual or spatial skills, thus such an approach has been deemed unsuitable for a truly integrated design-based program" (pp.264). Based on their teaching experience, Rutherford and Wilson also argue that studio tutors perceive the technical analytical nature of environmental design as an impediment and that this can be clearly reflected in their attitude in the studio and subsequently transformed to the students.

Szymkowiak (2003) also argued that the concept of sustainable design should be anchored through instigating an effective project-based teaching methodology that has the potential to win the acceptance and approval of the majority of design students. In an attempt to address this impediment, and building upon Szymkowiak's argument, Hamza and Horne (2007a) performed a study based on the integration of three modules (Design, visualisation, and energy consumption reduction) over three academic years. This study involved the coordination between staff responsible to teach these three modules (inter-disciplinary collaboration). The study attempted to involve the students in a unified project-based teaching methodology and refrain from modularisation. The study aimed to present and follow a pedagogic procedure that relates to the decision making process, thus allowing the students to effectively understand the implications of their design decisions. Hamza and Horne argue that integrating these modules could move students' knowledge to a more reflective, multi-structural, and relational level. Measuring the outcomes and/or success of this study was based on understanding the students' experience and monitoring their progression and improvement. This involved (besides the teaching staff's observation) utilising and analysing a semi-structured questionnaire for the whole cohort of students involved in this experience. This study yielded a set of conclusions:

- The way forward in preparing a solid base for young design professionals is to integrate the ideology of low energy architecture with the present design and visualisation modules, rather than appending it as a separate standalone technical module. Design and construction projects are rich central modules that can accommodate and incorporate other supplementary modules (like sustainable design).

- Design students are more motivated, and show greater interest in assessing their design models on a performance basis qualitatively. Simultaneous visualisation of geometric and non-geometric aspects of their design simultaneously is of greater interest, helping them to synthesize a number of features of their project (aesthetics, low-energy consumption, geometric masses and relations, etc.) into a whole single integrated model, and has the capacity to push students to a higher level of understanding.

- There is a growing need for inter-operable applications that have the capacity to assist students' learning and support the integration of the three concepts; design, visualise, and simulate. These tools can simultaneously pre-test both the visual and the environmental performance of the building at various stages of the design.

These findings, along with the reflection on the benefits, impediments, and challenges for integrating sustainability into the architectural design curricula -discussed throughout this chapter- formulate a set of conceptual requirement specifications that will constitute the basis and initial phase of development for the proposed learning support tool.

2.5.1.   Conceptual Requirements for the Proposed Tool

This section presents a compilation of conceptual requirements for the proposed tool, based on the preliminary research and investigation, including interviews with potential stakeholders (instructors, students, and researchers), as well as recommendations presented in number of research projects, case studies, survey and publications (cited and discussed earlier in the chapter). These are considered to be a higher (abstract) level of specification, which is different from the detailed functional requirements that are presented in Appendix A. Chapter five discusses the development of the proposed tool, and reflects on how these conceptual requirements are addressed and fulfilled in the proposed design of the tool:

CR1.   The proposed tool should be of a 'revelatory' nature, and guide the students and allow them to investigate different parameters and attributes of their design (allowing them to ask the right questions), and clearly present (and discuss) the

implication of any decision on the overall performance of the building. While the tool will have no direct role regarding the first BPS input information, the students can use the tool after their first iteration to get a better understanding of the preliminary decisions they have made and the related information they have used.

CR2. The tool should support the design students in understanding the cause-effect relationships, while recognising and reporting potential problems and pragmatic data patterns, along with highlighting the possible causalities for any noted problems. In so doing, the tool should reflect on the underlying physics and link to the principles and theories that were presented in the lecture, and walk the students through the whole process to the point of reaching an informed decision.

CR3. The tool should have the capability to rapidly assess decisions and their impact on the overall energy performance, through interrogative means with relevant discussions of 'what if' scenarios. This can be done through constant communication with the user in the form of reports and/or Q&A routines that form a narrative to the students' virtual learning experience.

CR4. The proposed tool should have a directive guiding nature, providing conclusive information and abstract knowledge that facilitates decision making. This can be done by utilising DM techniques for analysing the resultant data and extracting relevant knowledge that is otherwise hidden and need extensive work reveal and understand.

CR5. The tool should also be an effective DSS by presenting relevant zone-specific and building-specific design guidelines and strategies that, while informing the students of the rationale behind electing these strategies, can facilitate and guide them through effective decisions. The tool should attain a dynamic analytical capacity, while offering simple outcomes that resembles the guidebooks, but with higher specification and interaction.

CR6. The tool should utilise an effective method for the visualisation of geometric and non-geometric parameters of the students' proposed designs. The visualisation

strategies should accommodate and support designers, and facilitate the transition to and from their traditional qualitative aesthetical context of practice. The new tool should parallel "*the characteristics and logical relationships of the design process, and permits smooth transitions between domain-specific representations.*" (Yan and Jiang, 2005).

CR7.   The tool should use visualisation mechanism(s) that can accommodate both the conceptual cognitive visual nature design, as well as the multidimensional spatiotemporal nature of simulation data outcomes. It is thus recommended to use an interactive 3D virtual environment that can visually represent the different aspects of design (including the spatial aspect), as well as accommodate the simulation's temporal nature (the rationale for electing 3D virtual environments is discussed later in this chapter and in chapter three). The BPS outcomes should have a more qualitative dimension that supports the overall design direction, which is more essential at this stage than the accuracy of details.

CR8.   The proposed tool should an approach for 'simplicity' and 'abstraction, while offering a reasonable level of interactivity and interrogation (with simple and efficient user interface and intuitive interactivity mechanisms). High interactivity in a learning context will increase the students' sense of control as they will have freedom to exploit different aspects of their design. The interactive and visual nature of the proposed tool could positively affect the students' motivation and approach to use it, and subsequently getting a better understanding of environmental design entities.

CR9.   The tool should adopt a 'layered' approach similar to the methods utilised in the IPVs (Prazeres and Clarke, 2005). This approach presents information to the students in a hierarchical manner; abstract level as a starting point, and then the students are given the opportunity to investigate more according to their own preferences. This method is believed to be effective in preventing the students from experiencing overwhelming quantities of data and information at the initial level, which can clearly affect their motivation, understanding, and performance.

CR10. The tool should act as an eTutor; promoting a deep level of learning through formative assessment of the students' decisions with reflection to the theory and underlying physics, and presenting effective feedback to the users (in the form of reports and guidelines).

The remainder of the conceptual requirements, based on the literature findings from the following chapters are presented (along with the functional and technical requirements) in Appendix A.

2.5.2. Environmental Design and the Game Context

Yan and Liu (2007) argue that the design process involved adopting different concepts and strategies to formulate the design, and at the same time assess its performance. This process should attain a feasible sustainable and economical balance between long term cost and short term investment, leading to an overall compromised solution that can reach high level of satisfaction. They add that this process, in many aspects, is similar to a game play, and thus environmental design education can be easily mapped in a game's context. The temporal nature of the game can map that of the simulation process, presenting a more suitable medium for the representation of the sophisticated spatiotemporal data.

Attia et al. (2009), also argue that the successful utilisation of BPS applications as decision support systems (particularly in the preliminary design stages), required defining the simulation process as a 'social discipline'. They add that the simulation should comprise human-computer interaction with a reasonable level of information processing, while simultaneously providing an opportunity for exploring the design space and investigating its various entities. In this respect, incorporating design assessment criteria -in terms of sustainability and building performance- within a virtual 3D interactive narrative environment (like a 3D game) could prove quite effective and motivating to the students. In such an environment, students will have the capacity to investigate and visualise different features of their design, while obtaining feedback and evaluating their design. Many studies have been conducted to note the effect of the game as a motivating and engaging virtual

learning medium. Game, as a design-assisting learning tool, has great potential and huge benefit to design students in particular, as discussed in more detail in the next chapter.

Brooks (1986) argues that there are several advantages for adopting an approach where complex data is represented within a VR medium. A study by Yan and Liu (2007), concluded that utilising game-play to motivate design students towards learning and applying different aspects of environmental design has proven quite effective. The principle advantages lie in 'bringing alive' the information domain, through offering means of investigation within an interactive narrative context. It could be thus argued that games could be a powerful teaching tool if properly utilised for training design students various aspects of environmental design and sustainability, beside its fundamental role as an effective support context for designers. The next chapter looks more into the 'games' as a proposed integrated learning medium, and the philosophy, motivation and technology associated with such medium.

Chapter Three:

Games Technology & Education

3. Games Technology and Education

3.1. Introduction

"Games represent a new lively art, one as appropriate for the digital age as those earlier media were for the machine age. They open up new aesthetic experiences and transform the computer screen into a realm of experimentation and innovation that is broadly accessible." (Jenkins, 2005)

Rapid technological advance, notably in the last decade, in the fields of computer simulation and visualisation has facilitated the development and uptake of simulated virtual worlds as a means of exploring environments that currently do not or could never exist. Virtual worlds rely on engaging the user in a computer-mediated experience imitating real world effects and/or stimuli in an interactive narrative experience. 3D games have rapidly evolved to accommodate technological advance, and presented developers -as well as the public- with a chance to develop their own games to serve the requirements in a diverse range of disciplines including entertainment, simulation, training, and education. Being a pervasive concept in modern society, games have been the subject of research in many studies. These aim to point out the pedagogical benefits and advantages of games' application -as a philosophy, metaphor, and technology- in a learning context.

The previous chapter presented a discussion about the taxonomy of the challenges that architectural design students encounter when trying to integrate sustainability into their design process, along with the attempts, and directives to resolve these challenges. The discussion noted directives and calls for an integrated medium to accommodate simulation data representation and offer higher levels of interaction and interrogation. Some of these directives called for utilising an approach for employing VR technology and interactive virtual environments (like games), and highlighted the benefits and potentials of such approach. This chapter builds upon this notion, and investigates the 3D games context as a potential medium for the required interactive narrative virtual learning experience. It thus presents a rationale for electing 'games' as a philosophy and technology, to host this

research's proposed tool, in comparison with other standard contexts (like stand-alone desktop applications for example).

The chapter starts by probing the 'gaming' paradigm as a pervasive concept in society, particularly to adolescents, aiming to exploit the readiness of younger generations to accept games as a potential learning context. Following that, the chapter discusses the application of games in education, focusing on the notion of 'serious games', with its various aptitudes and potential opportunities to improve the students' learning experience. The chapter later presents a discussion about the use of games in architecture and design education, aiming to highlight and reflect upon some key requirements presented in the previous chapter, and present 'games' as the possible tool to accommodate these requirements. In essence, the chapter intends to address the second aim of this research (Aim B, outlined in chapter one), and subsequently its derived objectives.

3.2.   The Gaming Generation

"A society concerned with producing a fair number of creative and imaginative adults must protect the play modalities of thinking developed in childhood." (Bower, 1974, p8)

The games industry has engaged a diverse variety of users from all over the world, and the numbers are rising steadily. The swift progress in developing hardware with powerful processing capabilities, alongside increases in their availability and the decline in their cost, has enabled game developers to build games that are superior, professional, immersive, and engaging to the users (Moloney, 2002). Playing games, in recent years, has become a prevailing paradigm and a dominant pattern of life for many adolescents (as well as adults). Games have evidently become extremely pervasive in modern society. Immersion and engagement in games has become an integral part and an extension to the youngsters' lives, to the extent that some studies show that they spend more time on interactive digital media -particularly video games- than playing outdoors (Oblinger and Oblinger, 2005). Rapid technological advance, notably in the last decade, in computers' processing capabilities has led to substantial progress in the graphical and rendering qualities to the extent of achieving near-photorealism, as explained by Anderson et al. (2009). This encouraged games

developers to populate the games' virtual worlds with substantial amounts of high quality visual and graphical content, which combined with strong gaming narratives, positively affected the richness of the users' experience, and their degree of engagement and realism (Shiratuddin and Fletcher, 2007). Another factor affecting the shift of paradigm towards a more gaming generation is the diverse availability of different types of games reflected in the number of platforms for games' delivery; which include computers, consoles, online and social networks, tablets, and mobile gaming. These factors have attracted more and more players every day -particularly from the younger generation- and have ultimately affected many social, cultural, behavioural, motivational, and psychological aspects of living.

Interest in gaming is clearly reflected on the revenue and sales of computer games. According to the NPD Group[25], the games industry is the fastest growing industry of the last few years. It was worth -on a global scale- an estimated US$48.3 Billion during 2008, and expected to grow in 2012 to US$68.4 Billion[26]. The games industry revenue projected figures, and the compound annual growth rate (CAGR) are expected to challenge or even exceed revenues from other entertainment industries like movies and music (Figure 3.1).
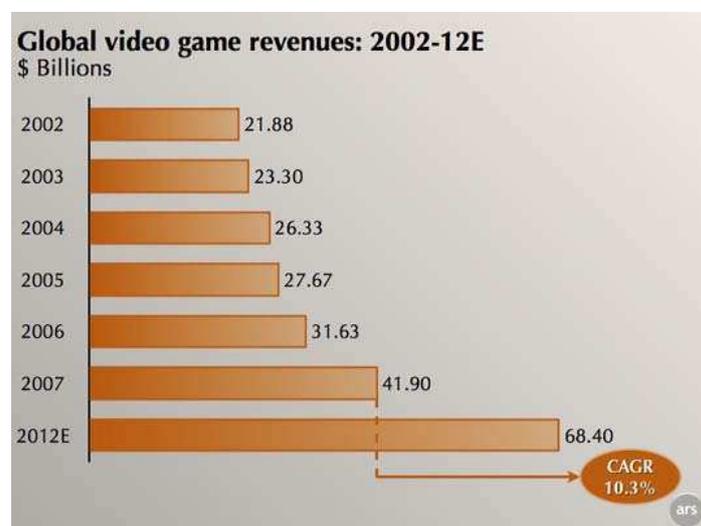
Figure 3.1: Recorded and projected global video games' revenue from
2002-2012. Source: PWC, Global Entertainment and Media Outlook.

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[25] NPD Market Research Group: http://www.npd.com/
[26] PWC, Global Entertainment and Media Outlook. http://www.pwc.com/gx/en/global-entertainment-media-outlook

The mounting attention that the games industry is receiving - according to Hoon et al. (2003) - can be brought back to the same means employed by the film industry (like the sophisticated sets, the storyline, the lighting and sound effects, and the elaborate overall production). However, the games industry has proven to have an edge over the film industry. This edge evolved from the interactive and interrogative nature of games providing the users with a similar (if not more intense) engaging and immersive experience to that of the movies, thus allowing them to *be part* rather than *be shown* or *be told*. Games have the capacity to build upon the users' imagination, allowing them to interact within a virtualised environment, to an extent of full control of the narrative structure in some cases. The keywords mentioned here -namely interactive, narrative, and being part- will be expanded upon, and investigated in more detail throughout this chapter, which aims to set the notion of 'game play' as an effective and potentially interesting learning medium and thus be embraced fully within the proposed tool.

The nature of gaming with all its mentioned attributes has been widely exploited in many industries and sectors (as discussed later in the chapter), particularly in training and education. Aguilera and Mendiz (2003) argue that "*adolescents with medium- or long-term experience playing video games show greater visual capacity, motor activity, and spatial abilities-reflexes and responses*" (pp. 6). Malone (1987) also argues that the ever-increasing popularity of video games, especially among the younger generations; place gaming environments as a potentially effective medium for knowledge transfer, skills acquisition, and delivering educational materials.

The effectiveness of games as a learning context is not solely dependent on the nature of the game, but also on the characteristics and mentality of the users (learners), and their willingness to embrace the technology and 'be part' of the experience. Prensky (2001) presented the characteristics of modern learners, labelling them as '*The Games Generation*'. This generation of learners have been adapted to the game-based learning techniques, as they are "*accustomed to the twitch-speed, multitasking, random-access, graphics-first, active, connected, fun, fantasy, and quick payoff world of video games, MTV, and Internet*" (pp. 64). In this respect, Prensky has distinguished between the '*digital immigrants*', who have just recently migrated to accommodate the use of digital technology in various aspects

of their lives -including education- and the latest generations labelled '*digital natives*'; who have grown up well accustomed to the technology, making it an integral part of their lives. Zyda (2005) supported this statement, adding that younger generations of learners have been exposed to games almost their entire lives. It is important to understand that universities are now admitting more and more of those 'digital natives', and this provides a valuable opportunity to capitalise on this fact and address the 'digital' mentality in the methods and approaches employed for educating this generation.

Having discussed the 'gaming generation', and their mentality and willingness to embrace games as effective learning environment, the following section of this chapter reviews and discusses in more depth the parameters, measures, and attributes of gaming that affect the effective application of games in an educational context, and directly influence the students' learning experience, ability to acquire knowledge and achieve learning objectives. This review will subsequently lead to formulating a clear directive that constitutes the basis for developing the tool proposed in this thesis.

3.3. Games in Education

The power and potential of games as a context and tool for learning and training has been exploited by many researchers -and educators- as early as the seventies and eighties of the last century (Malone, 1981). Since then, there have been a large number of case studies and research projects focusing on testing the effectiveness and success of games in education, and exploring the various aspects contributing towards this success. Squire and Barab (2004), for example, concluded that integrating game-play within the educational context promoted "*deep learning, hypothesis testing, strategizing, and appropriating content*". Aguilera and Mendiz (2003) also explain that, "*arguments in favour of the cognitive importance of video games are based on a number of studies indicating that many video games are conducive to the development of specific skills: attention, spatial concentration, problem-solving, decision-making, collaborative work, creativity, and, of course, ICT skills*" (pp.8).   Dondlinger (2007) adds that games directed for educational purposes promote "*strategizing, hypothesis testing, or problem-solving, usually with higher order thinking rather than rote memorization or simple comprehension*" (pp.22).

The benefits of utilising games for instructional purposes -as outlined by O'Neil et al. (2005) and Dondlinger (2007)- has been drafted along a number of axes; motivational factor for learning, interactivity, engagement by effective narrative structure, learning content, which is reflected into the game narrative, diversity of approaches to learning outcomes, and addressing cognitive and effective learning issues. This section will investigate in more detail these axes, their effect on the learning process, and how they can be effectively attained within an educational game. As the proposed tool is based on a game that moves beyond basic entertainment, the discussion starts by presenting the notion of 'Serious Games' – which the proposed game falls underneath-. The discussion will address the key differences in the fundamental design and implementation between this type and the conventional entertainment games, based on the axes mentioned earlier.

3.3.1.   Serious Games

The application of games technology -in recent years- has gone far beyond the sole purpose of entertainment, to serve rather more sophisticated purposes in a wider range of industries. This type of game is commonly known as "Serious Games". The term "Serious Games" was developed by Sawyer and Smith (2008) to collate number of terms that defined training games under one umbrella of gaming with a purpose other than pure entertainment. Before that, various terminologies were used to describe these types of games, for example, Educational Games, Games for Change, Social Impact Games, Games for Good, Alternative Purpose Games, and Advergaming. Zyda (2005) makes a clear distinction in presenting the definition and characteristics for both; 'entertainment/traditional/casual games', and 'serious games'. He defines the first as "*a physical or mental contest, played according to specific rules, with the goal of amusing or rewarding the participant*" (pp. 25). On the other hand, he defines serious games as "*a mental contest*" that utilises computing and gaming technologies and conceptualisation, in accordance with a modified set of game-play rules that reach beyond the purpose of entertainment to serve further institutional, governmental, corporate training, education, public policy, and/or strategic communication objectives.

Serious games, as mentioned earlier, have addressed a wide range of professions and domains. It is arguable that the scope of application of serious games is promising and limitless, and can extend to include all aspects that require training or information and knowledge exchange. Examples of disciplines that utilise serious games can include; healthcare and medical imaging (Sakas, 2002), experimental psychology (Frey et al., 2007), psychotherapy (Bouchard et al., 2006, and Robillard et al., 2003), military training (Potts, 2008), heritage studies and virtual museums (Lepouras and Vassilakis 2005), information visualisation (Kot et al., 2005), and human behaviour (Silverman et al., 2006).

Anderson et al. (2009) explained that serious games inherit key aspects of gaming that constitute their strong potentials. These aspects include facilitation of communication and collaboration mechanisms between users, visual representation of simulation data, advanced interactivity implementation, as well as the key aspect of entertainment. In this respect, some authors, including Zyda (2005) argue that although serious games have an implicit pedagogical foundation, careful consideration should be paid towards the implementation of the entertainment factor, to the extent that pedagogy should be secondary to entertainment. This opinion has been opposed by other authors, including De Freitas (2006), where they argue that knowledge-transfer is considered to be the basis of this type of games, and any attempts to contain it within an unnecessary entertainment framework could prove ineffective, unprofessional, and could deviate the game from its core objectives. However, specific criteria could be set to evaluate and assess the effectiveness of a serious game, which relate to the core objectives and rationale of the game design, and not solely to how entertained the players have been.

In general, there is a noted and clear distinction in the nature, purpose, characteristics, and attributes between entertainment and serious games. Many researchers (including Gredler, 1996; O'Neil et al., 2005; Zyda, 2005; De Freitas, 2006; and Derryberry, 2007) have conducted a number of studies and comparisons between the two types of gaming. It should be noted, however, that these comparisons were based on the general characteristics attained by most games of each type, and that there were evidently some exceptions to which these comparisons do not apply to. The results noted by these comparisons portray a clearer picture about the proposed tool as a serious game, and give a

clearer directive for the implementation of various games' aspects including gameplay, narrative, challenges, objectives, etc. The concluded results from the studies and comparisons can be summarised in the following points:

- *Goals*: These constitute the main purpose and objectives for using/playing the game. Both types of games (entertainment and serious) normally incorporate a hierarchical structure of goals. However, in trying to achieve these goals, entertainment games mostly utilise a linear goal structure, in which the accomplishment of one goal means that the player -with the game story- moves directly towards the next goal or set of goals. This also means that once a goal is achieved, it can't be revisited unless the player intentionally interrupts the game flow to 'reload' the corresponding part of the game. Serious games, on the other hand, don't necessarily adhere to this structure. In fact, most serious games follow a non-linear goal structure, where the players are free to elect the sequence of addressing the different goals set for the game. The goals also in this case differ from the first type, as they are focused on examining and/or achieving a desired output state, based on number of factors including the materials being presented, and the preferences and inputs supplied by the user within the experience (like virtual museums for example). The players are also free to revisit a goal after it has been accomplished, and apply modifications on the input parameters and examine the effect of this modification on the virtual experience without interrupting the game flow.

- *Rules*: These are the measures that manage and govern the players' experience throughout the game. Generally both types of games follow some constant rules governing the virtual experience, for example, game physics, collision detection, lighting, etc. The rules specified to entertainment games are the set of boundaries and parameters defined by the game's designer to control the users' experience, and make sure that they adhere to the narrative and the specified goals. In serious games, the rules are mostly a composite of the information and learning materials being presented in the experience. In other words, the rules can be seen as instructional measures that handle the knowledge exchange throughout the game's experience. The responsibility to structure the rules in a serious game fall primarily

on the information presenter (instructor in case of educational games for example), rather than solely on the game designer (who is still responsible for integrating the materials into the game events and narrative).

- *Narrative*: The unfolding story is integral in both types of games. In entertainment games, the narrative structure is mostly static and strict, following a specified path of nodes representing the story events. Although the game might offer alternative paths between specified nodes, this is done within clear boundaries in order not to affect the story. It is important in this type of game for the story to be pre-scripted in order for the game designer to incorporate dramatic elements that surround the events. In serious games the narrative is not necessarily static or pre-scripted, but it can be dynamically generated based on the information presented at run-time, as well as the players' inputs and preferences. The story in a serious game doesn't also necessarily follow a structural frame, but focuses more on a structure that can facilitate information presentation and feedback to the players. In this respect, there is not much reliance on drama to accompany the scenes and events of the story. Games' narrative will be discussed in more detail in the next section of this chapter.

- *The Play Metaphor*: In Entertainment games, the concept of play is fundamental, and constitutes the main motivation to use the game. Playing is set through a series of challenges and objectives strongly tied within a solid eventful narrative. Although some serious games (particularly educational ones) still incorporate the play metaphor to implement further motivational dimension to the game, most serious games incorporate 'play' as a representation of authentic cause effect relationship, reflected in the users' actions and reactions to the presented information or knowledge.

- *End Result*: In entertainment games, the flow of the story and events is normally terminated with either a winning or a losing scenario. In this respect, it can be argued that the ultimate goal for an entertainment game is to win, which can be either measured by reaching the end of the game and its story, or by comparing the scores of the players involved in the game's experience. Serious games incorporate

different implicit challenge types, leading to the ultimate objective of 'discovering causal relationships', and thus effective skills acquisition and knowledge transfer to the players. In this respect, there might not be a defined specified end to a serious game, but the story and experience can indeed continue to flow based on the users' preferences and input.

It can be thus concluded that 'serious games' can bring significant benefits to the educational process in particular. The nature and aptitude of this type of game can positively affect the drive and motivation for students to embrace the learning materials, and effectively improve their levels of engagement and comprehension. Throughout the remainder of this chapter serious gaming will be the main focus of analysis and review, as this research's proposed game (tool) lies within its boundaries. The review and discussion places the greatest emphasis on the educational value and potential of this type of game, and the fundamental aspects contributing to the effectiveness of using the games' virtual environments as a context for learning and knowledge acquisition.

3.3.2. Motivational Nature of Games

Several experiments and research projects have praised motivation as a key component of the game in relation to the educational context (Dickey, 2005). There was generally a common ground that the motivational aspect of a serious (educational) game, as argued by Dondlinger (2007), plays a fundamental role in students' approach, engagement, performance, and reaction towards learning materials. Denis and Jouvelot (2005) also explain that within an educational environment, motivation "*leads to the activation of efficient cognitive strategies for long-term memory issues like monitoring, elaborating or organizing information. On the opposite side, resignation and amotivation have negative results on memorization and personal development*" (pp. 463).

Some researchers link the source of motivation in a game to its compelling narrative structure coupled with a fair level of interactivity (intrinsic factors), which naturally captivates the audience and attains a high level of engagements with the unfolding story events. Dickey (2006) also explains that the careful structure of the game narrative, and not

the rewards system employed, is the main source of motivation. She explains that the degree of engagement in the game storyline promoted the user to develop their sense of challenge, fantasy, and curiosity. This in turn affects the general cognitive psychology of the student, their personal development, and the achievement of the overall learning outcomes.

Other researchers link the motivational aspect of games to the goal-oriented structure and the series of sub-objectives cast with multiple challenging nodes within the game (extrinsic factors), and thus physically and psychologically rewarding the characters (students) while still presenting the learning resources (Jennings, 2001). Denis and Jouvelot (2005) argue that reward-based motivation addresses the psychological and cognitive characteristics of the user, building effective strategies for long-term memory that affects the students' overall personal development. This is similar to Gee's (2003) achievement principle, where he explains that the learners' achievement within a game is related to the short-term and long-term intrinsic rewards attained on various levels of the games.

It can be argued, however, that the motivational factor of games is related to several contextual factors surrounding the game and its users, such as the overall objective of the game, the characteristics of the users, the nature of the learning materials, etc. In many cases, motivation can be a direct result of combining both; extrinsic and intrinsic factors. Denis and Jouvelot (2005) explained that effective educational games are based upon careful design and implementation of both intrinsic motivational entities that urges the users to act with a higher degree of freedom; and extrinsic motivation, this constituting the feedback or reward for their efforts. In this context, motivation can be seen as the integration between the desire to be competent and independent on one hand, and the pleasure of being one on the other (Dondlinger, 2007). Amory et al's (1999) findings suggest that games' players show more preference and higher levels of motivation when presented with a set of objectives that demand 'higher order thinking skills'. They add that these objectives should be contained within a carefully designed virtual environment (in terms of visualisation and communication of different aspects of narrative constituting the overall game objectives), that support the development of strategies designed to "*nurture creative problem solving and decision-making*" (p.317).

It was noted in chapter two that design students lack the motivation to integrate BPS applications into the design process, due to its relatively high technical nature which doesn't relate to the designers' cognitive schemata. In this respect, there were many calls for motivating students by moulding the use of BPS within interactive virtual environments (like VR and games) (Bambardekar and Poerschke, 2009; and Yan and Liu, 2007). It can be thus argued that the motivational nature of games can address this noted challenge through the careful design and balance between the intrinsic and extrinsic motivational factors. The game's learning environments can effectively accommodate the visualisation of qualitative and quantitative data, and motivate students by presenting this data within an appropriately designed gameplay. The implementation of the concept of gameplay, objectives and challenges, motivation, and feedback is discussed in more detail in chapter five.

3.3.3.   Interactive Narrative Structure

Amongst cognitive psychologists, Bruner (1990) highlights the importance of the 'narrative' as the means by which people's perception and communication are structured. Narrative is a notion that people are implicitly or explicitly well accustomed to, witnessing it in daily life which is populated with events, actions, and characters with intricate alterations within a clear timeline. In this sense, narrative structures have always been a significant entity exploited within educational contexts. A study by Dickey (2006) concluded that learning environments that comprise well-structured narrative presented the learners with 'a cognitive framework for problem-solving'. This is due to the fact that these environments offer the learners the opportunity to "*identify and construct causal patterns which integrates what is known with that which is conjectural yet plausible within the context of the story*" (Dickey, 2006, pp.2).

Many authors (including Fisch, 2005; Waraich, 2004; Dicky, 2006; and Laurillard, 1998) argued that the narrative structure is one of the most effective means by which the instructional message comes to be delivered and comprehended. Studies in cognitive psychology and cognitive development have led to a conclusion that people tend to remember things when presented in a narrative form, especially disorganised, unfamiliar

and ambiguous events. The narrative structure tends to stimulate the brain to either recall a mental model of similar events in order to make a decision about a forthcoming action, or to build a new mental model for recalling in future experiences. Dickey (2005) explains that learning environments incorporating narrative structures, relate to the students' real-world knowledge though building a visual metaphor. The strength of narrative is that it fills in the missing information and links or bridges entities and events in a casual relation where they are normally absent in non-narrative experiences.

Interaction, on the other hand, is the essence of the game. Crawford (1982) highlights the importance of interaction to the game, arguing that it "*injects a social or interpersonal element into the event. It transforms the challenge of the game from a technical one to an interpersonal one.*" (pp.7). According to Laurillard (1998), the idea of interactive media is based on the notions of "*lack of imposed structure*", and provides the user with increased "*freedom of control*". Swartout and van Lent (2003) also explain that effective games are those that integrate a high level of interactivity within a solid narrative.

Interaction is not only the means to reach this high degree of involvement in a game; the narrative structure also plays an integral part to reach this high level. Hence, 'Interactive Narrative' can be generally defined as "*a time-based representation of character and action in which a reader can affect, choose, or change the plot*" (Meadows, 2003). In a gaming context, interactive narrative can be seen as a story-telling approach, in which the users interact with the context of the story, in order to experience and be part of the events provided within carefully designed structures.

Unlike conventional Narrative media –like films and novels- in interactive narrative, according to Young and Riedl (2003), the user takes on the role of a character in the unfolding story, and is allowed -and in many cases encouraged- to perform actions that will substantively and dramatically affect or change the sequence of events in which the story is being played out. Users in this respect take part as active participants that have significant input on the experience and its general outcomes, rather than passive observers acting as sole spectators, which contributes to a more effective approach to strategies development and decision making (Bayon et al., 2003).

Although the interactive narrative coupling could have the potential of generating tension between the users' freedom and the restraints imposed by the game story (Juul, 2001; and Costikyan, 2000), the notion of interactive narrative have been widely praised and applied through various disciplines, and particularly in pedagogy. In an educational context, this form of interaction –coated in a solid narrative structure- leads to an even higher degree of 'Engagement', which is attained by involving the users in an effective virtual learning experience, where they are offered higher levels of investigation, reflection, problem-solving, reasoning, creating, decision-making, and evaluation of the presented learning materials. This degree of users' involvement and contribution provide learners with a sense of control over what they are experiencing (Hodhod, 2010).

For a virtual learning experience to be effective, it requires a careful balance between the narrative structure of the learning experience, and the level of interactivity offered to students. Swartout and van Lent (2003) argue that providing users with excessive freedom to interact with surrounding entities in a game can backfire and therefore render the whole experience boring and unchallenging. They add that users' perception to presented materials provided within an interactive media of entertainment or pedagogical characteristics (like a game), without a solid clear narrative structure was imprecise and questionable. This obstacle is normally resolved by presenting a "*storyteller*" or a "*narrator*" to impose a form of organized structure and control over the storyline. It can be thus concluded that the great control offered by interactive media, becomes useless and disadvantageous if it lacks an organized narrative structure (Laurillard et al., 1994).

In an educational game, the linear nature of conventional narrative is transformed within an interactive narrative into a non-linear (or meta-linear) nature, which is an engaged hybrid of two contradicting and yet complementary aspects, as discussed by Young and Riedl (2003). The first provides users with reasonable freedom to do whatever action they desire, or explore whatever areas they feel like exploring. Though this freedom offers students a high level of control over their learning experience, the threat is that it can distract the students and deviate them from the outlined learning objectives. Freedom, in this context, should be limited by boundaries that prevent distraction. The second aspect is preserving a structured storyline that addresses the general purpose of the interactive experience. In an educational

environment, this is where the overall learning outcomes are delivered and assessed. This aspect implies that the users are –more or less- constrained to experience this crafted story exactly as the authors (designers) intend, with reasonable amount of interactivity/control, and without deviation or variance.

Discussing and understanding the aspects and features affecting the effective implantation of interactive narrative structure is essential in the design of the proposed tool. Guidance from the afore mentioned literature suggests that the learning materials and knowledge gained should be integrated within a solid narrative structure and implemented into the game. This narrative is generated from two aspects;

- The first aspect is the story that the design itself with its various geometric, social, and cultural entities is telling. Porter and Sotelo (2004) explain that there is no design in silence, and that architects –either deliberately or not- like all their designed objects to tell a story. In this respect, every good design has a story behind it, and any design without a narrative structure is mute, dull, empty and rather dead. They argue that every design is defined by *"Social narratives that influence the behaviour associated with design spaces and objects"*.

- The second narrative aspect is that told by (or through) the building design performance. This mainly focuses on telling the story of how the proposed design is expected to perform once built and occupied. The data generated from BPS application is thus reformatted and presented as part of the narrative to the students during their virtual learning experience.

It is thus essential to understand that the success of an interactive narrative application is not just about incorporating various elements in a hypermedia application, but it is also about the implication of association, hierarchy and structure between these elements through a storyline. This should be accomplished in a user-centred manner that reflects the users' characteristics, preferences, expectations, and contribution.

3.4. Games in Architectural Design & Education

The visual and technical capabilities offered by a game, and the potential to construct virtual interrogative environments, have fundamentally changed the designers' approach to building design and visualisation. Shiratuddin and Thabet (2002) express that there is a growing interest in utilising games technology for a wide range of architectural applications that go far beyond the sole visualisation of building geometry. Von Borries et al. (2007) present a thorough survey and analysis of the use of games technologies within the architectural discipline, and the different sub-domains that can employ this technology to develop relatively more effective and reliable outcomes. These domains include games application for design collaboration and communication (Carrara and Fioravanti, 2007; Moloney, 2002), urban design and planning (Greenwood et al., 2009; Herwig and Paar, 2002; Gil and Pinto Duarte, 2008), environmental impact assessment (Loh et al., 2007), simulation of indoors and outdoors human behaviour and adaptation to the built environment (Yan and Kalay, 2006; Batty, 2001), cultural heritage studies and research (Lepouras and Vassilakis, 2005; Francis, 2006), form generation process (Belcher and Johnson, 2008), algorithmic design and autonomous architecture (Hoog and Wolff-Plottegg, 2008), and design education (Woodbury et al., 2001; Moloney and Harvey, 2004).

This section discusses the application of games in the architectural design context, focusing more on the educational and design visualisation aspects. It starts by presenting a brief introduction and discussion of the term 'Game Engines', which is the core of the games' technology. Later in this section, the pedagogical aspects of gaming in architecture are discussed, highlighting the potential and opportunities of incorporating this approach, with particular focus on 3D first person perspective of gaming.

3.4.1. Game Engines

A game's engine, according to Wunsche et al. (2005), is the core component of a video game that is comprised of one or more software modules integrating together to perform and handle various game-related tasks; including rendering geometries, lighting, sounds, networking, game physics, user interaction, games artificial intelligence, and collision

detection. The engine's software modules have the capacity to efficiently use advanced rendering methods, spatial data-structures, and acceleration techniques to generate high quality real-time texture mapped 3D objects, scenes, and worlds (Fritsch and Kada, 2004). The engine code comprises the basic framework of the game's technology, providing core re-usable software components for developers to build upon and/or manipulate.

Modern computer games, according to Kot et al. (2005) comprise two key components; game logic and game art, which are governed by and controlled within the game's engine. The game logic can take the form of a set of static or dynamic scripts, or a Dynamic Link Library (DLL) file, that controls the structure, hierarchy, and system architecture of the game. The game art is a set of visual attributes that constitute the users' visual experience in the game. The game art could contain texture maps, geometries, terrain, models, and/or interface components (GUI). The role of the game engine is to manage the structure and relation between the game's logic and art, and present the users with an experience tailored according to their actions and preferences.

Trenholme (2008) noted that game developers are not just keen about developing the game, but tend to provide some support tools and entities on top of the game. These entities might be separate from the game itself, like detailed documentation, the engine's source code, wikis, tutorials, support forums, etc. Some tools, however, can be provided with the game, like world/game/levels, and graphical script editors. These entities and tools give the end-users a chance to create specialised contents for their games, along with the opportunity to extend the game's capabilities by coding several complementary programming modules and implementing further functionalities, in what is commonly known as 'games modding' (El-Nasr and Smith, 2006).

One of the key initial challenges in the development of the proposed tool was to elect an effective game engine that could accommodate the objectives and requirements set for this project. The effectiveness of the elected game engine is based on two perspectives:

1. *The developer's perspective*: The engine should have the source code available and well structured, in order to facilitate the implementation of additional functional modules and game features.

2. *The user's perspective*: The engine should incorporate an effective and easy-to-use world editor; which is a CAD-like integrated application where the users import their models and adjust the game settings to their preferences (like geometric nodes properties, lighting types, materials, etc). In this respect, the adopted games engine should be able to easily and quickly communicate with the CAD tools that the students used to build their design models. In order to minimise the workload required from the students in every design iteration, where the proposed tool is used, the tool will include a template file which will comprise most of the default required settings (as explained later in chapter five).

The proposed tool presented with this research utilises the core technology (with both aspects; logic and art), that is built-in within the game engines' source code. The tool also takes advantage of the 'modding' feature of the game engines to implement additional modules that will incorporate the MAS structure and data mining techniques, which will be later responsible for analysing the simulation data generated from a BPS application and presenting the extracted knowledge to the design students within their virtual learning experience in the game. Chapter five discusses in more detail the basis and rationale of electing the 'C4 Game Engine'[27] for the development of this project's tool, and presents the system architecture controlling the implementation of the required additional modules upon the engine's code.

3.4.2. Interactive 3D Design Visualisation

As many aspects of people's lives depend on their ability to recognise the three dimensionality of the surrounding space (Dalgarno et al., 2002), it is important to maintain this manner of recognition in appreciating and comprehending the designs of the built environment, from its conceptual to final phases (Horne and Thompson, 2008). For many years, architects have relied on manual methods and software applications to be able to investigate their design in 3D perspectives. However, in the last decade, architects and schools of architecture have started -on a wider scale- to exploit interactive virtual 3D environments to enrich the design visualisation process, relying on the vast advances in

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[27] Terathon - C4 Game Engine: http://www.terathon.com/c4engine/index.php

technology and computer processing capabilities. This approach is gaining more ground and becoming increasingly popular throughout the architecture and construction disciplines. Shiratuddin and Thabet (2005), for example, explain that many architects have embraced the idea of assessing and presenting their work in an interactive narrative context, where they can explore many aspects of their design as virtual building occupants. Horne and Hamza (2006) add that supporting the architectural design education with interactive virtual environments (like games) leads to remarkable increase in students' engagement, and in turn offer better means for exploring concepts and ideas and communicating them. Tong et al. (2009) also argue that games technology has offered a chance -for the first time- to effectively interrogate and criticise un-built architecture over its finished state. They add that visualisation using games negates any aspect of 'artistic illusions' that could be implemented in earlier means of visualisation (like brushed perspective snapshot for example), and gives more focus and concentration on the core design elements. Maher et al. (2003), explain that the quality and immersive interactive nature of the virtual experience to investigate a proposed design concept, has clearly outweighed other traditional means of design representation and visualisation (namely 3D rendering and animations); allowing better comprehension, investigation, analysis, and experience sharing.

Although this section presents some examples of the clear and growing enthusiasm in applying virtual interactive means in the design visualisation (with particular interest to the pedagogical perspective), it has to be noted that this 'interactive' aspect is only complementing the traditional means for design visualisation and representation. In other words, interactive virtual environments –like those of games- can only augment paper-based design representation methods (like sketches and schematics), but can never substitute them. In fact, these sketches, as argued by Bouchlaghem et al. (2005), are the basis of ideas generation and upon which further/advanced means of visualisation (like 3D models, animations, and interactive walkthroughs) can be built.

From a pedagogical perspective, Mantovani (2003) argues that 3D virtual environments support experimental learning and have proven to be a rich and effective educational context. Dickey (2006) also concludes that 3D virtual learning environments have the potential not only to associate a narrative structure for situating and contextualizing

learning, but also to provide an enhanced sense of spatial reasoning, which go far beyond linear analysis. In another experiment carried out by Dickey (2005), it was concluded that representing geometric space and contextual entities in a 3D environment, and perceiving these elements in first-person perspective, enhances the learners' sense of presence, immersion, engagement, and collaboration, which accordingly improves the quality of learning.

In the design education context, more and more instructors are starting to encourage students to utilise games technology to improve their sense of understanding and relation to space. Burrow and More (2005) and El-Nasr and Smith (2006), for example conclude that virtual interactive 3D environments (represented in game engines) offer students the capacity to improve their learning experience through 'applied constructionist' techniques, where they can construct their own worlds in game engines, and start exploring their various spatial relationships, explaining that "*design and implementation of products are meaningful to those creating them and that learning becomes active and self-directed through the construction of artefacts*" (El-Nasr and Smith, 2006, pp.2). They add that such learning mechanisms have much greater emphasis on the students' critical thinking and evaluation than other conventional methods and mechanisms. The effect of such learning approaches has the potential to encourage students to think about their design more as a social and spatial experience than schematic drawings and a series of calculations, which clearly matches their cognitive learning approach. Shiratuddin and Fletcher (2007) report that the students' performance and the quality of the design produced are enhanced significantly when utilizing games development tools. They add that this effect can be related to the reality and believability of perceiving and assessing their own design with its geometric and spatial alignments in an interactive interrogative experience.

Lowe (2007) argues that applying games technology for educating undergraduate design students will enable them to endeavour on new approaches that will potentially broaden their design perspectives and capabilities. Hoog and Wolff-Plottegg (2008) present a case study for teaching architectural design within the virtual environment of "Second Life". They conclude that the manner in which the design briefs and instructions are provided to students has shifted from purely functionally focused to become more operational oriented,

in order to accommodate the new realm of design education. It is even noticeable that many 3D and CAAD application packages have accommodated the quality of the interactive narrative virtual experience in design evaluation, and evolved their interfaces to integrate more game-like features (like the case in Blender[28] and 3DS MAX[29]). In this respect, it is clear that 3D games don't just offer the technology required within the scope of this research, but also offer a more psychological aspect for education, and this will be explored in the next section.

3.5. Discussion and Concluding Notes

This chapter has discussed the potentials and values noted for the use of games technology in education in general, and within the architectural design community in particular. It has presented the basis and rationale behind electing such a medium to be the context that incorporates the mechanisms and technology required to host the proposed educational design learning support tool. From the discussion presented earlier in this chapter, it can be argued that using game engines -for the required purposes- offers great potential at multiple levels, including:

- *Educational Cognitive Psychology*: the application of games in an educational context has proven to be highly effective in motivating students to be involved in the learning process. The nature of games encourages students to participate in the learning experience as active participants rather than passive observers, which can promote 'deep learning' and higher levels of critical analysis and evaluation, as well as efficiency in decision making. Games demand that participants (students) build a strategy or hypothesis to proceed within the game, and develop the skills of observation, comprehension, and problem solving.

- *Design Visualisation*: Games offer higher levels of interaction and investigation, compared to other similar methods of visualisation, like 3D perspectives and animations. This is coupled with the ever-growing advances in computer processing

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[28] Blender: http://www.blender.org/
[29] Autodesk 3ds Max: http://usa.autodesk.com/3ds-max/

capability which enabled improved run-time rendering quality and increased sense of engagement with the virtual environment. Interrogating different aspect of students' design affords them a better sense of space, and understanding of different design components and their attributes and relations. Incorporating the visualisation potentials of games into the design development process has proven to be effective and hold great potential.

- *Technology for Data Analysis and Representation*: The technology offered by games (in the form of the engine code, as well as the capacity to accommodate endless functionalities and additional modules), presents a very rich and attractive medium to any educational software developer. Games is considered a powerful medium to incorporate and mould the educational data and knowledge into the narrative structure, ready to be experienced and investigated by the users.

- *Games Temporality*: Interactive virtual environments (like games) normally incorporate a temporal dimension. These environments have the ability to integrate a timeline in presenting stories/narrative/events at various periods and/or instances within the game experience. Genette (1980) argues that narratives are "*double-temporal sequences ... There is the time of the thing told and the time of the narrative (the time of the signified and the time of the signifier)*". This notion is clearly reflected in the games temporality as phenomenological/experiential and structural/descriptive events (Zagal and Mateas, 2010), in which the narrative structure relies on the 'non-identity' between the events themselves and the moment/time of their presentation (Juul, 2001). This is a notion that is clearly adopted in 4D methods of representation, which incorporate the temporal dimension to represent the change of events (data) along time. For design students in particular, the temporal nature of games can be considered a very effective feature. This is due to the fact that -as discussed in the previous chapter- they are more accustomed to the 2D and 3D methods of information representation, rendering the temporal aspect of the simulation data quite challenging to understand and deal with.

In this respect, using games technology as the basis of the proposed tool's development does not just offer a solution to resolve some key challenges for integrating sustainability and accommodating environmental design aspects in the architectural design studios (as discussed earlier in chapter two), but also adheres to the students' cognitive schemata and builds upon their knowledge and mental models. Messner and Horman (2003) argue that using 3D and 4D visualisation techniques (based on the temporal nature of gaming) offer students a valuable opportunity to effectively and thoroughly investigate multiple 'what if?' scenarios, and understand the cause-effect relationships between various domain entities, which was a fundamental requirement -raised in the previous chapter- for the development of the proposed tool.

A fundamental aspect of the proposed tool is to enrich the virtual learning experience with a solid well-structured narrative; i.e. to effectively incorporate the learning materials and required knowledge and represent them as and/or within the game's story. This aspect requires investigation into potential technologies and mechanisms to be able to attain the required results and ensure effective learning experience. In this respect, the next chapter investigates the potential for utilising MASs both as a technical module and an in-game embodied system acting as a 'communicator' or a 'narrator' to accompany the students throughout their virtual learning experience, and become the means for ensuring that this experience does not deviate from its original aims. The narrator is also essential for being a means of communication between the user and the system (game). This is coupled by using DM techniques aiming to gather and traverse through the generated BPS data in order to extract the relevant knowledge and present it to the users in their virtual learning experiences. Chapter five will later discuss the application of the pedagogical and technical concepts of games' technology in the proposed tool, and how this is reflected in the implementation of various features and functionalities.

Chapter Four:

Multi-Agent Systems

& Data Mining

4. Multi Agent Systems & Data Mining

4.1. Introduction

In the process of introducing and discussing the key challenges and pragmatic issues that design students encounter when using BPS applications and analysing the simulation outcomes (carried out in chapter two), two of the fundamental aspects that affect the users' understanding and decision making were highlighted. These are simulation data representation, and information extraction. The previous chapter has addressed the first aspect through discussing the notion of the 'game' as a proposed 3D virtual context that hosts the representation of information, in an attempt to satisfy the spatiotemporal nature of the simulation data. This chapter addresses the second aspect, through investigating the underlying technologies that are proposed and deemed appropriate for the scope of this project, aiming to extract the relevant information from the BPS analysis data (which could be quite substantial), mould it into useful knowledge, and present it back to the user.

Morbitzer et al. (2003) argue that building simulation exercises, particularly those carried out over prolonged periods such as annual simulations, have the capacity to generate significant amounts of quantitative data. The main objective of carrying out the simulation is to get an initial understanding about the building's behaviour and the key parameters affecting its performance. Hence, efforts to achieve this objective over prolonged simulation periods are "*often only carried out to a limited extent and simulation is therefore not used to its full potential*" (pp.911). As it is common for architects to assess/simulate the building's performance over as long periods as possible (Donn, 1997), the process has proved to be quite challenging, particularly for design students (as discussed earlier in chapter two). In this respect, there is a growing demand for a method that employs powerful technologies that can assist designers in processing and analysing the substantial quantities of simulation data, and render the embedded information into an abstract format (knowledge) that can be part of the decision system for design development. In this research project, the proposed technologies aiming to achieve this objective are 'Agent-based' technologies, with 'Data Mining' (DM) techniques.

Currently, agent-based technologies, as argued by Cao (2009), are being implemented and utilised in various domains for the purposes of learning, analysis, and simulation. The technology has been enriched even further in the past decade by integrating it with data mining techniques. Though the potential and capabilities of such technologies (MAS and DM) have been utilised to a great extent in current and recent applications (mainly focusing on the artificial intelligence and machine learning of a MAS, and the predictive analysis of data mining), the utilisation of these technologies within the context of this research project is set to a relatively smaller scope. As the target objective is to assist in the understanding of the knowledge embedded in the BPS data, and thus to support further decision-making, the utilisation of MAS and data mining in this context is set to only an interactive reporting descriptive nature -as explained throughout the chapter.

This chapter investigates the features, logistics, architecture, and technologies of both terms (MAS and DM). It starts with a broad discussion of the MAS concept, and then moves to discuss the application of MAS into the game's world, both as a supporting system architecture, and as a key aspect in formulating the virtual experience's narrative structure. The chapter later introduces the concept of DM, and discusses its role in the Knowledge Discovery Process (KDP). The chapter also presents some of the DM techniques that are utilised in the development of this research project's tool. Finally, the chapter discusses the potential of coupling and integrating DM with MASs, and how this can affect the outcomes of the simulation data analysis process. In so doing, the chapter targets the third main aim outlined for this research project, and subsequently its derived objectives (as presented in Chapter One).

4.2. Multi Agent Systems Technology

4.2.1.   What is a Multi Agent System (MAS)?

Many researchers, including Sycara (1998) and Lees et al. (2005), argue that there has been increasing utilisation of 'Agent-based systems technology' in recent years in various fields. Sycara (1998) explains that the reason for this is that agents' technology "*promises as a new paradigm for conceptualizing, designing, and implementing software systems*" (pp 79). In

general, the rapid advance in technologies has resulted in a progressively elevated level of complexity in systems' architecture and implementation, and in the overall problem domain. Thus, there has been a growing need for utilizing supporting technology (like MAS) that facilitates the whole process and attain the ability to handle such levels of complexity.

Based on compiling the definitions presented by Durfee and Lesser (1989) and Wooldridge and Jennings (1995), a MAS can be defined as an autonomous entity that is comprised of a set of multiple assorted and diverse software or hardware components (agents), that have the capacity to communicate and interact with each other and with the surrounding environment, aiming to achieve both specified and generic system's objectives. In a MAS, an agent can be viewed as a single, self-contained unit, that has the capacity to simultaneously execute a string of commands to achieve or maintain a specified state, and perform a set of defined tasks that are partial yet critical for the overall system. Each agent in a MAS has a limited viewpoint, based on the limited scope of capabilities and thus incomplete knowledge (Sycara, 1998). According to Jennings et al. (1998), agents in a MAS can be characterised as being:

- *Autonomous*: Actions performed by agents rely on their capabilities and scope of knowledge, as they do not depend on user intervention to stimulate or instigate their actions. Agent autonomy is about making their own decisions regarding what sort of activities to do, and when and how to do them.

- *Situated*: Agents are embedded, as part of the computational system. They act upon dynamic stimuli from the environment, and have the capacity to modify the environment based on the received stimuli and inputs.

- *Flexible*: Agents are highly adaptive to the surrounding entities and situations. Normally, agents are real-time entities responding to alteration in their system environment, and sometimes they can be proactive, where they exhibit opportunities and goal-related behaviour.

The ability of an agent in a MAS to perform its tasks is dependent on its scope, which could be restricted to knowledge, goals, computing processing resources, and general perspective

(Wooldridge, 2002). The prominent autonomous independent nature of an agent might be enough to perform the sub-tasks allocated, but agents still have to communicate and interact with each other to achieve overall system goals. Agents' interaction can be either cooperative or competitive (Siebers and Aickelin, 2008). Cooperative agents naturally collaborate, interoperate, communicate, and exchange information (normally via peer-to-peer message passing), thus increasing the problem-solving scope and achieving shared objectives. Competitive (self-interested) agents on the other hand attempt to exploit their benefits and dominate over other agents, thus normally a negotiation routine is implemented within agents' communication as part of the overall system objectives (Jennings et al., 1998).

MAS technologies have been widely applied and utilised throughout various fields and professions, including telecommunications, networking, financial analysis, business process modelling, mobile robotics, gaming, simulations, and general training and education (Bradshaw, 1997; Jennings and Wooldridge, 1998; and Cao, 2009). One field that is showing growing interest in utilising agent-based technology is architecture and the built environment. Some researchers, like Yan and Kalay (2005), have adopted a multi-agent approach to build simulation models for human behaviour in a proposed design, and how to develop the design based on the expected users behaviour and accommodations. Other researchers have investigated the use of MASs with machine learning strategies to develop an intelligent support system for promoting collaborative design (Beetz et al., 2004). MASs have also been utilised to simulate and assess the behaviour of various entities in a proposed urban space, thus investigating users navigational patterns, along with analysing spatial parameters in planning projects (Chen, 2009). Mo and Mahdavi (2003) and Lertlakkhanakul et al. (2008), have also adopted a MAS approach to develop models and tools for building system control and smart home automation. It can be argued, however, that the use of agent-based systems is still very much in its infancy, or rather experimental phase, and the full potential of this type of technology has yet to be reached.

4.2.2. Rationale for Utilising Multi Agent Systems

A multi-agent technology approach is elected as an appropriate method for the system development and implementation in this research project. The nature and aptitude of this approach can match the intricate nature of the BPS outputs, in terms of data analysis and pattern definition, as well as data representation. Lesser (1999) supports this assumption, arguing that computational environments where MAS implementation is appropriate, typically "have *a naturally spatial, functional, or temporal decomposition of knowledge and expertise among agents*" (pp. 3). In this respect, computational environments incorporating a high degree of intricacy, in terms of processing and/or information scope (like a BPS simulated virtual environment), could benefit from being structured as a MAS. The benefit of implementing multiple agents rather than a single omniscient agent in such environments affords the opportunity to simplify complex system objectives, and break down tasks (that could be rather problematic) to smaller supplementary tasks. Durfee and Lesser (1989) highlight the potential that a multi-agent approach could benefit the whole system's performance; as it increases the rate of task completion by performing tasks in parallel, and also as it increases the overall number of concurrent tasks (or sub-tasks) being processed by sharing the resources and knowledge.

Sycara (1998) adds that in terms of system development, management, and maintenance, a MAS offers a much simpler approach, due to the 'modular' nature that is produced from dividing the program into multiple functionally specific and modular components (agents). The modularity feature allows each agent to address its subset of the problem (sub-tasks), and use the most appropriate paradigm for that purpose. The broken down sub-tasks are delegated subsequently to the agents, which in turn cooperate and communicate in order to process, manage, and finalise all interdependent required tasks.

It is noticeable, however, that the autonomous and cooperative natures of the agents are inversely proportional (Alshabi et al., 2006). Increased autonomy in an agent means less dependence on cooperation with other agents to share knowledge (and vice versa). Thus it is important to carefully design the scope of knowledge and capabilities of every agent in the system, as it affects the overall interaction between agents and thus the performance of

the system. The knowledge and capability of an agent are initially designed and developed as independent components (modules), and are then allocated to the agents by system developers. This process was traditionally done using formal approaches and techniques based on games theory principles, market analysis and mechanisms formulas, or basic logical formalisation and philosophical patterns. However, there has been extended research into more heuristic approaches, mostly based on Artificial Intelligence (AI) implementation that can dynamically extend the capabilities and knowledge scope of the agent through real-time 'Learning' (Panait and Luke, 2005). In this later aspect, the MAS is known to be comprised of 'Intelligent Agents', that can interact with the surrounding system as well as the users and integrate their work, as argued by Lesser (1999). Intelligent agents have the potential to evolve and dynamically adapt their problem solving approaches to suit the ever-changing patterns and resources configuration in their environment.

It must be noted at this point that the design and development of the proposed supporting tool in this research is based on the traditional approach of cooperative MAS implementation, and not based on intelligent agents and machine learning implementation. This is accomplished through statically defining the set of rules and knowledge-base allocated to each agent, and thus the scope of their capabilities. Intelligent agents are not utilised in this project as the scope of service does not require their integration, and based on the requirements presented in chapter two, the developed technology is required to present the designer with focused relevant 'reports', gathered and formulated from different information resources, including BPS simulation data. Thus the scope of service for the required agents is limited to analysing and reporting information to the user, and thus there is no requirement for expanding their knowledge or capabilities outside that scope. In essence, the MAS in this thesis proposed tool is designed as an independent modular system that resides on top of the elected game engine's source code. The MAS in this research's tool is itself structured of multiple independent interoperable data aiming to 'retrieve' and 'analyse' all available geometric and non-geometric data (inputs), and 'report' any findings back to the students (outputs) through the game's engine's virtual world and/or interface. The structure and architecture behind the design of the proposed tool's MAS (including agents' taxonomy, scope of knowledge, capability, and scope of services) are discussed in details in the next chapter.

4.3. Games' Multi-Agent System

So far, the chapter has presented a discussion about the concept of MASs, and their technical utilisation as an integral modular part in the system architecture. However, technicality is not the only motivation and justification to implement and use agent technologies in a proposed system. It is arguable that MASs have a meta-technical perspective, which directly affects the virtual environment and the overall user's experience. The following section discusses the principles of using agents' technology in games in general, and the role they play in enhancing the virtual experience in terms of narrative structure and information reporting.

The computer games industry has witnessed extensive demand for the utilization of agent-based technology as part of both the underlying system architecture, as well as the interactive virtual world. Fielding et al. (2004) argue that agent technology is in the midst of rapidly growing gaming 'explosion', from games as simple as chess to much more sophisticated 'Massive Multiplayer Online Role Playing Games' (MMORPGs). Advances in processing capabilities combined with the falling cost of hardware, and the search for enhancing believability and sense of presence in games have motivated developers to exploit advanced techniques within their games. Lees et al. (2006) explained that MAS are currently utilised in games -in general- to achieve higher levels of objectives like generating real-time responses, dynamic data and information processing, handling multiple complex and/or conflicting goals, and adding improved emotional and social dimension. The modular nature of MAS entices developers to prefer this agent-based approach of development over adopting a singleton omniscient agent approach, or relying basically on the infrastructure of the game engine. This nature also provides the developers with a chance to scale, transfer, and reuse their agent code over a number of games. Moreover, agents can contribute improving the overall gaming experience (in a meta-technical aspect), through formulating narrative structures that can handle unscripted dynamic real-time activities, as well as contributing in the game world as Non-Playing Characters (NPCs) for reporting information to the users.

4.3.1.   Multi Agent Systems and Games' Narrative

Many game developers in recent years have resorted to exploiting MASs as a method for formulating and enhancing the narrative structure of their games. The motivation behind employing this approach is the growing requirement to extend the boundaries of user interactivity within the game's world. Tallyn et al. (2005) argue that although an interactive narrative is the core of any effective game, there is, however, an inverse relationship between the level of interactivity offered to the players and the control over the narrative structure. They explain that the pragmatic aspect of interactive narrative temperament of a game lies in the fact that the author's management of the narrative techniques is abridged if more and more interactivity is offered to the participants.

MAS, however, was not the only path taken to address the interactivity against narrative problem; several other approaches and strategies have also been attempted. One approach has been to set a pre-defined strictly scripted storyline that the users have to adhere to, one that has very limited flexibility whilst giving the players the illusion that they are controlling the game (Young, 2001; and Greenhalgh et al., 2002). Another approach has been to instigate sequential story paths that are determined by specific game objectives, where all these paths have the same start and end-point for the presented storyline, and where the number of story paths created is related directly to the level of interactivity offered to the players (Stappers et al., 2001). A third approach is to have developers manually restructure the level of interactivity and/or the storyline at run-time depending on the players' preferences, inputs, and activities (such approaches commonly employed, for example, in MMORPGs). Though there are attempts seen in many commercial games, where more than one of these strategies are employed (Tallyn et al., 2005), these methods have still been proven to lack a degree of flexibility, have little consideration to users' interaction, and negatively affect the sense of simulation as they are estranged from emulating real-life activities, as argued by Madden and Logan (2007). In the proposed tool, where the narrative is open-ended, and dynamically generated -based on the building design and the simulation data represented at the game's run-time (as discussed in the previous chapter)- such approaches will fall short of achieving the desired efficiency in the narrative structure, and thus a MAS approach would be potentially more effective. MAS technology is, to many

developers, a considerably more effective approach, that has many benefits and advantages over other strategies, including:

- Higher degree of believability, generated from an improved sense of real-life emulation.

- Higher degree of interaction offered to the users.

- Greater flexibility in the narrative structure of the game, as the agents reform the storyline according to the users' inputs and interaction.

- Real-time response to dynamic environments.

In this format, the agent-based system not only becomes a complementary part of the system, and a sole facilitator of task achievement and information processing, but also the architect of the users' narrative experience within the game. Having a powerful narrator in the game enriches the users' virtual experience and gives them more control with higher degree of interactivity and engagement. Thus, it is clear that one of the agents' roles is to formulate narratives in interactive virtual environments, based on data and information provided within (and from outside) the game world, which is the case in the proposed game, as discussed in the next chapter. The storyline of the users' game is no longer sequential or pre-structured (no longer conventional linear narrative); it is dynamically scripted according to the players' actions, decisions, strategies, and preferences. The agents in such context are fundamental part of the narrative structure, and are perceived as fictional personas (embodied or hidden), that are integrated within the game. They are responsible for receiving, processing, and presenting information in the virtual environment, in what could be referred to as 'narrative voices' (Tallyn et al., 2005).

The MAS approach to structure the narrative of a virtual experience may not always be considered optimal. Most commercial games do have a pre-designed and scripted storyline, and thus the use of MAS won't be needed. However, in simulation games (The Sims[30] for example) a MAS is quite important, as the story is open-ended and could indeed take any possible turn. In the tool developed within this research project, the storyline is not based

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[30] EA Games, "The Sims": http://thesims.ea.com/

mainly on events occurring in the game world, but rather on the data that is provided from various internal and external resources. This data indeed constitutes the narrative of the game, in that it tells the user the story of the building, the aspects of its performance, and the strategies to improve the design to suit the energy performance (as discussed in chapter two).

For a MAS to be effective in structuring the narrative within a game, the key principle of 'embodiment' should be considered (Logan et al., 2002; Fielding et al., 2004). Embodiment in a game means that agents who are responsible for presenting and exchanging information within the game world, should be directly situated in the game's virtual environment, and share the virtual space with the participants (for example, being an NPC in the game world). Madden and Logan (2007) explain that embodiment offers the participants an 'integrated interface', allowing the agents to directly communicate with the players, and be subject to the same constrains and influences that they are subjected to (Figure 4.1). It is important at this stage to distinguish between the two terms 'embodied' and 'embedded'; embodied refers to having a physical presence, and being a graphically distinct entity of the virtual world, while embedded refers to a computer system that is integrated within a bigger system, and as such assigned with specified tasks within a limited scope of capabilities and activities. In this sense, game/software agents in a MAS can be characterised as embedded, but not necessarily embodied.
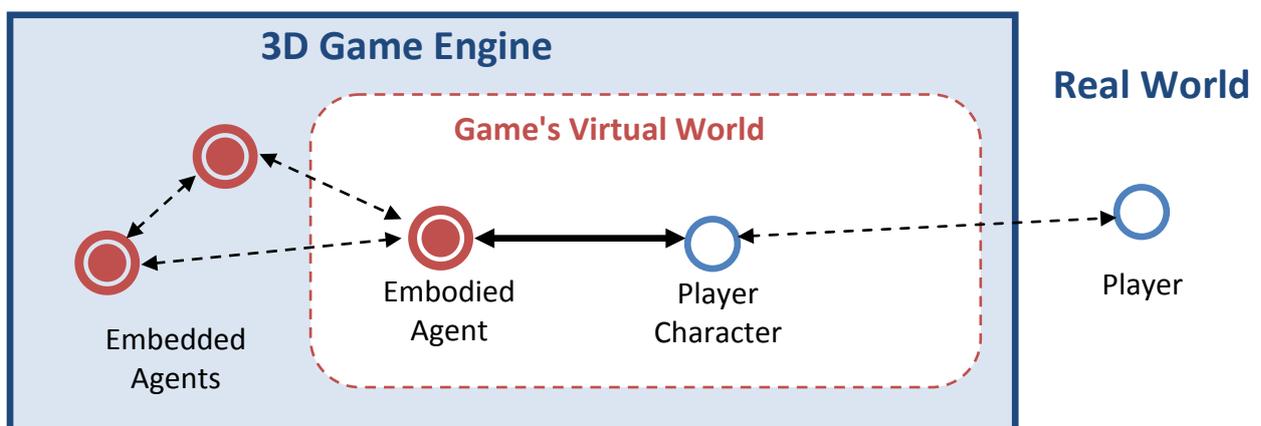
Figure 4.1: Embedded and Embodied agents in a MAS, and communicating with the player, based on the structure presented by Fielding et al. (2004).

Blumberg and Galyean (1995) present an approach to handle agents' activities and responses through managing their behaviour. Their approach is based on arranging the set of possible behaviours in a hierarchical fashion, dynamically electing agents' actions based on the assessment and competition mechanism that traverse between behaviours. This approach requires an initial declaration of sets of rules and regulations in the system architecture that can manage the behaviour assessment process and activity election. The request for information presented by the user generates specified agents' behaviours and activities, which in turn constitute the narrative structure of the game. However, the users' requests demand the agents to adopt specific mechanisms for allocating, processing, and reporting data, based on the concepts of data mining, which are discussed in the next section of this chapter.

4.4. Integrating Multi Agent Systems and Data Mining

After electing MAS as a potential technique for the proposed tool's system architecture, as well as the moderator for the users' narrative experience in the game, it is important at this stage to discuss how the agents will actually manage the information that will formulate the narrative structure. As highlighted in chapter two, a central problem in analysing BPS outcomes is interpreting, and correlating the data to extract useful information that will guide the designers to make further effective design decisions. However, the different variables that should be considered in this process as well as the amount of data generated, especially over long periods like annual simulations, makes extracting the required information quite a challenging task, particularly for design students. In this respect, there is a need to adopt a technique that can facilitate the interpretation and correlation of data, in an attempt to present abstract useful 'knowledge' back to the user. In this research project, the method proposed to achieve this is based on the integration between MAS and DM techniques. The following sections in this chapter discuss in more detail the concepts and techniques of data mining, and its role in the KDP.

4.4.1.   What is Data Mining?

"*There is an urgent need for a new generation of computational theories and tools to assist humans in extracting useful information (knowledge) from the rapidly growing volumes of digital data*".(Fayyad et al., 1996, pp. 37)

Kantardzic (2002) argues that in modern science and engineering, there is currently a notable paradigm shift from classical modelling that is based on 'first principle' analysis (using standard laws and equations), to modelling based on direct analysis of large, complex, information-rich data sets, that derive further substantial development decisions. In this context, many researchers, including Fayyad et al. (1996), Kohavi (2000), Hand et al. (2001), and Han and Kamber (2001) explain that the increased volumes of data generated are too much to be handled by conventional exploratory data analysis methods, thus demanding the development of advanced and powerful mechanisms for data interpretation and summarisation (through visualisation for example). This aims to identify significant patterns, trends, and relationships, and thus make solid decisions based upon the knowledge gained. DM techniques were some of the popular mechanisms that have been introduced for that purpose. As Han and Kamber (2001) explain; "*Data mining can be viewed as a result of the natural evolution of information technology*" (pp.1).

DM is also popularly known as 'Knowledge Discovery in Databases (KDD), Exploratory Data Analysis, Data Dredging, Data Driven Discovery, Knowledge Extraction, and Deductive Learning (Dunham, 2003). It can be defined as the process of extracting nontrivial, embedded, unidentified and potentially effective information from large stored sets of data (Fayyad, 1996; and Zaiane, 2004). Kantardzic (2002) adds that DM is itself an "*iterative process, within which progress is defined by discovery*". The process uses the term 'Mining', with reference to the more familiar process of rock mining to extract vein and valuable ore, as explained by Zaiane (2004). Both processes involve sifting through significantly large amount of resources and cleverly examining them to precisely identify the location of valuables and extract them accordingly. In this sense, the DM process performs sifting, identification, examination, and extraction through employing sophisticated analysis mechanisms to highlight relevant patterns and relationships in the raw datasets that might

be quite challenging to extract using conventional analysis methods, especially in large extended data sets like those generated from BPS applications. The employed mechanisms include mathematical algorithms, statistical models, and in some cases machine learning algorithms.

DM, as argued by Han and Kamber (2001), Kantardzic (2002), and Cao (2009), has attracted substantial interest in the information industry and decision support community, in both the public and private sectors. While it is still considered in its infancy, data mining is ubiquitous, and increasingly becoming a popular trend. The process can be employed by organisations in applications serving many fields including market analysis, retail, manufacturing, business forecasting, telecommunication, web mining, medical research and healthcare, insurance, transportation, investment strategies, law enforcement, national security, fraud detection, and terrorism prevention. DM has also been introduced in recent years as a potentially effective method to facilitate learning through online resources and virtual learning environments (VLEs), as discussed by Gaudioso (2005) and Pahl (2006). DM is thus deemed as a potentially powerful mechanism that can be adopted and integrated with MAS technology (as discussed later in this chapter) in an attempt to facilitate BPS's data management and representation within the proposed supporting tool.

4.4.2. Data Mining in the Knowledge Discovery Process

To employ DM as a technique in environmental data handling and management, it is important to understand the whole process of knowledge discovery, and the role of DM as a critical step in this process. Currently in database research arenas, the information industry, and in the media, the term 'DM' is gaining more popularity and dominating over the more generalised term of 'Knowledge Discovery' (KD), to the extent that they are frequently treated as synonyms (Han and Kamber, 2001). However, in technical terms, data mining is actually one part of a long iterative knowledge discovery process (Figure 4.2).
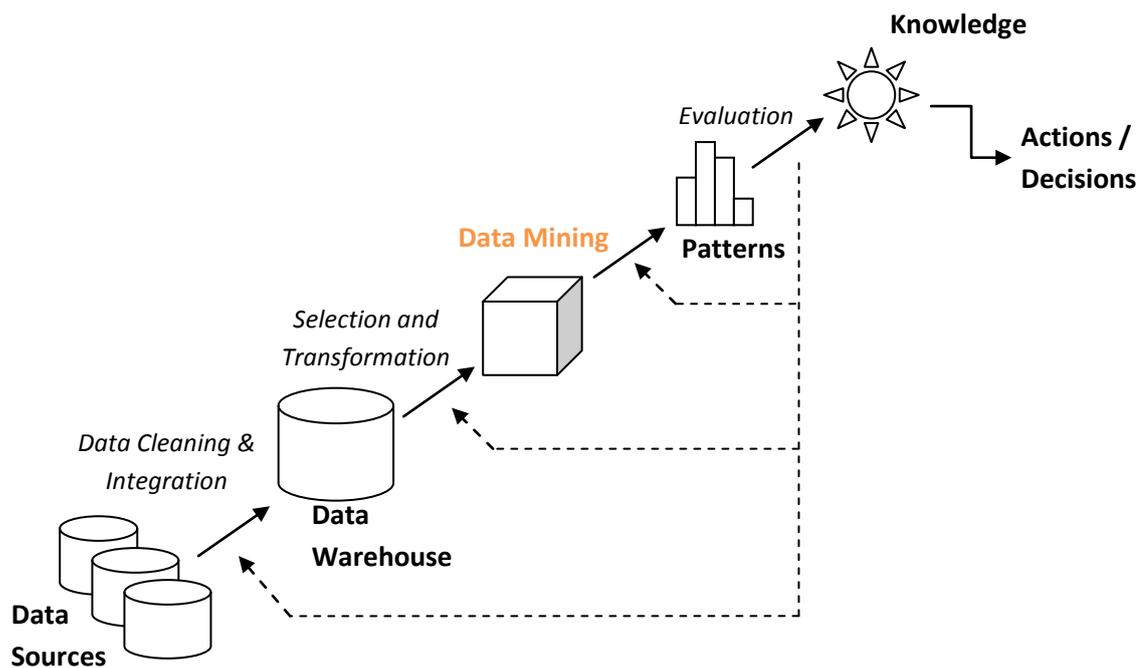
Figure 4.2: The KDP, including DM as a phase in the process. (Derived from Han and Kamber, 2001).

The diagram representing the KDP comprises a number of steps concerned with dealing with data; ranging from its primitive raw format residing in multiple (distributed) resources, to the final representation of specified data that form user's knowledge. The process consists of the following phases (as explained by Han and Kamber, 2001):

1. *Data Collection*: This phase identifies the resources (databases, file repositories, diagrams, multimedia, humans, etc.) that need to be addressed to start gathering data from.

2. *Data Cleaning*: also commonly known as 'Data Cleansing', it involves refining the collected data and clearing any 'noise' (irrelevant and out-of-scope data) and any inconsistencies. In some cases, this phase involves some reformatting of data to facilitate further storage and processing.

3. *Data Integration*: At this level, cleaned heterogeneous data collected from multiple resources is combined and stored in an intermediate repository, commonly known as 'Data Warehouse' (DW).

4. *Data Selection*: At this step, specified sections of data are elected and retrieved for processing and further analysis, based on measures and rules specified by the application, the developers, and the users.

5. *Data Transformation*: This is a transitional step, where selected data are consolidated and transformed into an appropriate format that is suitable for the following mining procedure.

6. *Data Mining*: This is the most critical step in the whole process. It is based on specified algorithms and defined rules that govern the criteria of mining. The purpose of this phase is to identify and extract potentially useful patterns that can formulate the desired knowledge.

7. *Pattern Evaluation*: In this phase, the data mining outcomes are reassessed and filtered according to some (statically or dynamically) defined '*interestingness*' measures (Zaiane, 2004).

8. *Knowledge Representation*: This is the concluding phase of the process, where the compiled, refined, and filtered data are visually represented back to the user to help interpret the results and proceed with further decisions.

It is common in developing a Knowledge Discovery system to combine more than one of the mentioned phases, as argued by Zaiane (2004). 'Data Cleaning' and 'Data Integration', for example, can be merged together in one pre-processing phase, preparing data from its raw format to be suitable for storing in the DW. It is also very common to consolidate the 'Data Selection' and 'Data Transformation' phases, depending on specified factors like the size of the DW, and the amount of rules regulating the selection process.

Knowledge discovery is generally an iterative process, particularly when formulated within an interactive virtual environment like a game. User involvement and interaction in the game define dynamic measures and rules that ultimately address an earlier stage back in the process. Changing the KDP rules can be either simple and direct, affecting the pattern evaluation only for example (like changing the date and time parameters in the game), or it can be deep and sophisticated, demanding the iteration to revert back to the earlier stages of the KD process (like making a design decision).

One of the most important steps in the KDP is collecting consolidated data into a central DW. Zaiane (2004) defined data warehousing as a process where noise-free heterogeneous data (which is extracted from multiple resources) is stored in a specified repository. The repository in this case is commonly referred to as a 'data warehouse' (DW), although in some cases -when the scope of stored data is comparatively limited, or when the data is customised into subsets- it can be referred to as 'Data Mart'. According to Hoffer et al. (2010), the DW can be characterised by being subject oriented (based on a specified domain), integrated, and time variant (can handle trends and changes). It acts as a centralised point of reference where the run-time queries always refer to in order to extract filtered formatted data, rather than addressing multiple distributed recourses for obtaining data in its raw format.

4.4.3.   Data Mining Types and Techniques

After reviewing the KDP and the role of DM in this process, it is time to discuss and reflect upon the techniques employed by DM for extracting valid information (Knowledge). Before discussing the techniques, it is important to understand that knowledge discovery DM is practically split into two types, each representing a separate set of objectives for the process, as discussed by Kohavi (2000) and Dunham (2003). These are presented in Figure 4.3, and can be summarised as:

1. *Descriptive Data Mining*: This is considered the passive type of data mining. This type is solely concerned about defining relationships and describing patterns in subsets of the available data that could be more comprehensible to the users. For example,

defining the periods where the indoors conditions in a particular zone are out of comfort range, and relating this to subsequent analysis data to present possible causalities. By understanding the underlying patterns and data relationships, users could make further justified decisions based on a more profound basis.

2. *Predictive Data Mining*: Unlike descriptive data mining, this type is considered rather proactive, in that it doesn't just define the currently existing data patterns, but foresees how these patterns would evolve and develop in the future. This type of data mining is commonly used in fields like financial forecasting and marketing. Though it is quite promising, this type is much more difficult to develop and implement, as it utilises analysis tools and algorithms that are more sophisticated; considering that any simple error in the analysis can cause a series of faulty predictions and thus flawed decisions.
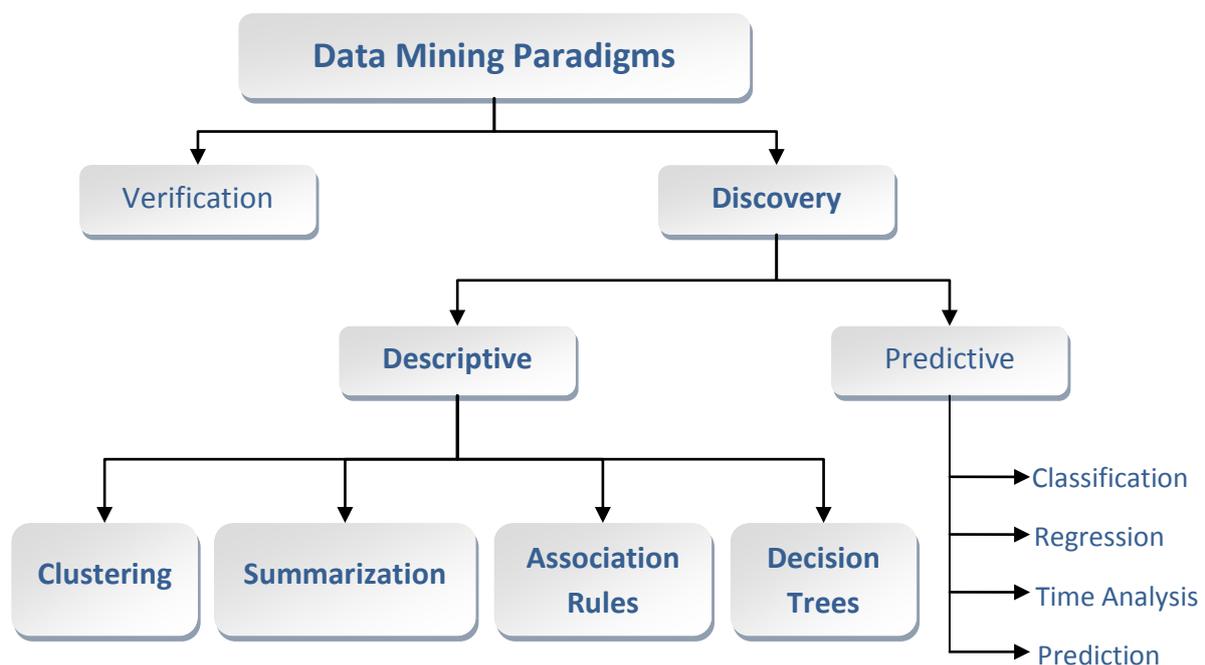
Figure 4.3: The paradigms and taxonomy of Data Mining Techniques.
(Derived from Dunham, 2003).

In developing the tool presented in this research project, only the first type of DM is considered. The reason for not using 'predictive data mining' is that the data available are

mostly static, generated from a series of calculations in the building's energy performance simulation process over a specified period of time (a year for example). The concern in this research project is extracting the knowledge embedded in simulation data, and presenting it (when needed) to inform the design students and assist their future design decisions. In this context, the 'descriptive' type is more suitable and appropriate to the tool's objectives, as future data patterns prediction is out of the scope of this study.

The following list presents some of the techniques used in the descriptive data mining process -based on Han and Kamber (2001), Dunham (2003), and Zaiane (2004)- and the suitability of their application in this research project domain:

- *Summarization:* also commonly denoted as '*Characterisation*'. In this mining technique, various stages of abstraction are applied on a set of relevant data (specified according to user interaction) to extract the generic features or essence for these data. In order to be able to accurately label the mined abstracted data, some metrics should be considered in parallel to the summarization process, to help formulate accurate rules. For example, setting characteristic rules for overheated periods in a thermal zone during a specified day, where the metrics associated with this case is the range of comfort temperatures. In this respect, the summarization mining technique is deemed suitable in presenting instant real-time zone briefs, as well as presenting more detailed (on demand) daily, monthly and yearly zone reports.

- *Association Analysis:* This is one of the key mining techniques that attempts to uncover relationships amongst data sets. It aims to discover what is known as 'association rules' that refer to the frequency of specified entities occurring together in a given set of data. For example, determining an association rule for linking wind speed, wind direction, and air change rate. In this sense, this technique is deemed suitable for attempting to correlate BPS analysis data to find possible problem causalities. Although this is a commonly used technique, it is known to have some disadvantages. As this technique is based on correlating data to determine rules, there is a possibility that it will produce many redundant association rules, and thus

needs further processing to filter these rules. This can be managed by defining some preset formulas and algorithms that can assess the rules instantly at run-time, and filter the appropriate ones to be presented to the users. Another issue that needs to be considered is that the generated rules are only pointers in an abstract form, and can be considered rather tentative. Thus further validation for these rules might be required.

- *Decision Trees:* This is one of the most commonly used techniques in data mining. In some cases it can be applied as descriptive DM and in others it is used as a predictive technique. As its name suggests, this technique is based on a hierarchical pattern of flow and branched rules assessment, till reaching the lowest level of the tree (a leaf node) where all questions are addressed and a decision can be made -similar to the 'Twenty Questions' game (Dunham, 2001)-. In descriptive DM, decision trees must assess predefined rules sets (normally defined initially by the developer, but can sometimes incorporate users' interaction and feedback at run-time), that manage the transition from one node to another in the tree. In this respect, the decision trees technique is deemed very suitable to manage the interrogation routines between the game agents and the players, as well as generating a set of design strategies and guidelines to assist the decision-making process to improve the design and thus the performance.

There are many other DM techniques that are widely applied in various fields and application. These techniques include classification, clustering, regression, discrimination outlier analysis, time analysis, evolution, and deviation analysis. However, these techniques were not considered in the development of this project's tool, for many reasons, including their suitability to desired objectives, the scope of outcomes, and the complexity of implementation. It is quite common to use more than one mining technique in a single system to achieve different objectives for data analysis. It is also not uncommon to integrate more than one technique to achieve a single (often higher level) objective.

As powerful a technique has DM proved to be, there are still some pragmatic issues that must be considered and addressed in an attempt to facilitate the process and improve the

quality of the generated outcomes. One of the key issues is communicating the mining outcomes back to the users, again raising the question of data representation. Since DM is an iterative process, it is very common for there to be constant dialogue with the users, which means that interaction is another critical issue, as it allows the users to refine the mining tasks, and set further rules that manage the process. Thus designing an effective method of communication and interaction between the system and the users is fundamental to achieving acceptable results and generating the desired 'knowledge'. A proposed method attempting to achieve an effective level of communication is through integrating MAS with DM, which is discussed in more detail in the next section of this chapter.

4.4.4.   Coupling Data Mining and Multi Agent Systems in BPS Analysis

During the analysis of simulation data, designers and design students constantly attempt to define specific problems or potential aspects that could directly affect the design and building performance. In this process, designers investigate the calculation outcomes in the manner they are presented in the BPS application most likely in the form of numerical data in tables, graphs and charts, and sometimes 3D representation. Some required knowledge can be derived instantly and directly from these representation formats, answering surface levels of questioning. However, deeper levels of questioning require the analysis of several parameters and compound data sets, that could vary significantly along different periods of the simulation. This means that the simultaneous investigation and analysis of multiple data outcomes of extended periods for different thermal zones is required to get a deeper understanding of possible problems and their subsequent possible causalities. This is -in most cases- a daunting task and a big challenge for design professionals, and surely a much bigger challenge to design students. Morbitzer et al. (2003) support this statement, adding that it would be a useful contribution to utilize additional analysis techniques that can traverse the simulation data and facilitate the knowledge transfer, and ultimately help integrate BPS in the building design process.

The DM process shows promise as an effective solution to the simulation data analysis problem. Generic DM techniques have the potential to facilitate a quick and interactive

analysis of the simulation outcomes. This process can assist the designers to uncover some hidden information that they may not be able to 'manually' uncover, and also to validate any findings that the designers were able to reach and formulate. It is certain, however, that DM can itself generate overwhelmingly massive quantities of data with numerous patterns and relations uncovered, as discussed by Morbitzer et al. (2003), most of which would be irrelevant or uninteresting to the user. The degree of relevance and interest of the generated information depends -to a great extent- on the users and the application settings. Zaiane (2004) introduces the term 'Interestingness', which reflects the level of relevance of mined information to the user, adding that interestingness increases when the outcomes confirm a valid hypothesis, or contradicts a common belief. He adds that in general, measuring the degree of interestingness is based on rules and thresholds defined within the process.

In this context, it is important to set the relevant rules that can manage the mining process and control the generated outcomes. These rules can either be relevant defined equations (like equations for ventilation and heat gains for example), or it can be set of users' preferences (designing an overhang with specified depth to mitigate against solar gains). Han and Kamber (2001) argue that a more realistic and effective scenario to improve resulting data is to communicate at real-time with the DM system, using questioning techniques to either examine and refine the results, or direct the whole mining process. This communication can be achieved via integrating agent-based technology and DM techniques.

Multi-Agent technology has frequently been used as a powerful technology for developing and incorporating DM systems (Zhang et al., 2003). The integration between MAS and DM has been exploited on a large scale during the last decade, as argued by Ralha (2009). She adds that MAS technology is a compelling method for structuring and managing the data mining process, particularly in distributed systems (where data is gathered from multiple distributed resources). Though the two research fields have been developed independently, with diverse objectives and methodologies, there has been growing interest in supporting the integration and interaction between agent-based technology and data mining. Cao (2009) argues that there are growing demands in many disciplines (like business, science, and engineering), that demand for this integration, which has reached a new and promising

level of proficiency, and which is "*moving towards becoming a first-class citizen in the science and technology family*" (pp. 5).

A proposed method to achieve the MAS and DM integration in this research project is through implementing real-time interrogation routines carried out by the system's agents. These routines aim to fulfil two functions; the first is to uncover any missing information from the user, and the second is to get the user's preferences to complete the rules that control and direct the mining process. The user can thus create and change different variables and filters that manage the mining run and its resulting information (for example, focusing on periods of occupancy in a building's zone, where temperatures are above the comfort range). Agents' architecture, and the interrogation routines for data mining, are discussed in more detail in the next chapter.

4.5. Discussion

It is critical in the preliminary stages of design to dig for all available information from the different possible sources, in order to formulate 'Knowledge' in its abstract form. Wilson et al. (2006) argued that in most cases, the feedback obtained from BPS analysis by designers in early stages of the design process is "*relatively notional*", as there is somewhat small amount of information available at this stage. In this respect, there is believed to be great potential for employing agents to traverse the available data, aiming to find out what is currently known (and can be taken further to make decisions), and what information is currently unavailable and is critically required to make sense of the data and present it back to the users. In this sense, employing data mining techniques could be useful to analyse the available data, but these techniques should be accompanied by a set of standards and rules implemented within the program code alongside the agents and DM code. These rules act as reference points that the DM techniques will regularly consult aiming to formulate and confirm their own judgements for rules and patterns generation. Based on their data analysis, information can be passed to the agents to be able to communicate with the player (design student).

The Information required by the data mining system that are not available directly from the simulation calculations, can be retrieved at run-time from the users. The dialogue created between the system and the user helps the whole process in two aspects; the first is filling the gaps in the available information to assist knowledge extraction, and the second aspect is to assist directing the whole process to a design strategy that suits the user's design preference. The generated dialogue and interrogation routines constitute an integral part of the narrative structure within the users' virtual experience. This dialogue and the associated reports aim to direct the users towards a more constructive critical evaluation and reflective analysis of the proposed design from environmental and sustainable perspective. They also provide the users with indicative picture about how the building is currently behaving and how this behaviour can be improved with guidelines to adjust the proposed design.

In summary, this chapter has looked into expanding the scope of capabilities and services presented by the basic game engine's technology, with relevance to the aims and objectives outlined for this research. This is done through electing agent-based technology and DM techniques to upgrade the 3D virtual experience from solely interrogating the building's geometry, to act as an eTutor that accompanies the student throughout the experience, and guide him/her for understanding the different aspects of environmental design. Further to the earlier deliberation of MAS and DM, with their concepts, methodologies, logistics, and techniques, these technologies are deemed effective and sufficient to resolve some of the issues related to BPS data analysis, in terms of representation, and knowledge extraction. It is proposed that these approaches are implemented as separate modules, but still embedded in the game engine's code to facilitate communication between other aspects of the both the code and the virtual world. More details about the proposed system's architecture and its implementation are discussed in the next chapter.

Chapter Five:

Environmental Design Game Development

5. Environmental Design Game Development

5.1. Introduction

The previous chapters presented a discussion and analysis regarding some of the challenges and pragmatic issues that design students encounter, while incorporating environmental design and BPS application in their design process. They also introduced the theories, philosophies, and rationale behind the concepts and technologies adopted within this research (including games technology, MAS, and DM) as means for developing a method and related tools that address these pragmatic issues and attempt to resolve some of the challenges encountered. Through these previous discussions, the problem in this research was defined and led to a set of requirement specifications that form the demanded features of the proposed research tool.

This chapter discusses the implementation and development process that interprets the notions highlighted thus far and the defined set of requirements and specifications that are incorporated into an environment design educational game. In this respect, the chapter presents the development process from two perspectives; technical and pedagogical. The technical aspect of discussion in this chapter is itself a combination of two prospects, which are environmental design (which is reflected in the formulas and equations implemented within some of the game's features), and software engineering (reflected in the methodology employed in this tool's development). The pedagogical aspect, on the other hand, discusses a set of learning theories that affect the students' participation, engagement, motivation, personal development, and satisfaction.

The chapter starts by discussing the preparation and approach for this process through introducing the BPS application and game engine utilised in the development of the proposed tool, and the justification behind electing them. The chapter then presents the case study building that will be used as an example/demo in the proposed tool. The chapter then goes on to discuss the technical aspect of development, through presenting the methodology for the proposed software development and the various phases it involves, leading to a discussion on how these phases result in the implemented features and

functionalities. Finally, the chapter discusses these features and the game experience in general from a pedagogical point of view, debating how these features attempt to meet and satisfy the presented theories.

5.2. Preparation
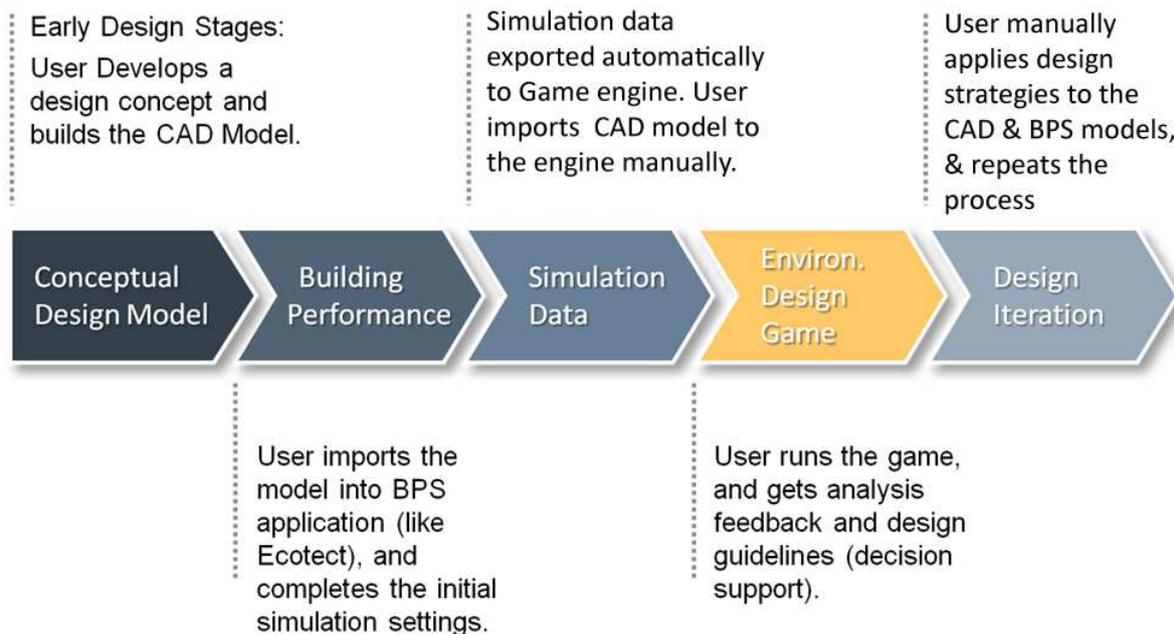
Figure 5.1: Moulding the environmental design game into the conventional design process

A major concern in the development of this tool was how to introduce it and mould its usage into the conventional design process/cycle. It is a fact that using this tool constitutes a -possibly unnecessary- additional step in the process, and thus motivating the students to carry out this additional step is crucial. It is thus essential in the design and development of this tool to focus on features (technical and pedagogical) that allow the student's experience in the virtual game's environment follow the natural flow of the process and minimise any additional work as much as possible. Figure 5.1 presents the position of the proposed game's usage within the design development iteration process. The chapter thus focuses on addressing the technical and pedagogical features that facilitates students' engagement and motivation, in an attempt to make it a useful learning tool and an effective decision support system.

5.2.1. BPS Application

Most BPS tools are generally designed with higher consideration to accommodate the requirements and behaviour of service engineers than those of the architects (as discussed earlier in chapter two). These tools generally have a complex interface -from an architect's perspective- making the learning curve to be able to use it and get solid information out of it quite steep (Punjabi and Miranda, 2005). The development of BPS tools, as argued by Obanye (2007), focuses on enhancing the functionalities, calculations, and validation of results, with much less focus on the intuitiveness of performing these functionalities and notable negligence for simplifying the user interface, making it less attractive to the architects. However, there are few exceptions to this statement, one of them is Ecotect.

Ecotect is currently one of the most architectural-friendly building performance analysis tools. The interface and the functionalities featured in Ecotect are deemed more designer-oriented, with much less complicated required inputs and generated outputs for the simulation, as compared with other BPS tools like IES and Energy Plus (Srivastav et al., 2009). Crawley et al. (2005) also argue that Ecotect is unique in the field of architecture in that it is designed and developed by a team of architects, and thus gives more consideration to the architectural aspect of the process, offering more interactivity and visual feedback. Ecotect also offers a scripting capability (using LUA programming language) that provides greater flexibility and access to the model's geometry and calculation results, as well as prospects for automation of many aspects of the simulation process. The simplified nature of Ecotect is considered very effective for use by design students, as well as being suitable for the use within the conceptual stages of design (Attia et al., 2009). Although Ecotect hasn't yet been validated for the accuracy of its results (according to the U.S. DoE, 2010), it can still be a viable means for comparing simulation results and design cases, rather than giving near accurate prediction of the building performance. In this sense, Ecotect was deemed an appropriate BPS application to be included in this proposed tool's system architecture, and to build the demo case-study upon.

5.2.2. Game Engine

There has been growing interest in the past decade in the usage of game engines in the architectural design curriculums (as discussed in chapter three). Design instructors are encouraging students to use interactive virtual environments (like 3D games) to investigate and interrogate multiple design aspects, and raise their sense of space and geometric awareness. This approach has proved effective, and has enhanced the quality of design produced by the students (Shirattudin & Fletcher, 2007). Building upon this fact, it was important to elect a suitable/appropriate game engine that will host and accommodate the proposed tool. In order to achieve this, numerous games engines were investigated and their capabilities examined during the preliminary phases of this project development. The most commonly used engines among the schools of architecture are UDK[31], Torque 3D[32], C4 Engine, and lately Unity 3D[33]. Upon reflection of the various engines on offer, the C4 Games engine was elected as the most suitable engine for the following reasons:

- The C4 engine, unlike some other engines, offers full and easy access to the core engine's source code, allowing developers to easily manipulate and implement new modules and features. The code architecture itself is very intuitive, well structured, flexible, and highly scalable.

- The world editor tool in the C4 engine (Figure 5.2) is simple and easy to learn and use. The fact that the engine's world editor is mimicking the structure and design of the commonly used CAAD tools potentially makes the process of familiarisation with and learning the interface relatively fast.

- The C4 engine offers dynamic lighting, and dynamic real-time shadow systems, with high frame-rate (up to 120 frames-per-second) and reduced lag.

- Interactivity in the C4 engine can be implemented (if required) graphically using a specific script editor, with no need for additional programming (unlike Unity 3D for

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[31] Unreal Development Kit (UDK): http://www.udk.com/
[32] Torque 3D Game Engine: http://www.garagegames.com/products/torque-3d
[33] Unity 3D Game Development Tool: http://www.unity3d.com/

example, where all interactivities have to be programmed). This is a key feature, as many design students refrain from using game engines because of their requirements for at least basic programming skills (Shiratuddin and Flecher, 2007).

- A Full license for the C4 engine is $100 (at the time it was purchased for developing this tool), which is fairly reasonable and affordable, if compared to other engines like Unity 3D ($1,500 for full license).
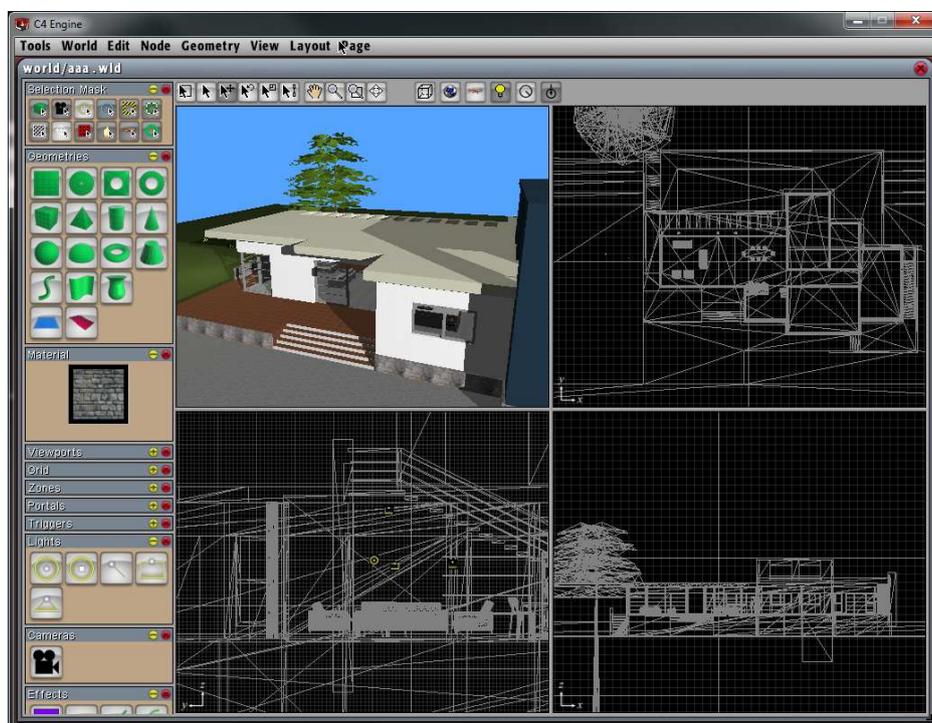
Figure 5.2: C4 game engine's world editor.

5.2.3. Case Study

A small demo building design was selected to be a case study to demonstrate the different features and aspects the proposed tool offers. The demo building is based on a design proposal for a simple/basic residential unit (Figure 5.3). It was an important for the building used as a demo for representing the key features and functionalities offered by the tool to satisfy a key requirement of being simple. The simplicity of the building facilitates the process of development and debugging of the different functionalities implemented in the

tool. It also serves the potential users, acting as an example/template/tutorial for how the tool is used and what it is offering. The chosen building is thought to satisfy this requirement (a simple-geometry, one story, three bedroom house).

The building was modelled in AutoCAD and 3DS Max, and imported to both; C4 game engine, and Ecotect. The tool and its different strategies and guidelines were designed (for demonstration purposes) for the UK weather. However, throughout the development and debugging process of the tool, multiple relevant weather files were used, so as to test the outcomes on different weather cases. This requirement is set to examine the relevance, suitability, and efficiency of the generated analysis outcomes (in terms of reports, interrogations, guidelines, etc.). For the purpose of presenting the tool within this thesis as a demo, the weather file elected for this was that of Cambridge, UK.

Figure 5.3: Illustrations for the case study model used in this project.

In the analysis of the case study design, the building spaces/rooms are treated as individual thermal zones, where each zone is regarded to be in a separate thermal state (Mourshed et al., 2003). The zonal approach is considered to be more specific as it creates distinctive homogeneous volumes of air (Marsh, 2006), which facilitates analysing performance conditions (like heat gains), and consequently in terms of addressing any flagged problems. This approach is thus simplified, as argued by Obanye (2006), as it attempts to minimise the computational processing time required, and the complexity of refining data and extracting information.

5.3.   Game Development Methodology

The development process of the proposed tool follows a specified software engineering-based path that incorporates both procedural and iterative structures. The game development process is thus based on the 'Waterfall Software Development Model' (Royce, 1970), as presented in Figure 5.4. This development approach adopts a cascading methodology, where the outcomes of the information processed in one phase subsequently constitute the inputs and basis for the following one. However, the elected approach is an alteration of the classic waterfall model, adding the possibility of iteration back to the subsequent phase, based on the outcomes and results driven from testing and evaluation.
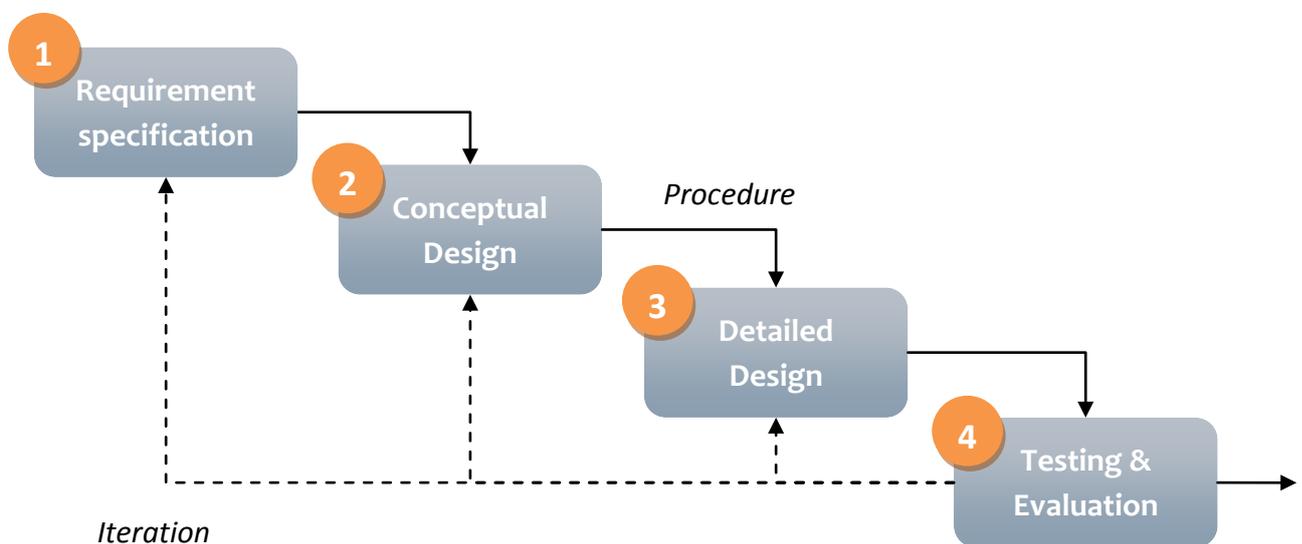
Figure 5.4: The proposed tool's development methodology, based on Royce's (1970) Waterfall Development Model.

The initial stage of development uses the main aims and objectives of the research (presented and discussed earlier in chapter one) as key referral points, which in-turn frame the core rationale for this tool's development. This rationale is reflected in a set of conceptual and functional requirements that are used to instigate features and functionalities that are considered in later stages of development. The second phase of development deals with developing preliminary and conceptual design elements, based on the formulated specifications. The conceptual design phase employ several sub-processes including abstraction, refinement, modularity, procedure, and architecture (Pressman,

2003), as explained in more detail later in the chapter. The generated design elements form the blueprint for the system structure and architecture for the detailed implementation of the tool. The third phase of development (Detailed Design) uses this blueprint to implement the required features and functionalities (as well as the user-interface elements), in the specified Integrated Development Environment (IDE), which in this instance is the game engine. The final phase in the adopted development methodology is the testing and evaluation, which involves the participation of potential stakeholders and users of the tool, in structured (pre-development, in-development, and post-development) testing sessions, resulting in feedback that formulates a set of recommendations for further specification and design iteration, aiming to overcome any shortcomings encountered in these sessions. This phase reflects back on the aims and objectives of the proposed system, and assesses the extent that the system has achieved in terms of fulfilling the desired goals.

Normally in a software development process, the testing and evaluation process is not the final stage of development, and it is commonly followed by a final implementation and delivery phase (sometimes even followed by maintenance phase), as discussed by Pressman (2003). However, due to the nature of this research, the supporting tool is solely a proof-of-concept, and thus it focuses on the main concepts of the research (hypothesis, and aims and objectives) and presents how they can be fulfilled and be reflected in the proposed tool. In this prospect, the game is not a final implementation, but can constitute a basis for it, and thus the testing and evaluation phase is considered the concluding development phase in this context.

The rest of this chapter discusses in more detail the first three phases of the development process, discussing the basis and rationale behind the implemented features of the game, and reviewing the conceptual and technical measures and methods followed in their development and implementation. The next chapter will discuss the final phase (testing and evaluation) in more detail, discussing the methods used and analysing the testing outcomes.

5.4. Requirement Specifications

It is comprehendible that when students and designers (who are not conversant with interpreting and analysing environmental analysis data) develop a design proposal, the initial outcome will require substantial improvement and iteration, in order to meet acceptable results and achieve the building's comfort/performance targets. There are two ways to achieve this objective; the first is to harvest passively (as much as possible) such as using/omitting solar gain, implementing different grades of insulation, addressing thermal mass, etc.; and the second way is to control the interior temperatures actively, through using HVAC systems for example. Since the students are still in their learning process, the value of the proposed system is not only to analyse data and flag performance problems, but also to walk those student through the process, attempt to facilitate their understanding of decisions' implications and cause-effect relationships, and present guidelines and possible routes for further design development.

In this respect, some key functional requirements can be formulated, constituting the basis of the proposed educational supporting tool. The rationale behind these requirements is derived from two main sources; the first is the research carried out (and described in Chapters Two, Three, and Four) to define and frame the problem with its various parameters and attributes, as well as a review into the current and recent attempts to resolve the pragmatic issues surrounding integrating sustainability into the architectural design curriculum. The second source is through performing a number of interviews with potential stakeholders to get a more comprehensive understanding of their views, concerns, and expectations. In response, preliminary interviews were carried out during the early stages of this research; these interviews being carried out mostly with individuals, but in some cases within a focus group. The participants of these interviews were architectural design students (with some experience working with BPS applications), as well as environmental design lecturers/instructors.

The initial investigation was done in two phases of semi-structured interviews. The first (pre-development) phase aimed to collate the participants' views on the current integration of environmental analysis tools in the design process, and the pragmatic issues that face

students within this process. The interviews also aimed to gather the participants' expectations for the features and functionalities included in the proposed tool. The outcomes of this phase matched to a great extent the results from the literature review that was presented and discussed in chapter two, in terms of designers' motivation to use BPS applications, complexity of the interface, preliminary input requirements, and interpretation of simulation data. The interviews also assessed the participants' acceptance of the concept of using a game engine to visualise their design, and integrate the environmental design aspects in their virtual experience. The interviews, however, added some more detailed/specified up-to-date expectations and wishes that reflect directly into the set of requirements. The second (in-development) phase of interviews was carried out after outlining an initial set of requirement specifications, which included higher levels of detail on what exactly would be included in the proposed supporting tool, and the justification behind the choices made. The participants were asked to critique the proposed features, and present their views and feedback. Based on this phase, some additional functionalities and assessment tools were considered for implementation (for example, investigating the effective area of openings to assess the zone's air change rate, and ventilation strategies). The outcomes of the interviews are reflected in a set of conceptual, functional, non-functional, and technical requirements presented in Appendix A, and selected users' responses for some of the questions used these interviews are presented in Appendix C.

5.5. Conceptual Design

The conceptual design phase is one of the key stages in a system's development process. This process is itself of an iterative nature that keeps a sustained referral process back to the information and requisites set in the initial rationale, and requirement specifications phase. The information gathered is processed in this phase forming blueprints and a clear complete picture of the proposed software, addressing data, functional, and behavioural domains prospects that are used for constructing the software (Pressman, 2003). The required system's design is represented at this stage in a high level of abstraction without addressing any low-level details. In this respect, conceptual design, according to Somerville (2001), represents a basic framework that transforms the available information domain model into specified data structures, and defines relationship between different structural elements in

the proposed system. It also sets the mechanism that defines the communication and interoperation between various entities in the software, and between these entities and the users. The framework and mechanisms defined in this phase lead eventually to a detailed structured system architecture that will be followed in the implementation process. For the conceptual design phase to be effective, as argued by Jackson (1975), some fundamental design concepts need to be taken into consideration to provide the necessary framework and structure. The following section discusses some of these concepts as well as the subsequently proposed tool's system architecture.

5.5.1. Abstraction

The abstraction approach, as argued by Pressman (2003), is one of the primary mechanisms that people accommodate in dealing with complexity. The abstraction process -in its highest levels- can be seen as extracting the fundamental features and core of an entity while ignoring and eliminating any details that could be deemed unnecessary or irrelevant. In other words, it is a process that allows the developers to focus on resolving the problems without being held back by irrelevant details. However, at lower levels of abstraction, some further relevant details could be associated, taking it to the process of 'Refinement', which will be discussed next in this chapter. At this stage, the requirements set in the initial stage of development are processed and redefined in an abstract format, leading to successive related design decisions. This is achieved through two types of abstraction, as discussed by Pressman (2003):

- *Procedural abstraction*: This refers to the decisions made based on a series of steps (procedure) taken to achieve a specified requirement. For example, the requirement of presenting the currently experienced thermal zone's temperature comprise a series of steps including detecting the current zone, current day, and current time, then formulating a query with the obtained parameters to get the relevant data, and finally communicating with the game's interface element to represent the data back to the user.

- *Data abstraction*: This type refers to the named collection of data describing a specified data object. In other words, it describes the data structure that is required for satisfying a specified requirement. In the example defined in procedural abstraction, the data abstraction could involve creating an object for 'Temperature'. This data object will encompass a set of attributes (functions) to fulfil the required procedure and fulfil the requirement (like attributes for detecting the current thermal zone according to the player's position in the 3D world or according to specified triggers, and another for formulating a query to the data warehouse to extract relevant data).

5.5.2.   Refinement

The refinement process is based on embellishing and enriching the specified requirements that has already gone through the process of abstraction. It involves decomposing the design decisions in a top-down manner to an elementary level (Somerville, 2001), introducing and revealing low level details (previously suppressed during abstraction), that offer more subtle characteristics to the systems entities. Pressman (2003) explains that refinement is a complementary process to abstraction. He adds that refinement helps the designer to move a few steps forward towards a level that facilitates the physical implementation of the system, in comparison to that level attained by the sole utilisation of abstraction. The process of refinement is normally performed by the developer in a sequential format, adding relevant details to each entity in an incremental pattern. Refinement develops a hierarchical format through the decomposition of 'procedural abstraction' in a subsequent manner till reaching the level of programming languages (Somerville, 2001). For example, in displaying the currently experienced thermal zone's temperature, the refinement process can start investigating how the data will be stored and structured to accept the query passed to it, and how it can extract and use the associated parameters (zone, day, and time) to obtain the relevant information from the data warehouse.

5.5.3. Modularity

The concept of modularity, as explained by Myers (1978), is the system structure's attribute that has the potential to make the program intellectually manageable. It is the process where the software is "*divided into separately named and addressable components, sometimes called 'Modules' that are integrated to satisfy problem requirements*" (Pressman, 2003, pp. 267). In this respect, modularity can be understood as the process of creating independent yet interoperable software components to facilitate the development, debugging, implementation, modification, updating and maintenance of a system. A module generally possesses its own set of data structures, processing logic, and control instructions, and can be characterised as a single separate entity with a well-defined purpose, that can be separately compiled and stored in a library, as explained by Aggarwal and Singh (2007). Thus a module is a breakdown of the otherwise monolithic bulk of software, which -as the scope of the software increases- could prove very problematic due to its complexity and thus compromising the software's achievement of its goals and objectives.

One of the advantages that modularity offers is the prospect of reuse among multiple systems. As a module is a well-defined subsystem, its interaction and dependence on the host application should be minimal. In this respect, the set of attributes and functionalities of a module can be easily transferred and applied into a different system with minimum alteration. In the proposed tool, the system design has been broken down to accommodate an agent-based system acting as an independent module. The Multi-Agent System (as discussed earlier in Chapter Four), comprises a set of agents (which can be considered themselves as independent subsystems) that communicate, cooperate and interoperate with each other, with the host system (the game engine), and with the users. The rationale behind employing a modular structure in the form of a MAS is based on the scale of the set of requirements and functionalities that the proposed system aims to achieve, along with the scale of data pulled into the game. The conceptual design phase of development addresses the modularity aspect, and processing it through procedural abstraction and refinement, aiming to outline the general characteristics of the MAS, and the scope of services that each of the agents have (as explained later in the chapter).

5.5.4.   System Architecture

System architecture is one of the fundamental components of the conceptual design phase of software development. The term 'Software Architecture' refers to "*the overall structure of the software, and the ways in which that structure provides conceptual integrity for a system*" (Shaw and Garlan, 1996). System architecture, as explained by Pressman (2003), is the arrangement and structuring of various program components (including independent modules), describing the manner and mechanisms by which these components interact and cooperate to achieve and fulfil the desired outcomes of the system. It also explains the relation of the various components with the system's data repository, and how the data are structured and organised. Figure 5.5 represents a structural model system architecture diagram. It includes the three fundamental constituents of the system; the game engine (C4 Engine), the BPS application (Ecotect), and the design CAD model. The diagram also represents the Multi-Agent independent module structured and hosted within the game engine source code, thus set as the point of communication between the user and the system within the context of the virtual game environment.
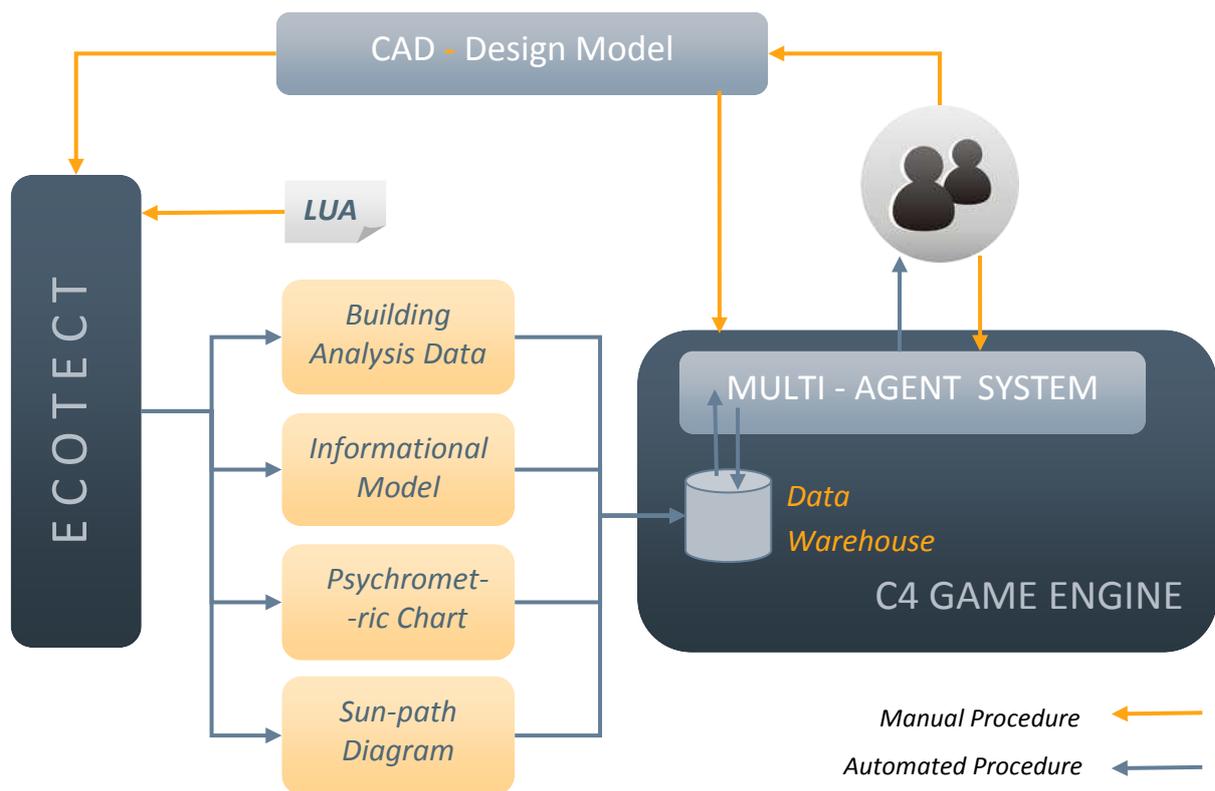
Figure 5.5: The proposed tool's system architecture, indicating the automated
phases of the method, and those that require manual intervention.

The process starts by the user developing a design and building its CAD model, which is in turn imported (or re-created) within the BPS application. The CAD model and all the relevant initial information are subsequently used to run the simulation and extract data from the BPS application. The data extracted from the simulation process, along with the general weather data related to the building location (including sun-path coordinates data, and Psychrometric chart) are gathered and imported into the data warehouse which is built within the game engine's code. When the user runs the game, he/she starts interacting with the virtual world and communicating with the MAS, obtaining feedback on their environmental design strategies and decisions based on the relevant data retrieved from the data warehouse, along with the user's inputs and environmental design equations that the agents assess the data against. Based on the feedback provided to the users, they perform another iteration in the design process, where the guidelines and strategies proposed in the game are reflected back in the CAD and Ecotect models. This process is

subsequently repeated by the users until they achieve results that satisfy their design. Figure 5.6 presents an interpretation of the proposed system architecture from the users' perspective in terms of their allocated tasks within the 'updated' design iteration; i.e. a diagram of how the proposed method and its associated tool will be integrated/used within the design process.
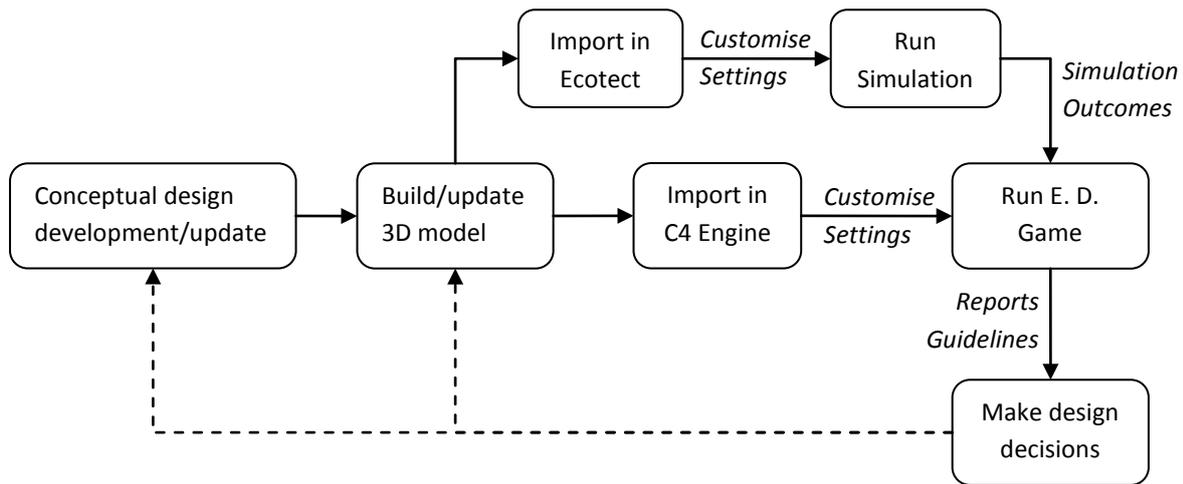
Figure 5.6: The projected structure of an iteration in the design cycle within the framework of the proposed method, including the envisioned tasks that has to be followed/carried-out by the users to complete a design iteration.

In order to facilitate the design iteration process, a pre-scripted LUA code (the programming language supported by and used within Ecotect) is prepared for use by the users in Ecotect. This code automates the process of simulation and extraction of relevant environmental data in the required formats and stores it in the desired locations. The LUA code used for this purpose is presented in Appendix G. The conceptual design's system architecture, with all of its components and connections, is later refined and interpreted into physical program entities and components (like classes and functions), and implemented within (or on top of) the engine's code.

5.5.5. Interface Design

All the previous discussion on the conceptual design processes were aimed at the underlying technology for the proposed tool, targeting its data structures, processing

mechanisms, and functional operations. However, a fundamental aspect of the conceptual design phase is the development of design elements for the proposed system's user interface. The importance of the users' interface design is that it represents the key point of communication between the system and its user, as well as the method by which knowledge is transferred (which is the fundamental aspect of any educational software). The approach for interface design is rather different and relies mostly on graphical representation and drafting. This is commonly achieved in two manners:

- *Statically*: by creating sketches representing various envisioned screenshots of the different features and functionalities of the proposed system. For example, the main walkthrough screen, the guidelines screen, the report screen, etc. This type of drafting requires high level of detailing and is itself a procedural process that undergoes constant refinement till reaching a level of detail that can be directly applied.

- *Dynamically*: through the means of storyboarding. In this type, the designer envisions the flow and progression in the users' virtual experience, aiming to cover the various aspects and scenarios encountered within this experience. Unlike the static type, the level of detail is redundant, making the main focus on the flow of the process and the users' experience.

After reaching an acceptable level of detailing, the interface design elements are reflected as Graphical User Interface (GUI) components that are designed and scripted within the game engine's code.

5.6.   Detailed Design and Implementation

After setting the rationale and defining a set of conceptual, functional, and behavioural requirements, and after processing these requirements within the conceptual design phase of development leading to software blueprints and outlines for key operational decisions, the previous planning and preparation were applied directly into a physical Integrated Development Environment (IDE). This IDE is the medium where all the set blueprints are

translated into structural elements forming features and functionalities that fulfil the desired system's objectives and address the requirement specifications. In the development of the proposed game, the system coding, debugging, and implementation was done in the C++ programming language within the core C4 game engine's source code. The IDE used for programming the proposed game was Microsoft Visual C++ 2005 and later 2008 (Express Editions)[34]. The following section presents further discussions about the 'Detailed Design' phase of development, discussing the rationale, philosophy and mechanisms behind the coding and implementation of different aspects and functionalities projected in the proposed tool.

5.6.1.   Multi Agent System Implementation

As the rationale and justification behind electing a MAS system in the development of this tool has been discussed earlier (in Chapter Four), it was important at this point to define a clear scope of service and functionalities for each of the agents utilised. It was also important to depict clear 'connections' indicating the means of communication and information exchange between the agents, along with representing the relationship between the MAS and any external contextual entities (like the data warehouse, the game's virtual world, and the players). Figure 5.6 represents a proposed structure for the MAS, including agent types, context, and connections.

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[34] Microsoft Visual Studio 2008 Express Edition with SP1:
http://www.microsoft.com/download/en/details.aspx?id=14597
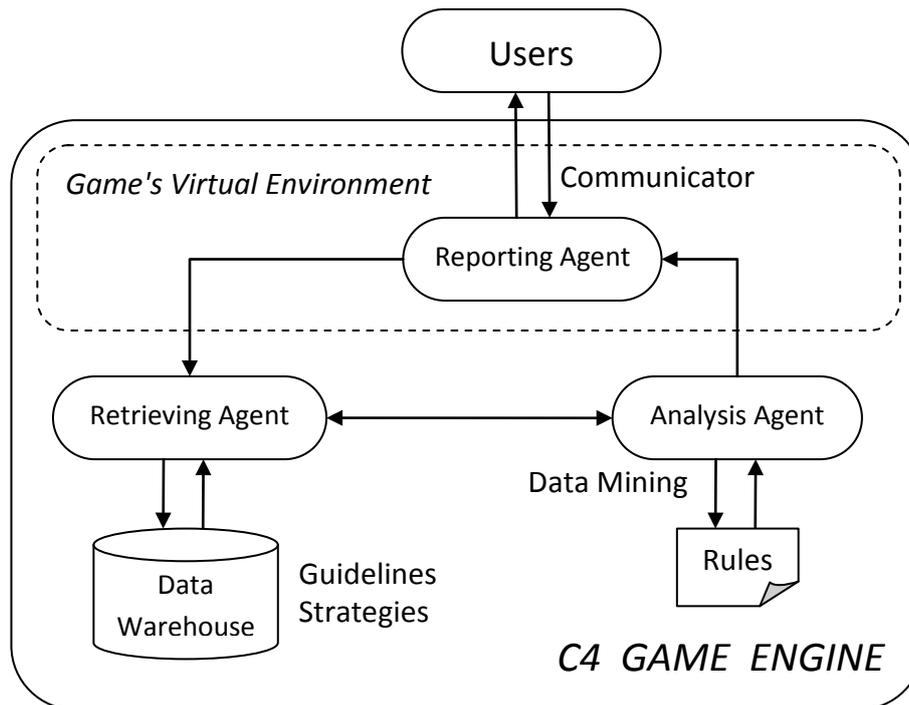
Figure 5.7: Multi-Agents System's structure as part of the game engine in
the proposed tool.

As previously mentioned, the MAS is developed as an independent modular entity. In other words, although the MAS is implemented within the game engine's source code, it is structured to have independent characteristics and scope of services. In this respect, the developed MAS is not restricted to the game engine elected for the development of the proposed tool, but can be transferred and reused within any other game engine (which supports the C++ language in its source code) with minimum alterations. It is important to note, however, that ultimately there has to be a link between that MAS module and that rest of the tool's entities, particularly with the engine's code. This link is achieved in the proposed tool through a 'communicator' (figure 5.6), or a system entity that facilitates the communication between the independent MAS and the rest of the system. The communicator in this instance is set as the engine's 'Display Interface', which includes all the GUI elements for the game. The reason behind electing this communicator is that it is a common factor that the three key components of the system use; the MAS, the engine's code, and the game users. Thus, the engine's display interface is deemed an appropriate

entity for centralising and managing the communication messages between the different entities of the game.

The proposed MAS comprises three agents; the retriever, the analyser, and the reporter. The following part of this section will discuss the scope and functionality for each of them, and their means of communication with each other and the host system. A UML Class Diagram including the MAS coding structure with its implemented classes is presented in Appendix E. The detailed implementation for the MAS, including the libraries and classes declarations and definitions is presented within the developed source code in Appendix H.

5.6.1.1.   Retrieving Agent

The retrieving agent is an embedded software entity that receives requests for information, and is responsible for formulating queries and specifying parameters to communicate with the data warehouse to extract the required information. It receives request for relevant contextual information in the form of unrefined queries. These queries can be generated automatically from other agents at run-time, or can be user-defined queries generated by the users seeking specified information during their experience. Once it receives a query, the retrieving agent seeks to gather initial contextual information about the current state of affairs of the game world (for example, detecting the zone that the player exists in, and the current date and time of the virtual experience). In the process of gathering this initial information, it is common that the retrieving agent would itself formulate a second level of queries (sub-queries) that access records in the data warehouse and pass them back to the main query (for example, getting the current zone's temperature, or the zone's opening areas). This initial information gathered by the retrieving agent is moulded into parameters that help in further specification, reduce the scope of search, and refine the information retrieval process. The refined query is finally passed to data warehouse and relevant data is consequently retrieved and passed to the analysis agent for further processing.

5.6.1.2.   Analysis Agent

After the retrieving agent gathers the requested information from the data warehouse, the relevant data are passed -in their raw format- to the analysis agent to start the process of

information analysis and knowledge extraction. In order to achieve that, the analysis agent starts analysis mechanisms and DM techniques on the received data. Before that, the analysis agent starts a check routine to ensure that the available data is sufficient to start the mining process. The check routines vary in nature according to the available information, and also the type of details and knowledge that the analysis process aims to extract. In this aspect, the analysis agent -in many occasions- might revert back to the retrieving agent to query for data that is required in the analysis process (as illustrated in figure 5.6). For example, when the user is experiencing an overheated zone, the analysis agent needs to assess the ventilation strategy implemented by the user, so it sends an initial request for relevant information to the retrieving agent, and receives back the results. During the inspection of the results, the analysis agent might encounter some key missing details (like the depth of the zone, area of windows, or the effective area of opening). This is then translated into a secondary query and sent back to the retrieving agent. Once all the required parameters are available, the data mining process could commence, which examines data against particular standards and climate equations (discussed later in this chapter). Finally, the data is processed to extract relevant knowledge in its abstract format, which could be later passed forward to the reporting agent.

5.6.1.3. Reporting Agent

Reporting agents are the most common and popular type of agents that has been utilised in recent years, particularly in MMORPGs (Massive Multiplayer Online Role Playing Games), as argued by (Madden and Logan, 2007). The reporting agent is the only embodied agent in the proposed MAS architecture, i.e. it is the sole entity in the MAS that has literal existence within the virtual game world, and thus has the capacity to interact and communicate with the game's participants. The embodied agents –discussed in the previous chapter- are considered to have a substantial effect on the flow of the game and structure of its narrative. In many cases, the embodied agents are set to act as 'reporters' to the player to pass them any information related to the game (and the gameplay), that is deemed important (Fielding et al., 2004). The term 'Reporters' has been commonly used to describe a MAS based game, that aims to provide users with refined information about the game's world (events, activities, data, etc.). In most cases, reporting agents are directly situated in

the game as NPCs that populate the virtual world, but not necessarily influence it directly or have a central role in the game's plot. The reporting agents can be physically visible to the players, in the form of avatars that are secondary elements or characters of the story. They can also be sensed in the game world without being visible, but can still (like the visible reporters) communicate and exchange information in the form of audio or textual conversations. The method of communication with the player is critical in this type of games/simulations, as it affects achieving the overall game objectives.

In a study by Madden and Logan (2010) for evaluating the use of virtual reporting agents, they concluded that the presence of the reporters in the game environment have increased the enjoyment and acceptance by the participants, and thus the motivation to play the game. However, around 75% of the participants agreed that the reporters can be -to an extent- quite intrusive and disruptive, particularly when physically represented as game avatars, and in their means of communication. Thus, the characteristics of reporting agents and their methods of communication with the game's participants have to be carefully designed and implemented.

The reporting agent -as the main communicator in the users' virtual experience- is responsible for creating the dialogue with the users interrogating them for information, and presenting relevant and filtered reports, feedback on their strategies and design performance, and design guidelines to improve the overall building performance. It receives filtered extracted knowledge from the analysis agent, and presents it to the user when required (user-defined requested reports), or when deemed relevant (in-game instant zone briefs for example). In this respect the reporting agent is not only implemented as a structural element in the system architecture, but also plays the role of the narrator/tutor that walks the users through the building's story. The reporters can thus be considered as the users' companion throughout their journey within the virtual environment (Tallyn et al., 2005). The reporter gathers information from the users and passes them back to the retrieving agent to either store in the data warehouse, or to process and retrieve relevant data that is required to continue the dialogue with the user. The iteration process is completed by the feedback and guidelines, which form further design decisions to the CAD model, and thus the process can be repeated.

5.6.2. Data Sources and Data Structures

After discussing the structure and scope of the implemented MAS, it is important at this point to focus on another elementary component of the proposed system, which is the data repository. As discussed earlier in Chapter Four with the knowledge extraction process, the data derived from the various resources need initially to be formatted appropriately and prepared for storage in a DW (data clearing and integration). In this respect, the derived data are not directly stored, but are primarily processed within specified filters. The scope of service for these filters includes:

1. Removing any data headers and eliminating irrelevant data that can be present within the exported data file. For example, in Ecotect it is common to include some statistics and additional information at the start of the Comma-Separated-Value (CSV) data file, which needs to be removed to process the actual data.

2. Changing the derived data format or data type, which could include extracting specified bits of data from the data source file, and re-formatting them or using them in an intermediate equations to store a derived version of the source data.

3. Extracting relevant subsets of data from their location in the source data file and allocating the extracted data into the appropriate setting within the data warehouse.

It is important also to note that the processes of importing, extracting, filtering, formatting, and allocating data are performed every time the user starts the game. The game is designed in this manner as it is based on the iterative nature of the design process, i.e. it is understandable that the users will need to make updates to their design based on the feedback gained in an earlier iteration, and thus much of the data will be consequently updated and requires re-importing. Figure 5.7 presents the main sources of data used to build the game's DW, and that is used as a main data repository throughout the game. The next section of this chapter discusses each of the illustrated data sources in more detail.

Interrogate for assessing design strategies that rely on the current zone's geometry.

Interrogate to present basic reports & seek patterns and causalities when a problem is flagged.

Interrogate for calculating comfort ranges, and effect of different design strategies (e.g. passive solar, evaporative cooling...)

Interrogate for positioning the sun within the game, and to assess design strategies that rely on sun-light access & solar radiation.

CAD Model

Ecotect Data

Agents' Data Warehouse

Psychrometric Chart

Sun-Path Diagram

Figure 5.8: The data sources used to build the game's data warehouse.

5.6.2.1.   Building Performance Simulation Data

The data generated from the BPS application (Ecotect in this project), is considered the main source of information that feeds into the proposed game. The value of the simulation data is that it is generated specifically to the proposed design and to each of the zones included within, based on the initial information and configurations set by the BPS users. It has to be mentioned at this point that the scope of this research and its associated proposed tool is focusing primarily on the thermal performance of the building and its zones. This is done through addressing the strategies and design decisions that affect the thermal performance, and consequently the energy consumption and carbon emission that result from having to resort to artificial methods (like air conditioning or heating) to maintain satisfactory indoor thermal conditions (comfort levels). In this respect, the focus is set on the simulation analysis and calculations that present relevant data that serve this purpose and help in assessing the design's thermal performance. The targeted simulation results include yearly hourly temperatures for each of the building's thermal zones, as well as zone-specific data related to heat loss and gains, through for example, fabric gains, direct and indirect solar gains, thermal mass, ventilation gains, and inter-zonal adjacencies. The proposed tool also targets a breakdown of data related to the energy consumption and loads utilised in the

building in general, as well as in each of its thermal zones (this can be derived from extracting data from monthly degree days, and monthly heating and cooling loads).

The amount of BPS data required for assessment and analysis within the proposed tool is considerable, covering multiple aspects for prolonged periods of time. Exporting this amount of data manually from Ecotect to the game would be a daunting task, and would consume a lot of time and effort to complete, and could jeopardize the feasibility of using this tool -possibly leading to more frustration from the students' perspective. Moreover, as the data analysis within the proposed game is done automatically and dynamically, the game initially looks for specified sets of data that have to be present and in a specific format. There is a great risk that manual export of simulation data could miss some of the essential datasets (especially as it is an iterative or repeating design process), and again jeopardizing the feedback presented at the game's run-time. For this purpose, it was deemed necessary to employ a method that can quickly and accurately export the BPS calculation data and make it ready for filtering and storage in the game within every iteration. This was accomplished through developing a template script written in the LUA language (that is used in Ecotect), that automates the whole data export process, targeting the same sets of data in the required format (CSV files for example), and storing them in the required location. In this case, the students need only to set the initial configurations for the Ecotect model, and click the 'play' button to export the data for further analysis within the proposed tool. The LUA script template is presented in Appendix G.

5.6.2.2. The CAD Model

The digital CAD models that the students develop for their designs constitute one of the fundamental aspects of the proposed tool. The model is used both within the BPS application where the configurations and calculations are applied, and also within the game engine itself. The CAD model is imported in the game and resides in the game's world/level editor (see figure 5.2). Importing the model is accomplished via specified plug-ins within the CAD application, for example, 3Ds MAX and MAYA use the Collada plug-in[35] to export the model in an appropriate format (DAE extension for the C4 game engine) that can be then

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[35] Open Collada: http://opencollada.org/

used and altered within the game's world editor. The CAD model then constitutes the geometric and physical basis of the interactive narrative virtual game's experience.

The importance of the CAD model doesn't just lie in being an arrangement of physical boundaries and collision entities in the game's environment, but is also important for the MAS to interrogate within its analysis and data mining process. The geometric parameters derived from the CAD model are commonly used by the MAS -within a set of relevant equations- in the assessment of existing design strategies and their effectiveness and feasibility, as well as the feasibility of any proposed design strategies and guidelines. These include geometric parameters like the zone's area, depth, height, and orientation, zone's opening areas and orientation, as well as neighbouring zones and external overhangs and louvers. For example, it is important to know a room's depth and windows' size in order to assess performance against equations for single sided and cross ventilation. For this purpose, the tool interrogates the CAD model, and pulls the relevant geometric details, as an step to form an initial informational model within the game; making the CAD model a valuable source for information and basis for assessment. This informational model will include the area and volume of the zone, its orientation, number of windows included with their glazing area and orientation, etc. Appendix H presents the procedure and source code used to build this information model.

It is common for the MAS to seek supplementary information about the CAD model from other available resources, if the CAD model itself (in terms of it being a geometric entity) is not sufficient to provide the required information. The MAS can -for example- revert back to the BPS data to examine the thermal mass of a zone from configurations set within the BPS application, and detect the insulation as an interlayer which ultimately affects the heat gain or loss and admittance. In some other cases, the agents revert back to the users for any missing information to assess a design strategy, for example, asking the users for the effective area of opening to assess the air flow rate, or the depth of an overhang to assess the strategy to prevent direct solar gains.

5.6.2.3. Psychrometric Chart

The Psychrometric Chart (also abstracted as a Bioclimatic Chart) is one of the fundamental sources of information used within the proposed game. In general, a Psychrometric chart provides a graphical representation of the thermodynamic properties of moist air (Ren, 2004). In environmental design, these properties are reflected in identifying the range of temperature within which the building's occupants will be in a state of thermal satisfaction, or what is commonly known as 'Thermal Comfort Range' (ASHRAE Standard 55, 1992) . The comfort range is determined based on number of parameters, including the thermal zone's mean and neutrality temperatures, Relative Humidity (RH), saturation vapour pressure, etc (Szokolay, 2008). The comfort range is also calculated based on the occupants' metabolic rates (Khodakarami, 2009), which in turn depends on the type of activity carried out within the zone in question. The metabolic rate is in an inverse proportion to the comfort range temperatures, i.e. higher metabolic rates require lower comfort temperature range. The method of calculating the thermal comfort range for the specified zones is discussed in more detail later in this chapter, and in Appendix F.

It is important to interrogate the Psychrometric chart to identify the periods where the air conditions (e.g. temperature and humidity) of a specified thermal zone in the proposed design are out of comfort ranges, according to the numerical and contextual factors discussed earlier, and thus identify the periods where the conditions in this zone require artificial/mechanical intervention to be brought back to the desired comfort ranges (using HVAC systems for example). This is in turn reflected in the energy consumption values associated to this zone at these specified periods, which could assist highlighting the problem, identifying the possible causalities, and ultimately proposing design guidelines to improve the performance.

Another aspect that is useful to interrogate in the Psychrometric chart is the effect of different design strategies that may inform the indoor thermal comfort parameters. These strategies include passive solar heating, evaporative cooling, natural ventilation, etc. Identifying the effect of these strategies on the thermal comfort ranges will in turn assess the feasibility of applying these strategies and thus interpreting them into design decisions.

Figure 5.8 presents an example of the distribution of yearly temperature values within the Psychrometric chart (blue dots), along with the plotted comfort range (yellow-bordered area), and the effect of multiple strategies on this range (known as control or climatically protected zones).
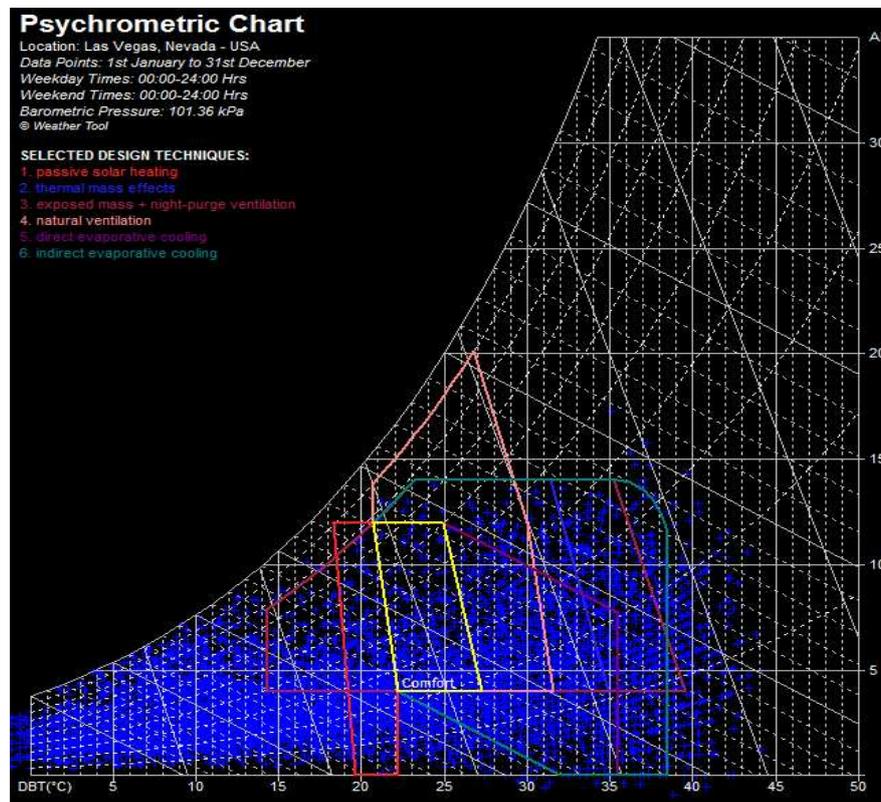
Figure 5.9: Psychrometric chart, sample of annual temperature and comfort range depicted, along with the ranges of selected design techniques. Image produced from Ecotect.

The Psychrometric chart is interrogated by the embedded MAS, which is done dynamically at the game's run-time, and updated every time there is a contextual change in the user's experience (like changing the zone, or date and time of the experience). For the MAS to be able to do this, the underlying equations of the Psychrometric charts have to be extracted and set as a referral point (rule) to be assessed against dynamically. For example, it is required that the initial zone brief should display the current temperature, and indicate if it is within the satisfactory comfort range. To be able to do this, the MAS mines for relevant data from the DW to assign values to the different thermal comfort equation parameters, and thus can make a reasonable assessment of the zone's condition.

5.6.2.4.   Sun-Path Diagram

The study of the sun path in general is concerned about tracing the annual and seasonal hourly position and trajectory of the sun, and the significant changes to the sun's positions resulting from the earth's movement and rotation around the sun (Figure 5.9). This study has been of great effect and potential to a broad range of disciplines, in particular, architectural and environmental design. Examining the sun path diagram within the design process is a critical factor in determining the projected heat gains and lighting requirements and/or effects within different zones of the building. Based on that fact, the sun-path analysis is deemed one of the critical processes within the proposed tool.

Spherical Projection
Location: 36.1°, -15.2°
Sun Position: 164.1°, 54.6°
HSA: 164.1°
VSA: 124.4°

Time: 11:30
Date: 26th Mar (85)
Dotted lines: July-December.
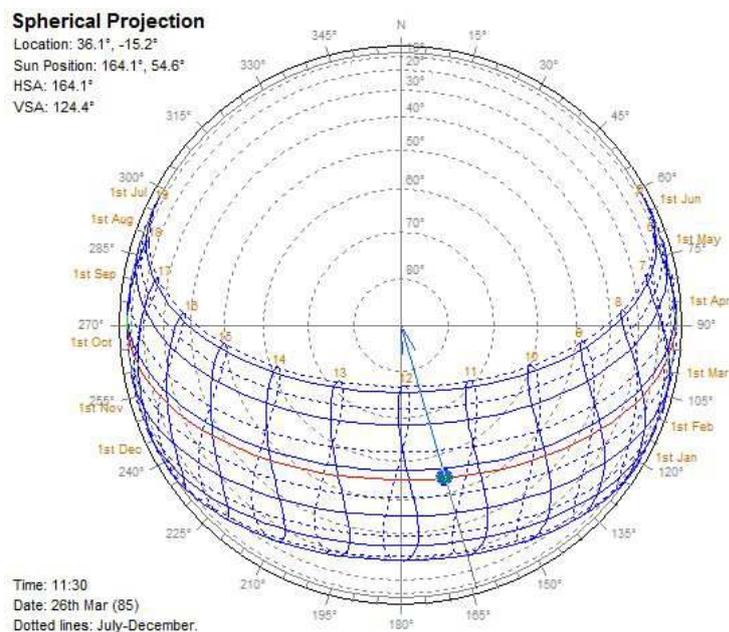
Figure 5.10: Spherical projection of the sun-path diagram, representing the sun at 11:30 am on 26th of March. Image generated from Ecotect.

Determining the sun position and path in a particular day or along a season is considered a significant part of the interrogation routines carried out by the MAS, aiming to assess the design decisions and strategies made. For example, if the users want to drive a mass by solar radiation, the sun-path diagram can help determine if this is achievable, and examine how much sunlight (radiation) reaches the walls of the zone in question. Another example for the benefits of sun path analysis lies in recommending the placement of overhangs, louvers and/or sun breakers/shades at specific angles with specific depth, in order to accommodate

the amount of solar radiation required inside a room. Figure 5.10 presents the interpretation of the sun path data within the game's environment, with the indication of the current sun position in the sky by the white sphere. The mechanism of extracting the sun-path diagram data and interpreting it into the game engine's code is explained later in this chapter.

Figure 5.11: The reflection of the sun-path data within the game's virtual environment.

5.6.2.5.   User-Defined Data

The user-defined data denote the information presented by the users within the game's virtual experience that can be used as parameters in the analysis of the simulation data, and the assessment of any current or proposed design strategies. User-defined data differs from the other data sources used within the proposed game (discussed earlier in this section) in that it is the only source that is exported into the game at run-time. All other sources are compiled and stored in the game's DW before the virtual world is loaded, so that all the initial information is made ready for the users. However, the user defined data are added during the game, and it has to be instigated by one of two means namely:

- Via a request from the MAS in the form of a question set in the interrogation routines. These questions demand the user to either specify a missing bit of

information (for example the depth of an overhang), or demand their views on a potential design strategy or guideline (like changing the type of glazing for example).

- Via the users themselves on changing specific settings for the game (for example, changing the operating hours, number of occupants, or the type of activity within the building).

5.6.3.   Game Features and Functionalities

After discussing the theory, rationale, scope, and general features of some of the key components of in the game, it is important to highlight how these components are reflected within the game's environment (in terms of features and functionalities), the main 'rules' that these components follow, and how the users interact with them in order to assimilate the gained knowledge to inform design decisions. The following section will discuss in more detail the technical aspects and mechanisms utilised in developing and implementing some of the proposed game's features and functionalities.

5.6.3.1.   Initial zone brief

The zone-specific brief is an initial short report presented at run-time, highlighting the main issue or problem encountered in the current zone. This is considered a preliminary conversation between the embedded (but unseen) reporting agent and the player, forming the basic narrative of the game's experience. The report is updated every time the user moves to a different room (zone), or when the user changes one or more of the experience settings (like the date and/or time). Figure 5.11 shows an example of a zone's initial brief, which presents a text-based report, along with the current indoors and outdoors temperatures and, current date and time. The temperatures presented in a colour coded background with associated icon to represent whether the current temperature is below, above, or within the thermal comfort range.
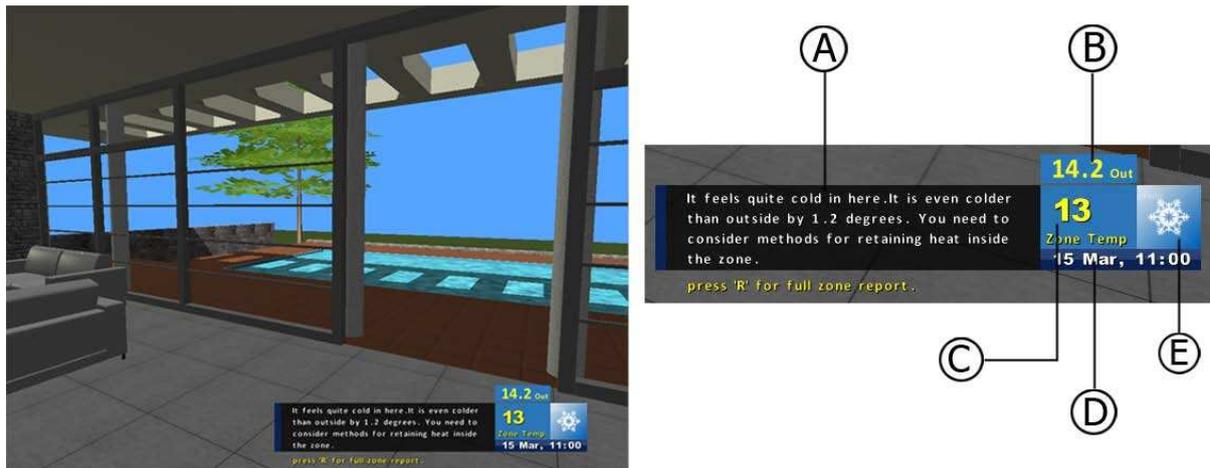
Figure 5.12: The 'Zone Brief' report GUI, representing a brief summary about the current condition of the zone being experienced (A), with presentation of outdoors temperature (B), indoors temperature (C), current date and time (D), and whether the current zone's condition is below, within, or above comfort range temperatures (E).

5.6.3.1.1. Calculating the Comfort Range

As discussed earlier this chapter, the comfort range is a fundamental referral point to determine when and where an intervention via artificial methods is required to move the current indoors temperatures (air / boundary properties) to a satisfactory level. There are currently a number of methods to calculate a thermal zone's comfort temperature range, but in this project the formulas for calculations are derived from Szokolay (2008). The initial calculation step is to establish the mean temperature (T_{av}) of the warmest and coldest months. This is done via the analysis agent to determine the monthly average temperature and thus identify the coldest and warmest months, and calculate their average. The next step is to calculate neutrality temperature (T_n), along with the upper and lower limits of comfort (T_U and T_L), as explained in the following formulas:

$$T_n = 17.6 + 0.31\, T_{av}$$

$$T_L = T_n - 2.5 \; °C$$

$$T_U = T_n + 2.5 \; °C$$

Following this, the upper and lower SET (Standard Effective Temperature) are determined (Gagge et al., 1986), using the Absolute Humidity (AH) value measured at the current instance within the zone's Relative Humidity (RH).

$$T_{LS} = T_L + 0.023 (T_L - 14)AH$$

$$T_{US} = T_U + 0.023 (T_U - 14)AH$$

The instance relative humidity data can be extracted directly from Ecotect, however, the conversion from RH to AH require further calculations using formulas that include Saturation Vapour Pressure (P_{vs}), and Saturation Humidity (SH). The details of these calculations are listed within Appendix F. Calculating the comfort temperature range for specified periods can assist in highlighting performance problems and thus their possible causalities, and also in identifying the periods where the zones in question require air conditioning or heating to accommodate the building's indoors temperatures.

5.6.3.1.2.   Assessing Daylight Factor

The assessment of the average daylight distribution within a zone is an important aspect, particularly during the early stages of design. The quantitative examination of a room's daylight distribution allows the designer to know if the room is not appropriately lit and could ultimately rely on artificial sources of light, which could in turn affect the overall energy performance of the building. The equation for calculating the average daylight factor DF_{av} in a room is derived from CIBSE/SLL (2002):

$$DF_{av} = \frac{\theta \, A_w \, \tau \, MF \, GBS}{2A_T(1 - \rho_{av})} \times 100\%$$

If (DF_{av}) is less than 2.5, then the agents will flag the problem and present it in the zone brief (as illustrated in Figure 5.12).
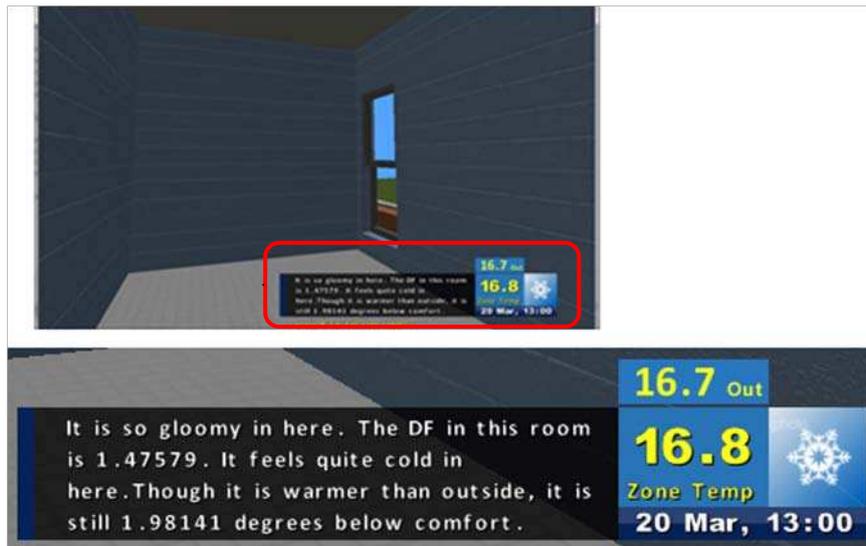
Figure 5.13: Assessing average Daylight Factor (DF) and presenting
feedback within the 'Zone Brief' report.

Another method of daylight assessment used in rooms that are lit from a single side, is the
'Ratio Limit' (CIBSE/SLL, 2002). This is a formula that examines the light at the back of the
room, considering the parameters of length (L), width (W), and height (H) of the room, as
well as the average reflectance factor (ρ_{av}) of elements at the back half of the room (floors,
walls, and ceiling). The daylight in the room in question is acceptable if the condition of the
formula is met:

$$\frac{L}{W} + \frac{L}{H} \geq \frac{1}{2(1 - \rho_{av})}$$

One of the key benefits of reporting problems regarding the daylight factor, is that it allows
the designer to understand the area of glazing -and possibly the orientation of the window-
needs to be reconsidered to increase the average to above 2.5. In this respect, a
rearrangement of the above DF_{av} formula can be used to recommend the minimum
required area of the zone's windows (A_w) that can accommodate effective daylight factor,
as presented in this equation:

$$A_w = \frac{2A_T \, (1 - \rho_{av}) \, DF_{av}}{\theta \, \tau \, MF \, GBS} \quad m^2$$

5.6.3.2. Zone Reports

Like the initial zone brief, the zone reports are a method of communication between the reporting agent and the users, and thus form again a fundamental component in the game's narrative. However, unlike the run-time briefs, the zone reports are generated on user's request (on pressing the 'R' button in the game), and presents the user with more detailed information about the current zone's performance. The information included in the reports' tabs relate directly to the game's current settings, which the users can control and adjust from the 'Settings Window' by pressing the 'V' button. These settings include the date and time of the game's experience, as well as number of occupants, hours of occupancy, etc. These settings constitute important parameters in the data analysis process, and in turn in the presented reports. The presented information form a feedback report on the current strategies and components that the user implemented in the design, focusing on highlighting any problems in the performance along with the possible causes for these problems. The reports are presented in multiple tabs:

5.6.3.2.1. Daily Reports Tab

As presented in Figure 5.13. This tab highlights the periods in the day (currently experienced in the game) where temperatures / air conditions are outside the comfort ranges. In order to be able to report this, the MAS uses the association analysis data mining technique - explained in chapter four- aiming to create specified sets/fragments of data which particular characteristics (for example, overheated periods). The MAS then traverses the daily temperature and RH data within the data warehouse, and assess this data against the current comfort range formulas (explained in the previous section). The MAS then assigns each bit of data to it corresponding data fragment, and uses these fragments in the wording of the daily report presented to the user.
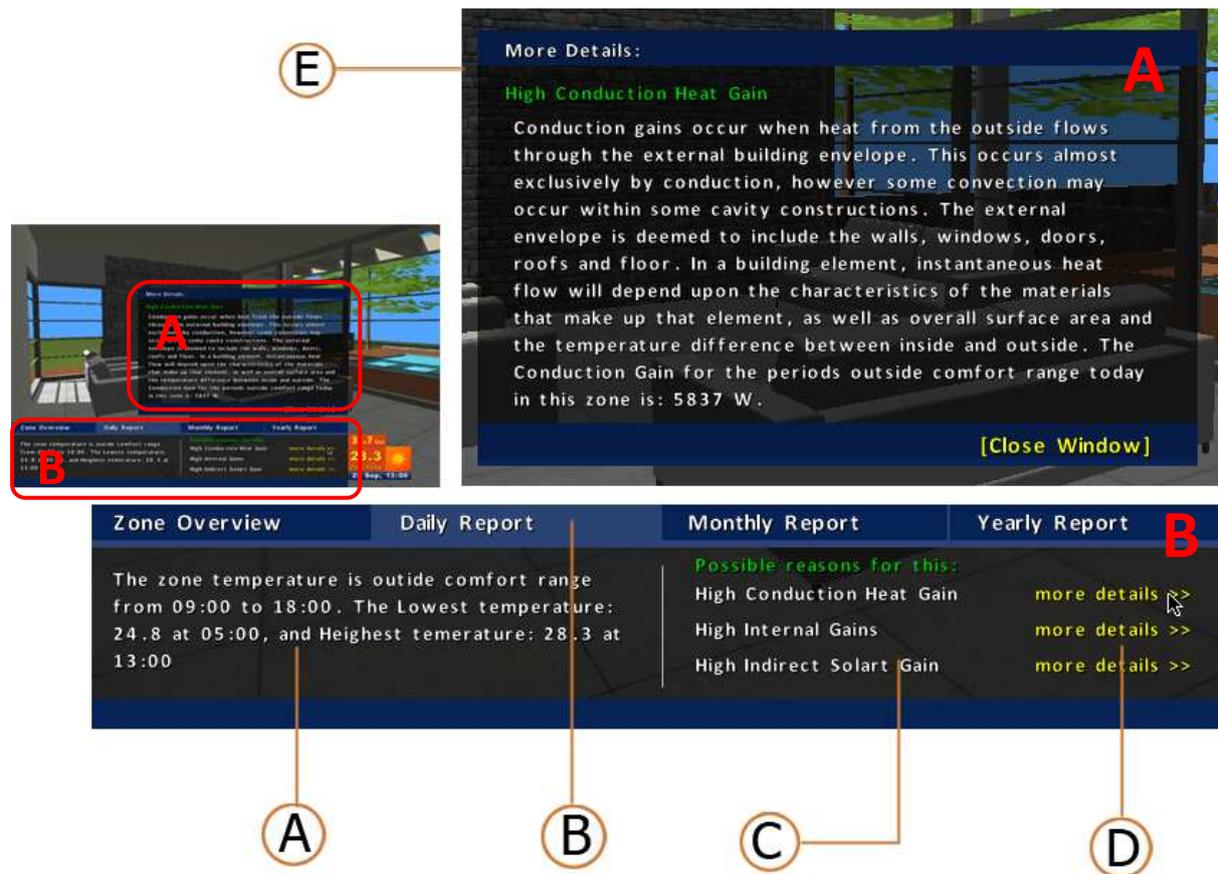
Figure 5.14: Current zone's Daily Report tab (A), presenting a summary report of the day, highlighting the periods where temperatures are out of comfort range (B). The report also presents the possible causes for any highlighted problems (C), and options to get more information about each identified cause (D), which opens in a new GUI window (E).

The MAS then uses the same association mining technique, along with the generated data fragments, to traverse all the available information for the specified zone at the specified time. By traversing the data, the MAS can associate any relevant high values as possible causalities to the problems identified. For example, if the current zone has six hours of overheating, and the MAS associates high value of direct solar gains for the specified overheated period, then it reports that one of the possible causalities of this problem is direct solar gain. The report also includes a button beside each possible cause for reported problems, which opens another GUI element/window that presents further information about the particular possible cause.

5.6.3.2.2. Monthly and Yearly Reports Tabs

The information presented in this report provides a more general overview of the current zone's performance. It focuses on highlighting some important facts and feedback to the users over longer periods of time. The feedback presented includes information about the overall monthly and yearly required heating and cooling loads to accommodate the zone's indoors temperatures within the current zone. The reports also include the peak periods where heating and cooling are required (yearly reports, as presented in Figure 5.14), as well as the day and time for the highest and lowest temperatures (monthly reports). The rationale behind presenting this bit of information to the user, is that it highlights the periods where further consideration and investigation are needed, and thus informing the users so that they can use the settings windows to jump to these specified days, and review further details within the daily reports tab, as well as the zone's overview tab and the recommended guidelines window (discussed later in this chapter).

Figure 5.15: Yearly zone report, highlighting the overall required heating and cooling loads for the zone being experienced. The report presents the dates in day-month format (ddmm) and time in hour-minutes format (hh:mm).

5.6.3.2.3.   Zone Overview Tab

The zone report window also includes another tab, named 'Zone Overview', which also presents specified information and feedback to the users. However, unlike the other reporting tabs, the zone overview forms a rather interactive interrogative conversation (Q&A session) where the users are involved and asked to supply information and feedback on the presented subject(s). More details on the 'Zone overview' tab is presented in the next section.

5.6.3.3.   Interrogation routines

"*In addition to the information management capability of any information system, a DSS [Decision Support System] will support the decision maker in solving ill-defined problems. That is it will support the exploration of the various branches of a decision tree, for example allowing the decision maker to pose a series of 'what-if?' questions*". (Bracken and Webster, 1990, pp. 28)

The interrogation routines are the core mechanism utilised by the MAS of the proposed tool, aiming to dig for information as an initial step for extracting useful knowledge. This is done through analysing all the available information, and creating a conversation with the user aiming to better understand the problem, and find suitable solutions. In this respect, this Q&A mechanism attempts to mimic a tutorial session, and engage the students into a dialogue where effective decisions can be made. The routines are presented within the 'Zone Overview' tab (Figure 5.16), which is part of the reporting GUI offered to the users on their request.

The structure of the questions that later provide the answers formulating the decision tree is based upon a preset database, constituting a set of guidelines and design strategies that are pre-scripted in the engine code, and stored within the data warehouse. These are derived and compiled from a number of resources including Watson (1983), Loftness (1970), Brown and Dekay (2001), CIBSE Guide A (2007), Kwok and Grondzik (2007), and Lechner (2009), Climate Consultant 4.0 - Milne et al. (2009), and Szokolay (2008). As the tool presented within this thesis is a proof of concept, and for demonstration purposes, the

design strategies and guidelines extracted from afore mentioned resources and stored within the tool are suitable for the temperate maritime weather, like that of the UK, and for the northern hemisphere (i.e. southern sun). In this respect, the proposed guidelines (as they stand in the current version of the proposed tool) might not be suitable to other type of climates, like hot-arid for examples, and for southern hemisphere geographical locations. This, in turn, affects the structure of the interrogation routines, and the subsequent decision trees.

The generated decisions trees also vary within the same design (the case-study demo model for example), according to the zone that the user is experiencing, and also according to the thermal condition of this zone. In this respect, the generated decision trees for one particular zone will be different if the user changes the date and time settings from winter to summer; each investigating the current thermal condition of the zone, and walking the user through the problem and possible solutions.

For the decision tree to be structured, a hierarchical investigational process is carried out initially, aiming to formulate a solid base, upon which further decisions can be made. The top level(s) of this hierarchy/tree investigates for some core information that can drive the rest of the process and its branching. Examples include, if the temperatures in the currently investigated zone are above or below the comfort range, and if the zone is facing south. Based on the information derived from the top-level nodes, further levels of the hierarchy can be structured, according to two types of parameters:

- Contextual Parameters: These are information gathered from the game context as well as the data warehouse. For example, the zone that is currently being experienced, its geometrical parameters, areas of its openings, etc. The contextual parameters examine the relevant stored data for this particular context, and accordingly pass the information to the guidelines set to extract the relevant strategies, and generate the next set of nodes.

- User-defined Parameters: These are the information provided by the users, and it normally occurs in one of two cases. The first case for asking users for information is

when the answer to a specific node question cannot be found in the provided data, and a decision cannot be made without this piece of information. The second case is when the tool is presenting a suggestion for a design strategy and seeks the user's views and input if whether this is a route hat he/she is willing to follow in the design, or if the tool should mine for another (next node) strategy.

Each of the stored guidelines has a set of attributes and conditions that should be fulfilled before being released as a node in the decision tree. These attributes and conditions for the set of 'rules' for the data mining technique. These rules might include the users' preferences or input. The rules might also include the standard underlying building physics and rules-of-thumb. For example, a rule might be set for the possibility of single-sided ventilation for a zone according to its depth and height. Based on the investigation process and the defined set of rules, the analysis agent traverses the available set of guidelines and strategies to assess each against the formulated rules. This process ultimately finds a question/guideline that satisfies the rules, and thus the analysis agent generates the next node in the tree hierarchy. Figure 5.16 illustrates a representation of the process of structuring a decision tree node and its question.

Generate
Next Node
Question

*Feedback
from previous
node*

Analysis
Agent

*Examine Feedback
& Update Data*

*Rules
satisfied*

Guidelines

*Extract next
Guideline*

**Data
Analysis**

*Rules NOT
satisfied*

Discard &
Extract next
Guideline

*Assess
Guideline
against Rules*

Rules
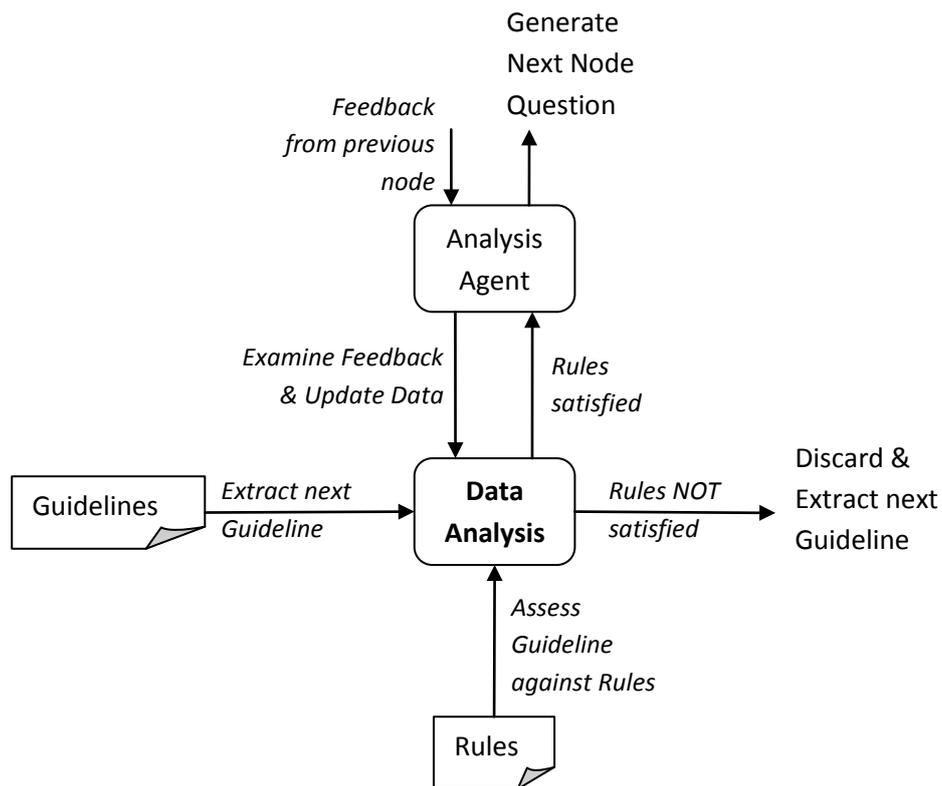
Figure 5.16: Generating a node question in the interrogation routines.

Figure 5.17 presents an example for the interrogation routines within a zone where temperatures are below thermal comfort range. The routine in this example is based on a combination of data warehouse interrogation, and user-based questioning via a decision tree technique for DM. As the aim of DM is to extract useful knowledge, the decision tree traverses through number of levels, each demanding a decision either to stop the process and present the feedback and knowledge gained so far to the user, or to move to the following level of interrogation. The MAS -in its own decision tree mechanism- comes across number of critical nodes (representing the levels of interrogation) where a decision has to be made. The decision in this instance can either be done automatically by the MAS, or it might require the users' intervention, and in the latter case, the MAS needs to establish communication with the users through carefully formulated set of questions.
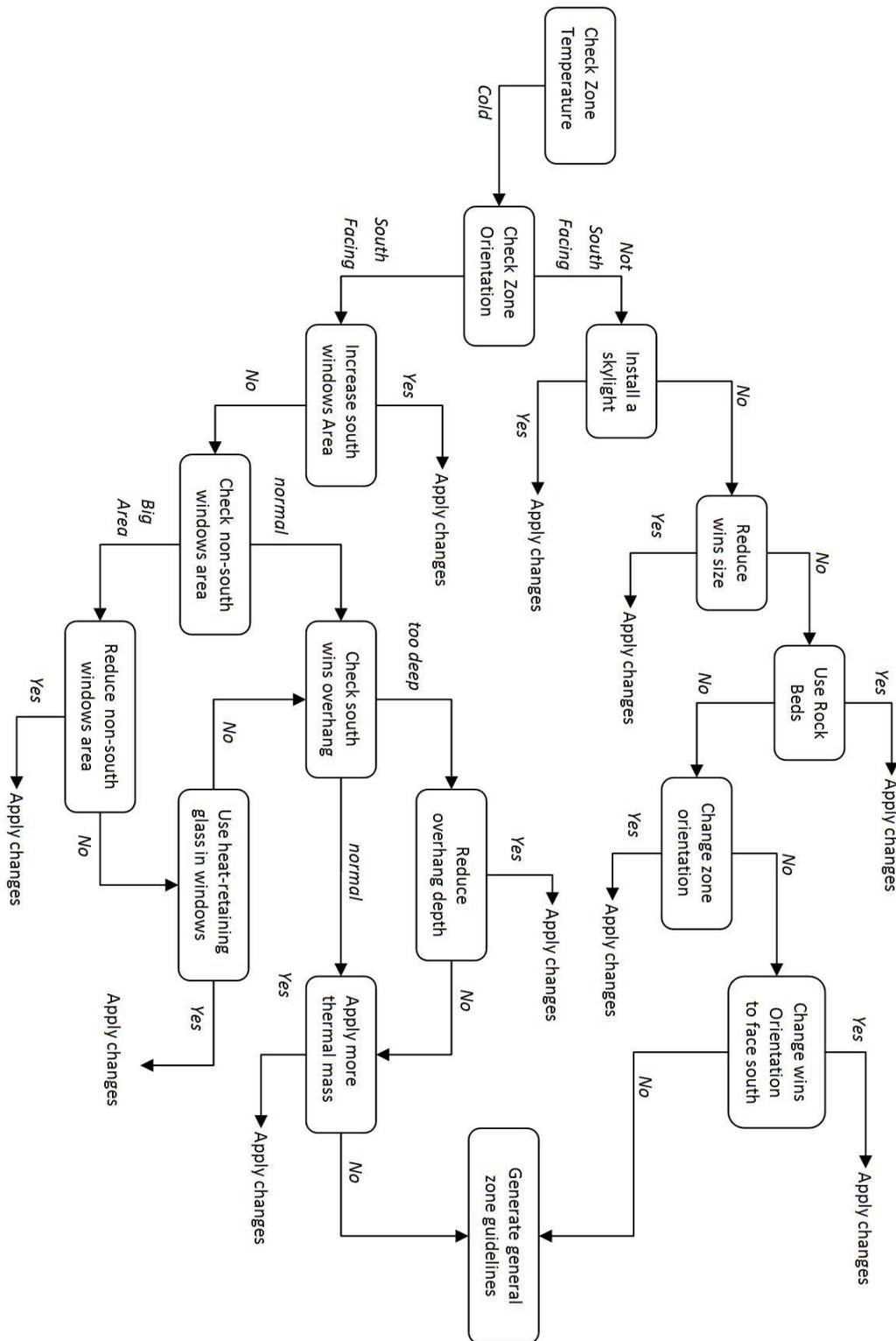
Figure 5.17: Decision tree for interrogation routines with users in a thermal zone where temperatures are below comfort range.

The embedded geometric and non-geometric parameters of the currently experienced thermal zone are dynamically examined and calculated, and subsequently a node's question

can be formed. For example, if a thermal zone has relatively large area of glazing and its temperature is below comfort ranges for prolonged periods, the generated question would be about the type of glazing used (as well as its area and orientation), and in this instance if the user opt to use 'Heat absorbing glass' (Lechner, 2009), as presented in Figure 5.16. In this example the MAS interrogates the psychrometric chart to obtain the comfort ranges, and the CAD model for the area of the current zone, as well as the overall area of the windows used in this zone. The MAS also uses the decision tree mining technique to reach the appropriate question in this situation, and digs the description available for any terms used in the questions that the students (users) may not be familiar with.

Figure 5.18: Example of the users' interrogation routines, with zone-specific and condition-specific formulated questions, and a brief description to any vague terms used in the question wording.

As previously discussed, the MAS will structure the remainder of the interrogation session according to users' input, and the dynamic assessment against the formulated set of rules. For example, in the case presented in Figure 5.18, if the student is using heat-absorbing glass, the MAS will move to the next level asking about the depth of the used overhang in

the south-facing windows, or the possibility to reduce the area of non-south facing windows as they have potential effect on heat loss within this zone. This process is repeated till reaching a decision that offers a satisfactory level of performance, and the users may see it appropriate and aesthetically acceptable.

5.6.3.4. Sun-path Analysis and Representation

As discussed earlier in this chapter, the sun-path representation is an important aspect in terms of the analysis for solar radiation and lighting capacity. It was thus an important requirement to represent the sun position clearly and accurately within the game's environment, and to update this position according to the users' preferences. For that purpose, a geometric node (sphere) was created within the engine's word editor, and linked to the imported CAD model (making the model the central/origin/zero coordinates in relation to the sun object's position. The created sun node was assigned an 'Omni' light object as a child element. This light is a predefined element in the game engine, generating parallel non-converging light rays, mimicking that of the sun within the virtual world. The annual hourly sun position data is retrieved from Ecotect (directly from the location's weather data file) as a combination of two angles (altitude and azimuth) representing its current position, as can be seen in Figure 5.17. The position data is initially stored in the game's data warehouse, which is then processed and filtered to translate each latitude and azimuth coordinates for every stored position into a three dimensional coordinate node.
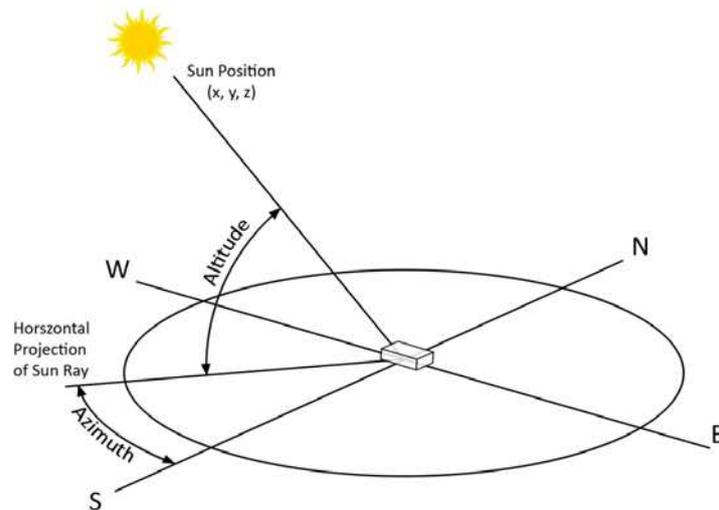
Figure 5.19: Representation of the Altitude and Azimuth solar angles.
Image derived from Lechner (2009).

If the azimuth angle can be denoted as α and the altitude angle denoted as β, then the equations required to obtain the three coordinates for placing the sun object (node) within the virtual game world are:

$$x = \sin \alpha, \qquad y = -\cos \alpha, \qquad z = \tan \beta$$

The coordinates are then passed to the engine code, which will look for a specified node with its name tag (which was defined initially within the game world's template file). After finding the sun node, the position is updated according to the passed coordinates. This process is updated every time the user updates the date and time settings during the game, as expressed in figure 5.10.

The sun-path data is not just restricted on positioning the sun object in the game world, but also can be used as guidelines for design modification and improvement. For example, the MAS can use the mining techniques to determine the periods within a year where a specified zone is overheated, and consequently if excessive solar access is contributing to this problem (for example, if the zone is facing south). The agents then retrieve the sun positions along the overheated periods, and subsequently calculate the required depth of the window's overhang, as represented in the following equation and in Figure 5.18.

$$\text{depth (d)} = \frac{\text{Length (l)}}{\tan \alpha}$$

It is important to recommend an overhang depth that will negate only the periods of overheat, as implementing an exaggerated overhang depth could prevent the access of winter sun that provide required solar radiation.
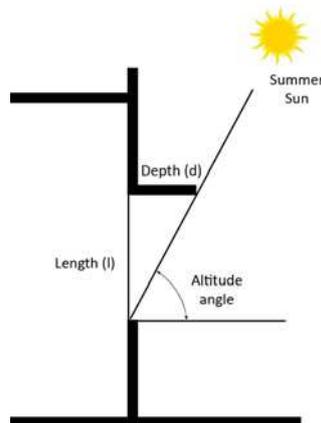
Figure 5.20: Using sun-path data to calculate the required depth of a window's overhang, aiming to protect overheated zoned from excessive solar radiation. Method presented in Brown and Dekay (2001).

5.6.3.5. Guidelines

One of the major components in the proposed tool is presenting and recommending relevant design strategies and guidelines to the users, which assist them in making proper effective decisions that pours back directly into their designs. The guidelines are presented as a sub-element within the current zone's report GUI, along six tabs, as presented in Figure 5.19. The guidelines are a set of data structures stored within the game's data warehouse and loaded once the game starts. However, the specified guidelines are generated according to several contextual factors that form a set of parameters used within the queries formulated by the retrieving agent to pull the relevant information. Unlike the zone's reports and the interrogation routines, the generated guidelines do not consider the current state of the thermal zone, but in fact the tool generates a set of relevant suggestions that apply to the zone in question during the whole year throughout different thermal conditions. The rationale behind this approach is to generalise the presented guidelines - making them applicable throughout the year- and to present a set of effective suggestions

and design strategies that can be applied to the building or current zone, while negating any confliction or contradiction among them. For example, Figure 5.20 presents a design guideline for using/implementing skylight in the current zone, and also presenting the effects and benefits of this guideline in both hot and cold weather conditions. As previously noted, the set of guidelines and design strategies stored in the game's data warehouse is compiled from number of resources (cited earlier in section 5.6.3.3). A full set of the implemented guidelines is presented in Appendix D.
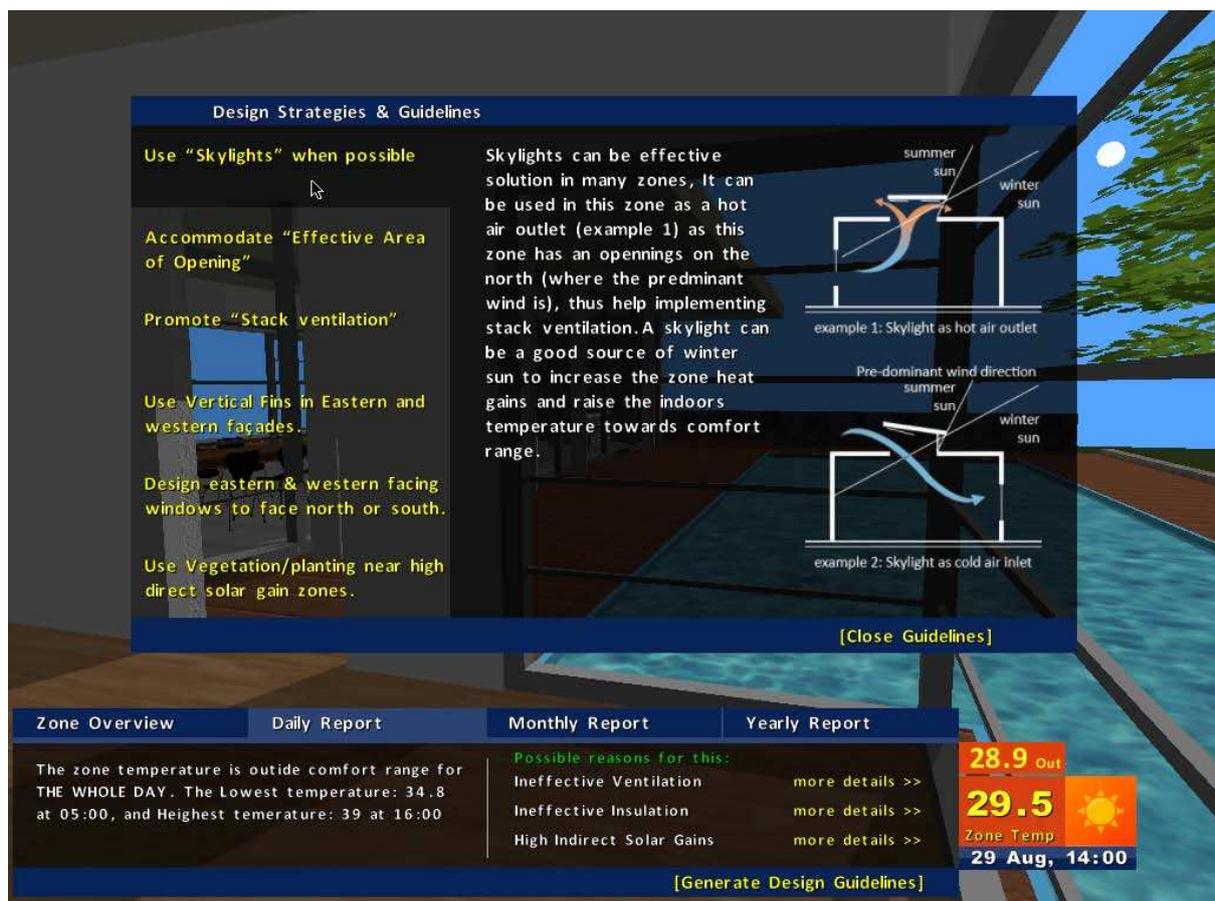
Figure 5.21: Presenting a set of general, building-specific, and zone-specific guidelines in one of the thermal zones, highlighting the benefits of using skylights in this particular zone, along the hot and cold weather conditions.

5.6.3.5.1.   General guidelines

These are a set of guidelines that are of a generic nature, and can be applied -in general- to any building of similar properties and nature within the same environmental conditions. These types of guideline do not seek any specification or building parameters, and hence

don't pose any queries to the game's database for getting any information. The information presented within these guidelines is based mainly on the weather data and the weather file loaded and used in Ecotect. Some current applications, like Climate Consultant[36], incorporate only these types of guidelines in their analysis and feedback to the users. Examples of these guidelines include using suitable foliage and vegetation along the areas affected by direct solar gains, and using specific suitable types of materials and colours.

5.6.3.5.2.   *Zone-specific Guidelines*

These are custom guidelines that are specifically formulated to suit the requirements of a particular thermal zone. In this type, a number of variables and parameters are included in the guidelines that formulate specific suggestions or minimum requirement to achieve effective results. These parameters are pulled from the data warehouse and assessed against a set of built-in relevant formulas/rules-of-thumb (see Figure 5.20), and document any shortage or error noted between the rules and the actual zone settings in the form of guidelines to eliminate this error and push the parameter to the acceptable range.

Examples for zone-specific guidelines include calculating the ventilation requirements for a specified overheated thermal zone, and comparing them with the implemented ventilation strategies. In this case, the MAS gathers relevant initial information about the zone, like its area, dimensions, orientation, number of windows used and their orientation and areas, as well as the effective area of opening. To fulfil its objectives, the MAS might need to extract some contextual information like the predominant wind direction and velocity, and the periods of overheating due to direct solar access, and so on. All the gathered information is used and assessed against the number of rules-of-thumb and ventilation equations (CIBSE Guide A, 2007), and thus feedback is given to the user if any problems are noted. For example, if a zone is too deep for single-sided ventilation, or when recommending stack ventilation, and its effective area of opening to accommodate sufficient air flow rate (Figure 5.20).

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[36] Climate Consultant 5.0: http://www.energy-design-tools.aud.ucla.edu/
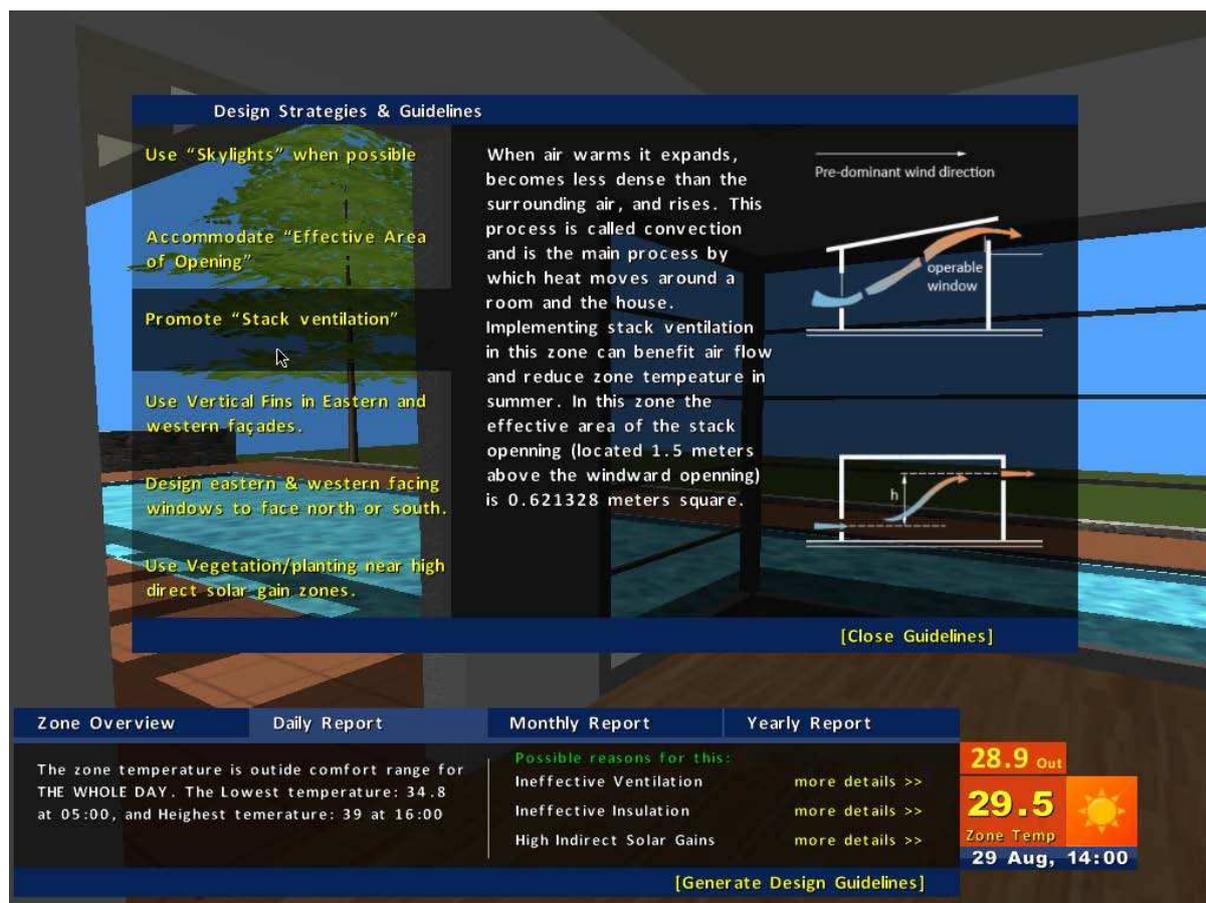
Figure 5.22: Presenting a set of general, building-specific, and zone-specific guidelines in one of the thermal zones.

Formulas and equations used in calculating ventilation requirements and assessing the used ventilation strategies (including single sided, cross, and stack ventilation), as well as the equations used for assessing the effective area of openings for air flow rate assessment), are presented in Appendix F.

5.6.4. Gameplay

Gameplay is the key aspect of any game, and is responsible for motivating players and engaging them into the virtual experience (Costikyan, 2002). Gameplay can be defined as "*an ensemble made up of the player's sensations, thoughts, feelings, actions and meaning-making*", (Emri and Mayara, 2005, pp. 2). The aspects of an effective gaming experience is commonly tied via gameplay, which controls and directs the path of the game and how different game entities and features interact and interoperate. Gameplay -in general- is not a fixed rigid operational setting, but in most cases it offers the players a degree of freedom

allowing them to perform activities and apply previous knowledge that construct and guide their own experience within the gameplay framework.

The 'Gameplay' aspect has a much added significance in a 'serious' educational game, as it controls the pattern of communication and information delivery, and manages the progress of the overall learning experience. Though many efforts made to design engaging educational games have failed, due to over-domination of the educational aspect over the gameplay (Kiili, 2005), a carefully designed and reasonable balanced gameplay can effectively incorporate the educational elements and produce a meaningful educational game. This section discusses the four main aspects constituting gameplay, and how these aspects are reflected in features implemented in the proposed tool, aiming to achieve the rational equilibrium between learning and playing.

5.6.4.1.   The Challenge

One of the most significant aspects affecting players' engagement in a game is the design and implementation of the challenging factors. Challenge in a game constitutes the obstacles that the players face, that stand between them and achieving the games specified or generic objectives. Malone and Lepper (1987) explain that challenges in an educational game should be created by attaining clear and fixed goals that refer directly to the desired learning objectives. They add that it is critical to provide instant and frequent feedback on the players' performance, which should be clear, focused, unambiguous, and supportive. The game challenges and their feedback should generally promote the sense of competence in the players, and should constantly and positively motivate them to achieve better results and/or improved performance.   According to Novak's (2005) taxonomy of gameplay challenges, two types have been implemented in the proposed game as part of the gameplay design:

1. *Intrinsic/Extrinsic Knowledge Challenge*: In this type, players rely on integrating the information they gathered from the game with their previous knowledge and experiences (gained from outside the game world) to develop a knowledge base that can help them progress through the game and achieve the set objectives. Example of

games that implement this type of challenge is 'Escape the room'. This type is deemed appropriate in the proposed educational game, as it builds on the students' already gained experience (promoting experiential learning), and assists them in applying this experience in combination to the newly acquired knowledge to reach an effective design decision. This is implemented in the game through the 'Users' Interrogation Routines'. The game -for example- may propose a design strategy that can improve the current thermal zone's performance, and can ask the user if this strategy is appropriate or convenient. In this sense, the challenge for the users is to learn about this strategy (if they don't already know about it), and assess its feasibility in terms of functionality, aesthetics, and effect on the rest of the building (promoting reflection in action). This assessment is again based on both the students' knowledge, and the information they gathered within the game world.

2. *Perfect Informational Challenge*: This type relies on the presence of almost all the information the players will require once the game has started. The players' role is to assimilate the information in order to yield logical actions. Many strategy-based games employ this type of challenge in their gameplay. In the proposed tool, before starting the game, all the required information is gathered, processed and stored into the data warehouse. It is the player's role to choose what to investigate, and what actions to take (in terms of strategies and design decisions). The challenge in this type is performed through assessing the players' skills and decisions against the set of rules the game builds based on the initial knowledge processed (promoting reflection on action). For example assessing the feasibility of single-sided ventilation against a zone's depth. General feedback on the students' performance (in terms of the general building's performance) is presented through the period reports for each zone, in which the students can note and monitor the improvement of their design with relevance to performance aspects (after applying the design updates to the original model).

5.6.4.2.   The Rules

Game rules are the measures that control different entities in the game world and guide the player throughout the progression of his/her game. These rules define the set of explicit and implicit game goals and objectives, and define the structure to meet them. Rules also control players' actions and abilities in the virtual world, as well as their limitations and constraints. In this respect, rules affect to a great extent the game's 'playability' (Kiili, 2005), which concerns the functional variables affecting the flow of the game. In an educational game, the playability factor should be reflected in the ease of control, immediate presentation of feedback, and reflection on the intended learning outcomes.

The proposed game integrates two sets of rules; static and dynamic. The static rules are those strict conventions that are applicable to all the games within this context, and that are built-in within the core game engine's source code. Static rules can be categorised as geometric (affecting the physical elements and geometry of the game world, like shaders, game physics, and collision detection), or non-geometric (affecting non-physical aspects of the game, like player controls, capabilities, and limitations). Static rules also include 'performance rules', which refer to any standard formulas or equations that the game data can refer to for obtaining feedback (like daylight factor and ventilation equations for example). The dynamic rules -on the other hand- are a set of interchanging parameters that can be altered during the game's run-time. These are mostly user-defined parameters, based on the choices made and general inputs of the users (like their responses to questions asked by the reporting agent, or choice of strategy to apply in a specific thermal zone).

5.6.4.3.   The story

"*Many architects have something to say, a story to tell... The architect's tale can be as captivating and powerful as the writer's*" (OZ, 1988).

Jenkins (1998) argues that each building is designed to serve a purpose fulfilling the functional and aesthetical needs of its occupants. This purpose and its derived parameters constitute the scenario or script of the story the building is telling. Porter and Sotelo (2004) support this statement, arguing that there is no design in silence, and that architects –either

deliberately or not- like all their designed objects to tell a story, and any design without a narrative structure is mute, dull, empty and rather dead. They add that every design is defined by *"Social narratives that influence the behaviour associated with design spaces and objects".* In this respect, the narrative structure of the proposed game is based on the story being told at run-time by the building's design within its geometric and social spaces. This story represents the idea and concepts behind the design and the relations between spaces and their overall functionalities.

The proposed game extends the aspect of the story from its geometric social dimension to include the design's sustainability and the building's performance. The zone briefs and reports presented during the game constitute an integral aspect that feeds into the story of the game, forming something that resembles 'the conflict' in conventional stories. The proposed strategies and zone guidelines presented also contribute to the game's story forming the 'resolution', attempting to rectify any conflicts encountered. In this sense, the reporting agent (though not physically present in the game world) plays the role of the game's narrator, as it is responsible for conducting the dialogues with the player, and generating the briefs, reports, and suggestions to improve the design performance.

5.6.4.4.   The Interaction

Interaction in media is a key aspect for involving and engaging the audience as active participants rather than passive observers. According to *Laurillard* (1998), the idea of interactive media is based on the notions of "lack of imposed structure", and providing the user with augmented "freedom of control". In a game, interaction between the player and the game's virtual entities, according to Crawford (2003) can be achieved as a dialogue, that is *"A cyclic process in which two active agents alternately (and metaphorically) listen, think, and speak"*.

Interaction in the proposed game is implemented along two paths. The first is the interaction between the player and the 3D virtual space representing the building design. In this path, the players investigate and effectively criticise geometric relations and spatial elements of their design with almost complete freedom of control. Malone and Lepper

(1987) argued that "*The ingredients of contingency, choice, and power contribute to the control feature of the learning experience. When the individuals face choices that produce powerful effect, it increases their sense of personal control*". The second path is the interaction between the player and the 'Reporting Agent'. This interaction is achieved through series of dialogues and interrogation routines instigated by either party, sometimes to uncover unclear or missing information, and other times to present feedback and reports, or suggest strategies and guidelines.

Although some researchers praise the importance of representing the reporting agents as a physical entity in the game world (Tallyn et al., 2005), this concept wasn't followed in the development of the proposed game. The representation of the reporting agent in this game follows a non-physical embodiment concept, where it is represented only by the text-based messages and dialogue with the player. The decision was based on these factors.

- The nature of the game -being an educational tool- gives more emphasis on the knowledge transfer and feedback elements. The method of communication and representing the information and feedback to the players in a textual format could prove to be more effective in terms of delivering the message and ensuring students' comprehension. Representing data in the game with other formats (like voice over on the agent's avatar) is quite problematic and much less dynamic.

- It is important to minimise the workload required from the students within the game's editor prior to running the game. Physical representation of the agents in the form of an in-game avatar meant further settings and relations needed to be set with the player and the game geometries (particularly setting the method of communication and data representation).

- The design of the game aimed to minimise distracting the players with unnecessary or pointless elements in the space (like the agent's avatar), giving the greater emphasis and focus on the designed space geometries and the dialogues with the reporting agent.

5.7.   Game's e-Tutoring

E-tutoring in general can be defined as a method that offers learners knowledge transfer, support, management, feedback, and assessment, which involves a significant use of technologies to create a virtual learning environment (TechLearn, 2000). E-tutoring offers a virtual medium that acts as an alternative to the conventional face-to-face student-tutor sessions, and involves the use of multimedia and technology, not only to mimic a standard tutorial, but also to offer the learners tools and capabilities that might not be available in other forms. Benjamin (1994) summarised the characteristics and benefits of e-tutoring, explaining that "*Every learner can, at his or her own choice of time and place, access a world of multimedia material... immediately the learner is unlocked from the shackles of fixed and rigid schedules, from physical limitations... and is released into an information world which reacts to his or her own pace of learning*".

To design and develop the proposed tool to be an effective e-tutoring system, it is important to reflect upon the underlying pedagogical theories that constitute the basis for its development. In this respect, this section revisits the educational theories and directives defined and discussed earlier in Chapter Two (particularly those discussed within section 2.2.1), focusing and reflecting mainly on those introduced as keywords in the principles and objectives for effective sustainable development in education (EDUCATE, 2010; ARB, 2011). These theories (along with the taxonomy presented by Lehmann and Dunne, 2008) include deep, and experiential learning (Biggs, 1999; Kolb, 1984), incorporating the aspects of Motivation, Autonomy, Reflection, feedback/feed-forward, and Assessment.

5.7.1.   Motivation and Learner's Autonomy

Motivation is a fundamental element in effective active learning (as discussed earlier in Chapter Two). Higher levels of motivation and active learning directly address the students' cognitive psychology, and contribute positively towards the students' sense of engagement, acceptance to the presented materials, which subsequently contribute to better comprehension and more effective learning. In this respect, careful design of the virtual learning environment, with its scope of functionalities and the level of students' interaction,

is fundamental for reaching an acceptable level of learning efficiency and participants' motivation.

As the motivational factor was one of the main pragmatic issues and challenges noted in incorporating environmental design and its technologies within the architectural pedagogical realm (as previously discussed in Chapter Two), it was important to address the students' motivation and integrate BPS application into their design process. This was attempted within the proposed tool via two aspects:

- Creating an interactive narrative virtual experience (within a 3D game), which incorporates the technical aspects of environmental design and simulation data, within the qualitative aesthetical geometric experience, and offering them reasonable levels of control and freedom over this virtual experience. This is a context that design students are more familiar with and accustomed to, particularly if compared with the BPS application IDE.

- The proposed tool tends to extract relevant information (via the MAS and DM techniques) and present the abstracted knowledge in a clear, simple, and meaningful format (omitting any highly technical details, at least from the first level of investigation). The tool –represented in the reporting agent- is thus accompanying the student through the whole process (from problem definition, through identifying possible causalities, till reaching one or more directives to resolve the problems and improve the design performance). Within this process, the tool tends to maintain a 'conversation', constantly communicating with the students to seek their inputs and opinions, and present them with feedback and directives.

5.7.2. Reflection

The design of a successful learning context and procedures that effectively fulfil the desired outcomes, according to Biggs (1999), should incorporate explicit 'Reflective Analysis' mechanisms that clearly manifest a 'Deep Learning' approach. As explained earlier in chapter two, students' reflection, according to Schon (1983) is a fundamental aspect in ensuring the effectiveness of the teaching and learning process. Reflection, as argued by

Bartlett (1990), makes students more conscious of the approach they adopt in learning, and thus motivating them to engage more into the process and promote deeper level of learning. He adds that reflection shifts the instructional techniques to be more critical; changing "how to" questions to "what" and "why". Richards (2008) defines critical reflection as the activity of experience recalling, analysing, and evaluating for further improvement.

Based on Biggs (1999) 'Deep Learning' theory, and based on the case study carried out by Hamza and Horne (2007a), integrating design, visualization, and simulation in the same module (on the same project) has a strong potential to instigate a profound level of learning, and have greater effect on the students' level of comprehension, skills acquisition, and achievement of the desired objectives. It can be argued that addressing sustainability and energy efficiency in a design exercise –as solely a technical report in a stand-alone module- might only satisfy a 'Surface' level of learning (Marton and Säljo, 1976), where students are more passive in simply accepting the facts/figures being presented (Soebarto, 2005), which in turn negates the merit of reflection and critical evaluation and deep learning. The proposed game attempts to implement this theory through incorporating an attempt to tutor the students with a walkthrough into their ideas, strategies, and design concepts and decisions. The tutoring incorporated in the proposed tool is adopting a discussion-based scenario, through interrogation and Q&A routines involving the students in virtual tutorial context (as can be seen in Figure 5.16), where they are offered reasonale levels of interactivity, control, decision-making, attempting to create higher prospects for reflective analysis. Tutoring the students in this manner can potentially provide them with logical arguments that give them an opportunity to critically evaluate and analytically reflect on their work and understand the consequences of any design-decisions they make. In this respect, the design of the proposed method can promote deep learning through reflective analysis via two means:

- *Reflection in Action*: The proposed method fortifies this concept in its implemented features, particularly within the interrogation routines. These routines aim to help the student think and review his/her knowledge and theoretical understanding on-the-spot, to assist him/her make the best/optimum decision -based on the current givens- to complete the action. For example, the interrogation routines may present

information relating to the state of the currently experienced zone, and/or any problems noted in it. These routines ask the students to review the current status (providing them with the relevant required knowledge), and recall their own experience, to make a decision on which option to choose and how to make changes to the current design to obtain better performance.

- *Reflection on Action*: The proposed tool can be considered itself a means for supporting reflection on action throughout the design process. The arrangement of the tool to be the final stage in the design process before starting another iteration (see Figure 5.1) makes it appropriate for reflecting upon what has already been accomplished in this iteration (and the stages it incorporate). In this respect, the students would use the proposed tool to reflect on their design decisions, and evaluate the general building performance. The presence of a narrator in the game (a reporting agent) can facilitate and direct the reflection process (through the reports and performance summaries) and help students to formulate informed decisions that can be applied in the following iteration (through the guidelines). The proposed tool can also potentially build upon the students' theoretical background, which is a fundamental aspect to support students' interpretation of physical laws into effective creative architectural forms (Yannas, 2005). The tool can thus assist the students reflect upon the application of these laws/theories into practice (evidence-based learning), and fortify their understanding of the direct implications and effects of decisions made based on their interpretation of the physical laws.

5.7.3. Assessment and Feedback

Assessment contemplates an interactive cooperative relationship between the learner and the presented materials, through which not only the knowledge gained is validated, but also a structure for the learner's performance development is set, (Wiggins, 1993). In the proposed game, the students' learning and knowledge are assessed in an iterative formative manner (formative assessment; Sadler, 1989), within the physical application of this knowledge in their designs. For example, assessing the students' ventilation strategies to cool down an overheated thermal zone. The idea behind this type of assessment is not

grading or labelling the students' work (although it could be argued that this is reflected in the energy consumption reports in the game), but is focused more on presenting informative constructive criticism that feeds back into their knowledge in the form of solid and meaningful design decisions. In this respect, the process is shifted from the notion of examining what they know, or what is known as 'Assessment of Learning', to become building upon their knowledge, or what is referred to as 'Assessment for Learning' (Black et al., 2003). The latter provides accurate relevant specification of opportunities for students to iterate, revisit, and evaluate their work and reflect upon potentials and drawbacks in order to facilitate reaching their desired goals and achieve the overall learning objectives. A high level of learning efficiency through assessment for learning should be coupled with effective formative feedback.

Hattie and Timperley (2007) defines feedback as the information returned by an agent (a lecturer, a tutor, or an application for example), which reflects on the aspects of the learners' performance and knowledge, and helps them build a solid base for further knowledge acquisition. Boud and Falchikov (2007), argue that feedback should allow students to comprehend the level of their performance and in-turn go on to restructure and build on their ability and perceptions which further enhances their learning and achievements (and promotes experiential learning). Sadler (1989) identifies three vital rules for students to benefit from feedback:

- Feedback should help students to have a clear perception of the goals and objectives to be targeted. This benchmark will assist students in understanding the qualities associated with good performance, and motivate them to aim for it. In this respect, feedback should be utilised as a motivational tool (as explained earlier). Feedback's assistance in understanding the goals and objectives will help the students in formulating a set of questions that seek to form a knowledge base for the proposed design and the strategies implemented and/or suggested, thus, directing the students' knowledge path and helping them ask the right significant questions.

- Feedback should carry out a comparison between the actual students' performance and the targeted benchmark, thus identifying the variance in performance level. This

is ultimately reflected in assessing the students' work and their building design performance. The benchmark for the performance is set as designing a sustainable building that can -to a great extent- passively accommodate its occupants. This benchmark is revisited in every design iteration and feedback is given accordingly.

- Feedback should help students to participate and engage in an appropriate action plan which should as a result minimize the performance variance or gap. This rule is interpreted in the game within the feedback provided for the proposed design strategies and guidelines, which allows the student to formulate a set of design decisions that feed into the required action plan.

5.8.   Chapter Summary

This chapter presented the methodology followed for the development and implementation of the proposed tool. It discussed the rationale and mechanisms utilised in each stage of the development methodology, and how this is reflected in the game in terms of features and functionality. These features were in turn addressed and discussed from an environmental design and software engineering technical perspective, and were constantly related to the requirement specifications defined and set in a previous stage of development, based on the research and reviews presented in previous chapters. The chapter then discussed the development process from a pedagogical perspective with reference to number of educational theories. The chapter also analysed how the proposed tool attempt to enrich the student's learning process to ensure better understanding and more effective learning experience. In this respect, the proposed tool attempts to provide the students with a chance to virtually investigate and interact with in their own (un-built) design, where they can discover and build upon their experience through number of embedded learning-support methods (such as the report, interrogation routines, and guidelines). This approach to learning can be effective and suitable to the design education process, due to its cyclic/iterative nature.

The following chapter will adopt a user centred approach to assess the feasibility and functionality of the proposed tool, as well as its suitability to the current educational and

architectural design domains. This is carried out through phases of user testing and evaluation that involves a number of stakeholders including mainly design students and also design tutors and instructors.

Chapter Six:

Method Testing

& Evaluation

6. Method Testing and Evaluation

6.1. Introduction

The previous chapter discussed the methodology -and the different phases- for the development of the research's learning support tool. It explored the formulation of requirement specifications list (including conceptual, functional, technical, etc.), the conceptual design phase (including abstraction, refinement, modularity, etc.), and the detailed design and implementation process. This chapter resumes the discussion of the development methodology, discussing the fourth phase; users testing and evaluation. As such, it explores the approach and methodology employed to address the fifth objective of this research (set and discussed earlier in chapter one), which seeks to obtain the opinions and feedback of the proposed tool's potential stakeholders on the effectiveness, feasibility, and suitability of utilising this tool to facilitate the integration of sustainability into the design curricula and design process.

The chapter starts by discussing the user-centred development approach employed, and the testing methodology, which comprises a number of phases in which the obtained feedback is used to validate the literature findings, and the subsequent requirement specifications for the developed tool. These phases include:

- The preliminary pre-development and in-development interviews.

- The post-development testing and evaluation sessions.

A copy of the pre and in-development interviews' questions and a copy of the post-development questionnaire form are presented in Appendix B. The chapter later focuses on the detailed post-development trials/testing sessions, and its supplementary detailed questionnaire, which comprises five sections, including three related (and similar) to the questions asked in previous phases/interviews. The two additional sections in the detailed questionnaire aim to reflect upon the conceptual and pedagogical aspects of the proposed tool, as well as the interpretation of these concepts into implemented features and

functionalities. The chapter presents the results obtained from each section, followed by a discussion based on the analysis of these results. Finally the chapter concludes with a general discussion on the outcomes of the various testing sessions, and a general reflection on the research's main aims and objectives in view of the obtained results and feedback.

6.2. Methodology and Scope of Users Testing

The methodology of development carried out through this research project adopted an explicit user-centred approach, in which potential stakeholders were involved during different stages of the tool's conceptualisation and implementation, aiming to provide views and feedback that governs and direct the process and provide directives to follow in further development. These views and feedback were correlated directly to the literature that helped guide the tool's development, therefore the tool evolution is a function of this informed approach to system development. In this respect, the users were approached in multiple phases of review and evaluation at the preliminary conceptual stages (as discussed in the previous chapter), to assess the initial research concepts, and perform a pre-development analysis that yield further design specifications for the proposed tool.

The potential users and stakeholders involved with the various testing phases for the proposed tool can be categorised as students and instructors. The participating students were either third-year undergraduate architectural design students, or those undertaking a postgraduate architectural degree (masters or research). All participating students (undergraduate and postgraduate) have basic experience working with at least one BPS application, and have used this application in at least one design project. All of the participating instructors were environmental design lecturers and studio tutors; all considered to be highly experienced users of one or more BPS application; working on and/or teaching number of projects using these applications.

As the tool is designed to be a first point of contact with the novice users (students), the target population for the proposed method is the design students who have never used BPS applications before, and who are in their very first environmental design exercise. However, all participants in the testing sessions had previous experience with at least one project

where they used BPS application. In this respect, the testing session was designed to reflect on their experience with using BPS applications as novice users, and their approach to understand the simulation outcomes and subsequently make informed design decisions. In the case of participating instructors, it was a matter of reflecting on their observations from teaching novice students, the pragmatic issues and barriers encountered, the approaches to resolve these barriers (if any), and how/to-what-extent can the proposed method address and attempt to resolve them. In this respect, the subject participants elected for this study represented –to a big extent- the population that the proposed method is targeting; representing direct users (the undergraduate students), and direct stakeholders (environmental design instructors).

The results obtained from the testing phases were restricted by some key issues that should be highlighted at this point before presenting and discussing these results. These include:

- The participants involved in the testing sessions and experiencing the proposed 'eTutor' were in a more relaxed state, compared to a real tutorial or learning session. In other words, the testing sessions carried out for evaluating the conceptual and functional elements of the proposed tool only demonstrated part of the learning session, which cannot grasp the actual effect of a real one. The views provided by the participants in their feedback are what they envision the tool will (or will not) offer them in their learning process. Using the tool in a real exercise within an iterative design process might yield another set of observations and subsequently opinions (positive and negative).

- The provided responses relied to a great extent on the experience of the participants and their competence in working with BPS applications. For example, more experienced users (who used BPS applications in multiple projects) might find interpreting the simulation data and standing upon performance problems a less problematic task, compared to the less experienced ones.

- The testing sessions were designed to be rather thorough and extract as much valid and relevant information and feedback from the participants as possible. The

questions asked in these sessions aimed to cover all the aspects discussed throughout this research thesis, and that directly affect the environmental design process. In this respect, the testing session was relatively long (around 45 minutes in average for the post-development trials), discussing the structured questions, as well as obtaining feedback on some of the recorded responses through unstructured questions. For this purpose, the number of participants in the testing sessions was limited to 54 participants.

- Although this sample of participants represents the tool's stakeholders and the target population of its users, the recorded responses and the feedback provided is only indicative, and by all means not conclusive. The feedback from these testing/trial sessions aims to assess the acceptance and feasibility of incorporating the proposed method in the teaching process, how this might affect the level of motivation to integrate BPS applications in design iterations, and how the tool is envisioned to affect students' understanding and interpretation of the simulation outcomes. These sessions also aim to stand upon low-level requirements that form further specifications for the further development and implementing a final version of the tool. The obtained feedback thus addresses these aims, however, due to the relatively small sample of the participants, and due to the fact that the method was not actually tested within a real learning context, it has to be highlighted that the conclusions drawn from these sessions is just an initial indication, and further trials and testing sessions will be required before validating the recorded findings.

6.2.1. Initial Users' Review and Evaluation

These initial (pre-development and in-development) sessions were carried out with the users individually, and in some cases small (three or four students) focus groups, involving a total of 19 participants (5 instructors and 14 students). The questions in these sessions were all open-ended (see Appendix B), offering the participants a high level of flexibility and freedom to express their thoughts and present their opinions and suggestions. These sessions aimed to validate the initial research findings relating to the challenges facing the integration of sustainability in the architectural design curriculum. The initial sessions thus

complemented the formulated conceptual and functional requirements presented earlier in Chapter Two (section 2.5.1), and assessed the initial interpretation of the research concepts and aims into the developed tool. Moreover, these sessions led to refinement of the research concepts and further (conceptual and technical) specification for the supplementary tool's development. The yielded complementary requirements include:

- The tool should be very motivating to the users, to push them to not only overcome the motivational challenges for integrating sustainability, but also to spend the time and effort to build and use this tool/game.

- The tool should encourage the students to explore and investigate more into the sustainability concepts; i.e. it should promote deep learning.

- The tool should communicate constantly with the student, and create a conversation that can lead to better understanding of their design performance, and the implications of any decisions they make.

- The students need a quick overview of the building's (and its different zones') performance in terms of energy consumption and/or carbon emission. They also need a quick and easy overview of the lighting analysis in each of the building's zones.

- The tool should extract the information and present it in an abstract/summarised and cognitive format, in an attempt to eliminate any ambiguity in the presented information, which could be confusing for the students leading to un-informed design decisions.

- The students should be offered a short and quick access to the 'abstracted' information/knowledge (qualitative and/or quantitative), and a quick interpretation of this information into design directives.

- The information should be presented in a hierarchical manner (in multiple levels/layers) to avoid overwhelming students initially with too much information.

The tool should thus offer more details and links to the underlying physics in different sub-levels, which can be investigated by the students for obtaining deeper understanding of the information and how the design decision is subsequently derived. The students should be encouraged/motivated to explore each level of this hierarchy.

- The tool needs to clearly highlight the performance problems in the design, and link these problems to one or more possible reasons.

- The tool needs to provide directives on how to resolve the highlighted problems, and those should be linked back to the environmental design concepts and theories and the underlying building physics.

- The tool should incorporate guidebooks and rules-of-thumb, and apply these guidelines and rules to the specified design elements.

The feedback obtained from the testing sessions (including pre-development and in-development sessions), are coupled with the literature findings and conclusions, and interpreted into the sets of conceptual, functional, and technical requirement specifications. These requirements are categorised and presented in appendix A. Selected users' responses in these initial sessions/interviews are also documented and presented in appendix C.

The questions from these two phases were carried forward to the final post-development testing and evaluation (presented within the sessions' questionnaires). In this respect, the detailed analysis of the questions asked in the initial interviews is incorporated with the analysis of the same/similar questions that were presented in the post-development sessions, and thus the results of all the user trials are combined. The next section discusses the methodology of these final user trial sessions, followed by detailed presentation and discussion of the obtained results and feedback.

6.2.2. Post-Development Detailed Trials

The post-development user testing sessions took part after the requirements -derived from the literature findings and the initial pre-development and in-development interviews- have been interpreted into features and functionalities within the proposed tool (as discussed earlier throughout Chapter Five). These sessions involved the presentation of the proposed tool to the participants, as well as a detailed questionnaire (a copy of this questionnaire is presented in Appendix B, and the detailed analysis of the results and feedback is presented in the next section of this chapter). The main directive for the design of the session's questionnaire was to divide it into multiple series/sets/sections of related questions, also referred to as '*questions modules or sequences*' (Oppenheim, 1998). Each of these sections is concerned with a particular '*variable*', which is directly related to the main aims and objectives of the research. It is important in the design of these sections to create an explicit link between them, making a clear and uninterrupted flow of information between multiple sections, which ultimately help in keeping the participants interested and motivated to continue with the trial session.

In this respect, the questionnaire was structured in two parts, with the first part comprising three sections/modules, and the second comprising two more. The first part of the sessions was carried out before presenting the proposed tool/game, and generally sought the participants' responses, views, and opinions on their current approach to environmental design coupled with the utilisation of BPS applications, as well as their current aptitude and experience with 3D modelling software as part of their design development process. This part also questions the participants' experience with 3D games, and their acceptance of this medium as a potential learning context. In this respect, the questions asked in this part of the questionnaire were similar to those asked in the initial interview, and addressing the first two aims of the research and their derived objectives (discussed in Chapter One, section 1.3). The importance of these questions lies in validating the literature findings -in context of the project's main aims and objectives- which were the basis for the development of the proposed tool. The three sections in this part aim to prepare the scene for the participants, get them to thoroughly discuss multiple aspects of the 'problem' (related to the research hypothesis), and thus formulate a basis for comparison of

methodologies and approaches; which will be debated and compared to the proposed method in the second part of the questionnaire. The second part directly sought the participants' views, opinions, and feedback on the proposed method and its related tool. The first section of this part investigates the conceptual and pedagogical aspects of the tool, while the second section probes the effectiveness of interpreting these concepts into the tool's features and functionalities.

The questionnaire generally consists of a series of 'factual' and 'attitudinal' questions (Rodeghier 1996); the factual questions mainly demand actual information (facts) from the participants (based on their previous experiences), and are mostly arranged as either single or multiple response questions (Payne, 1951), where the participant gets to elect one or more appropriate responses. The attitudinal questions, on the other hand, are mainly asking the participants for their opinion on specified matters, and their acceptance and/or agreement on issues related to this matter. This type also demand the participants judgment on a proposed and or existing subject through a selected rating system, similar to Likert uni-dimensional scales (Rodeghier 1996); normally consisting of five (or more) position points scores. The first part of the questionnaire thus relies more on the factual type of questions, while the second part adopts a more attitudinal approach.

The questionnaire thus comprises a combination of both 'closed' and 'open-ended' questions, as an effective methodology to drive deeper evaluation and more thorough justification and reflection, and obtain a variation of quantitative and qualitative responses (Jordan, 1998). Although closed questions are more specific, easy to process and analyse, and important in obtaining facts, quantitative data and relating to the participants' previous experiences, this type has been criticised for enforcing preset responses to the participants, and depriving them from spontaneous responses, and from the choice to provide their own answers and/or views (Converse & Presser, 1986). Open-ended questions, on the other hand, are not bound by the moderator's limit of responses (like in the case of closed questions), and thus can widely expand the range of views (Oppenheim, 1998). Although this type of question normally requires more time and effort (from the participants to respond, and from the researchers to analyse), it is considered most effective in probing the effectiveness and feasibility of a conceptual hypothesis. As such, the questionnaire

demanded 'facts' using closed questions (like Likert scale questions) to record an average response (for example, the effectiveness of a feature in the proposed tool). The questionnaire coupled those closed (attitudinal) question with open-ended ones to seek the justification and the rationale behind the selections made in earlier (factual) questions.

The questionnaire session involved 28 students and 11 instructors, and was carried out in the presence of the moderator (the researcher). This was deemed appropriate due to the need for the moderator's intervention in multiple occasions during the session to direct the flow of the whole session, and introduce external aspects to the participants. For example, the moderator needs to introduce an interim discussion that comprises presenting samples of a BPS application's printed simulation data outcomes (graphs and charts for example) -as discussed in more detail later in this chapter- and also the need to present the proposed game demo with its controls, features, and functionalities between the two parts of the questionnaire. The moderator's presence is also considered important for obtaining a more in-depth analysis of the participants' responses and opinions (particularly in the attitudinal rating questions). The moderator's intervention sought to achieve certain quality of outcomes and ensure the effectiveness and validity of responses and feedback, and whilst the moderator was not trying to interfere with the experiment overall, the intervention was aiming to get positive or negative correlations with the research hypothesis. As such, and due to the length of the questionnaire, the session was arranged more like a structured interview with interim sub-sessions. There was careful attention, however, not to affect the responses or bias any of the participants' views and/or feedback. In fact, the participants were made aware that it is important for the sake of research and the development of the proposed tool to clearly stand upon the negatives and positives of the elements discussed throughout the session. The remainder of this chapter discusses in more detail the five sections in the post-development testing session questionnaire, with a review of the aims and objectives of each section, and detailed analysis of the participants' responses and feedback.

6.3. Post-Development User Trials' Analysis

6.3.1. Section One: Digital 3D Modelling

This section aims to investigate the design students' regular procedure and behaviour towards visualising their conceptual design ideas, focusing mainly on the utilisation of 3D modelling applications to build virtual models of their designs. The set of questions listed in this section aims to realise the significance of 3D environments to the development of their ideas, and also aims to realise how often –and at which stages of development- the students tend to exploit their 3D models for more comprehensive design analysis. Knowing these aspects is deemed fundamental to the development of the proposed tool and its specifications. As the tool is primarily based on students importing their design models into the game engine's editor (which constitute the geometry of the game's virtual experience), it is important to get an overview as to when these models are normally generated and used, which in turn gives indication as to when the proposed tool will be used during the design development process. It is also important to understand the level of competence that the potential users possess to generate and amend their design models at different iterations. This is an important conceptual aspect in the tool's specification, as it can affect the users' motivation and acceptance for using the tool, which mainly relies on carrying out constant updates and amendments to the design model until a satisfactory performance level is reached.

6.3.1.1.   Results Presentation
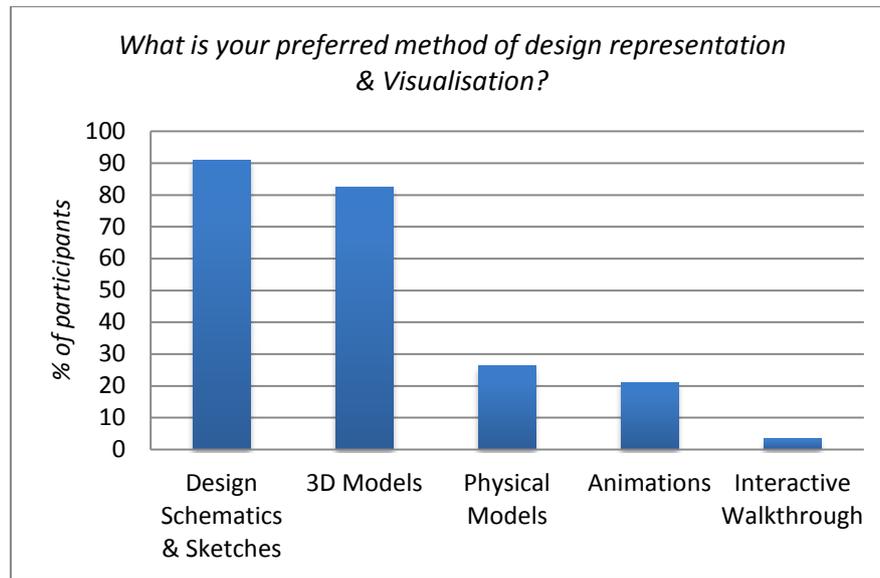
Figure 6.1 Participants' responses on their preferred method(s) of design representation.

The first question in this section asked the participants about their preferred method of design visualisation and representation (Figure 6.1). This question aimed to generally identify the popular methods that designers utilise to develop and iterate their design ideas, and the position that 3D modelling occupies in this scale. Analysing the responses indicates that students prefer two main representation methods, namely 'design schematics and sketches (91%) and '3D models' (82%), while other methods are considerably less favoured. In discussing the results with the participants, they explained that they preferred sketching as it is the fastest and easiest method to interpret/draw ideas. They also explained that using 3D modelling applications (like 3ds Max or Google SketchUp) is becoming common practice, and that they tend to exploit it more into their projects as they gain more experience and familiarise with different features of the software. Participants who selected physical models and animations (26% and 21% respectively) believed these methods would be more impressive than sketches and/or 3D models, however, they also indicated that the downside for these methods is that they can be laborious, and require extensive time (and computer processing, in case of animations). When asked if they normally develop a 3D model for their designs (question 1.2, which was a filter question that leads to a focused set

for the participants answering 'yes'), 96% of the participants indicated that they would (at some point within their design development process).
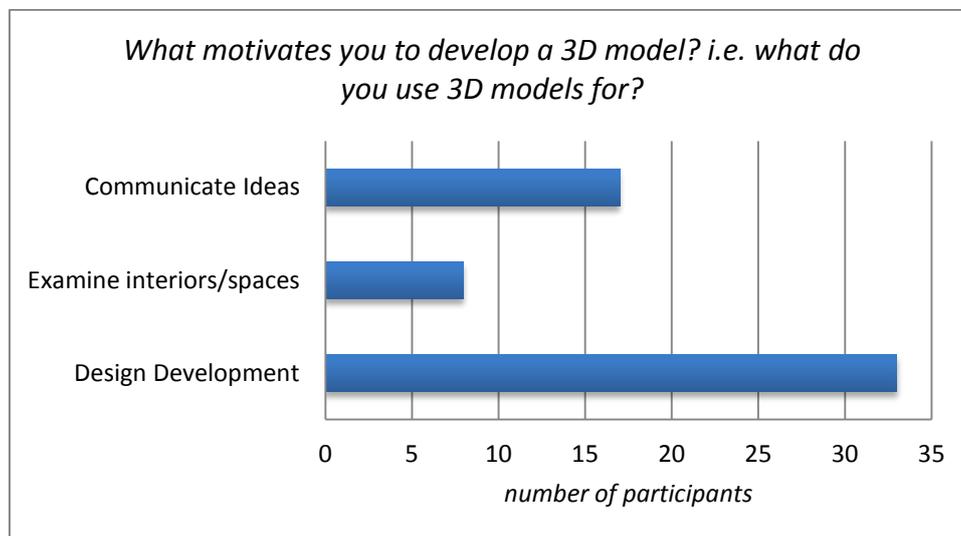
Figure 6.2: A categorisation of participants' responses on the motivation to develop 3D models in the design process.

The third question (1.3) aimed to obtain the participants' reasons/rationale for developing 3D models (Figure 6.2). The responses were collated into three categories; the first (56%) was using 3D models as a method for developing the design, in terms of examining masses and geometries. The second (30%) was using the 3D model as a method of communicating the design idea to other parties (such as colleagues and tutors), and the third category of rationale responses was to examine the design interiors and spaces and adjust higher level of detail accordingly.

How important are the digital 3D models to your design process?
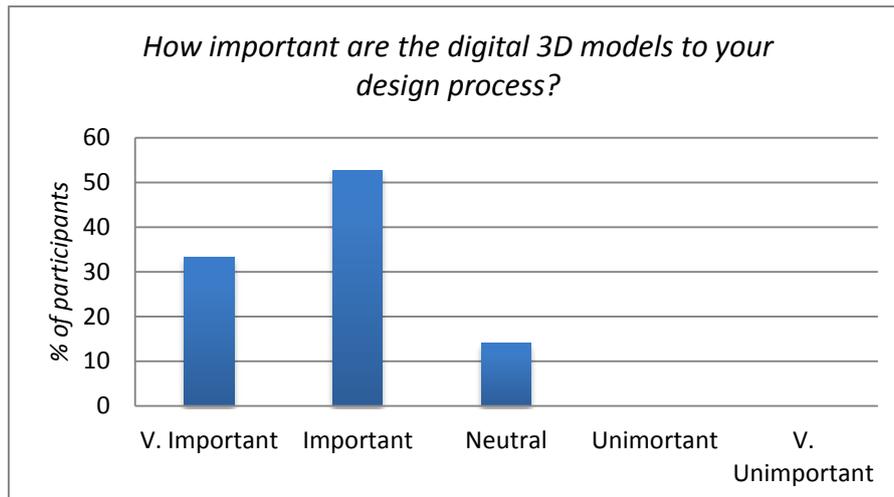
Figure 6.3: Participants' views on the importance of 3D models in the
design process.

The next question in this section used a Likert scale to obtain the participants' views on the importance of a 3D model to the design process (Figure 6.3). The aim of this question, combined with the previous one, is to get an overview of the level of motivation that the students have towards developing 3D models in their design process, which directly affects the expected level of motivation for using the proposed tool. In this question, the average score on Likert scale was 4.2 (just above the 'important' node). The majority of responses (86%) indicated that the 3D model is an integral part of the design process, and that in turn; students will be motivated to develop 3D design models, while only 14% believed that 3D models are of neutral importance and that they can still produce a good design without having to develop a model.
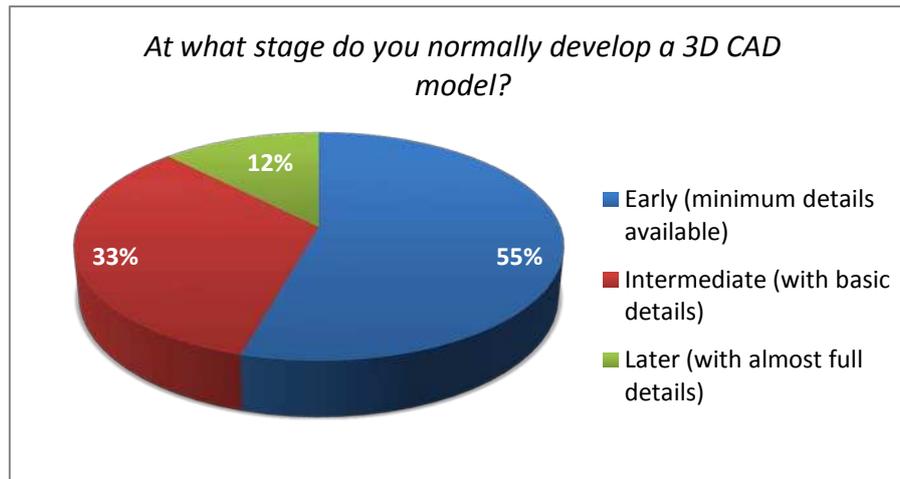
Figure 6.4: The stage at which a 3D model is developed.

Building upon the feedback gained from the previous questions, the next question (Figure 6.4) asked the participants about the stage –in the design process- at which they normally develop a 3D model. The rationale behind this question is to get an understanding of when the students will have a preliminary 3D design model, which is an indication as to when the proposed tool can be integrated within the process. In this question, 55% of the participants indicated they tend to develop a 3D model early in the design process with minimum details, while 33% noted they would wait until there is a reasonable/basic amount of detail available to start developing a 3D model. Only 12% tend to wait until late in the process (with high levels of detail available for the building) to develop a 3D model. In the discussion following this questionnaire section, the students who normally develop a 3D model at the earlier stages of design added that they sometimes tend to develop their conceptual idea directly in a 3D modelling software, and that this initial mode is ultimately subjected to series of modifications adding more refinements and details as the idea progresses. In a later question in this section asking about the level of confidence that the students have for constantly applying changes to the 3D model, the average score on Likert scale was 3.9, which is just below the 'confident' node. The majority of participants (around 56%) indicated that they are confident (22% even indicated that they were very confidant) to apply modifications as the design iterates (with 18% indicating that they are neither confident nor unconfident, and only 4% indicating they were unconfident).

	Using/Developing 3D models at early design stages	
	Advantages	**Disadvantages**
A	Facilitates detecting design flaws and errors (through 3D visual confirmation of masses and geometry) of the design idea in its conceptual form.	It could be time consuming for an already tight schedule.
B	Important to develop the idea further, and add more details to the fairly new ideas.	Require high technical skills to be able to develop and amend.
C	Easier to communicate to colleagues and tutors.	Requires a minimum level of detail before it can be constructed.

Table 6.1: Categorisation of participants' responses on the advantages and disadvantages of using 3D models at early design stages.
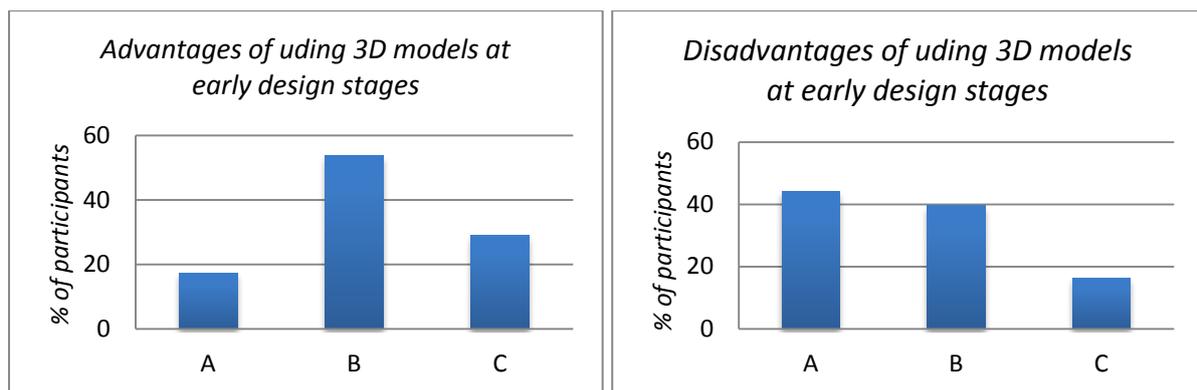
Figure 6.5: Percentages of participants' responses in relation to Table 6.1

The section concludes by asking the participants for their views on the advantages and disadvantages of developing and using 3D models at the 'early' design stages. The responses obtained are collated, categorised, and presented in Table 6.1, and the percentages contributing to each of the responses' categories is presented in Figure 6.5.

6.3.1.2.   Discussion

The feedback recorded for this section gives an indication that design students -in general- are well accustomed to designing and representing their ideas in a virtual 3D context. The highest percentage of participants tends to exploit 3D models at various stages of design

development, with particular interest on the earlier stages. They noted that the 3D models are no longer for final presentation and communication with other parties in the design project, but indeed an essential tool for the ideas development. Around 80% of the participating instructors noted that they generally encourage their students to use 3D modelling applications at the earlier stages of the design in particular, as this promotes better reflection and deeper understanding on different aspects of their design, and improves their spatial awareness of masses and geometric relations.

In this respect, the feedback confirms the earlier literature findings (presented in chapter two), and supports the idea that design students like to think spatially (Srivastav et al., 2009; Prazeres; 2006), and 'reflect on' their design ideas through the development of visual elements that they can interrogate and amend. Spatial 3D design visualisation is thus a reflection of the conceptual model developed by the designer that relates to and feeds-back into his/her cognitive schemata. This –in turn- feeds into a key requirement for the tool's development; which is maintaining a visual spatial 3D context for delivering learning materials (in this case, a 3D game environment). The next section of the questionnaire builds upon the participant's views on 3D environments, and examines their experience and readiness to visualise and represent their design ideas in an interactive real-time virtual context, like that of a game.

6.3.2. Section Two: Games in Design Visualisation and Education

This section addresses the second main objective [B] for this research (set earlier in chapter one), intending to probe the design students' views on games as a method for learning in general, and a method to be incorporated into their design education process in particular (focusing later on the environmental aspects of design). The questions set in this section investigate the students' opinion and experience of 3D games –as a general paradigm- as well as their willingness and acceptance of incorporating this paradigm into their learning process. The participants are thus asked for their opinions on the potentials, strengths, threats, and weaknesses of adopting such learning approach, in an attempt to formulate further specification that reflects the expected potentials and eliminate any envisioned threats and disadvantages.

6.3.2.1. Results Presentation
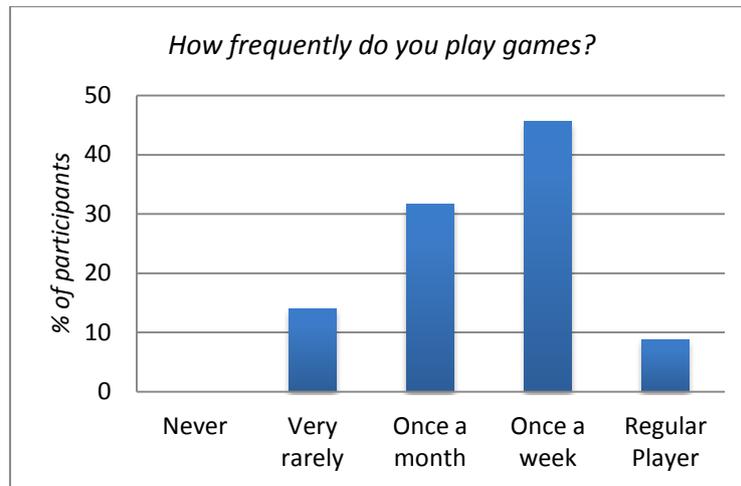
Figure 6.6: Participants' responses on the frequency of playing games

The participants were initially asked about their experience with gaming, and the frequency of getting involved within a 3D gaming experience (Figure 6.6). The highest percentage of participating students (46%) confirmed that they play once a week and 9% noted to play even more frequent, while 32% noted playing once a month on average, and 14% indicated that they play very rarely (less than once a month). In the discussion that followed this question, the frequent players related the increase in frequency of playing to number of factors; the engaging nature of games, the rapid advance in processing technology which results in much higher quality of graphics and visual effects and thus a vastly improved gaming experience, and finally the wide availability of games on number of platforms (computers, consoles, mobile devices, and tablets).
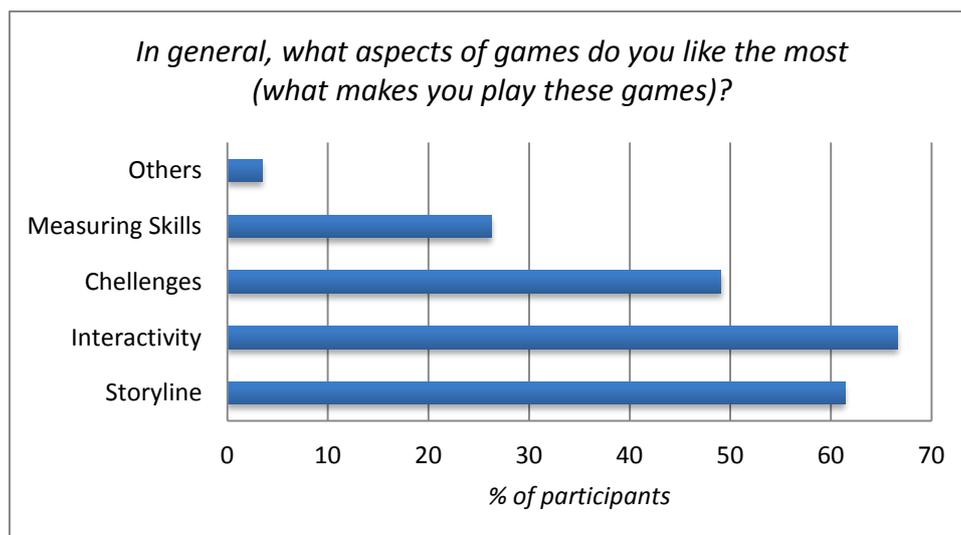
Figure 6.7: Motivational aspects that affect playing games

The following question aimed to obtain a justification to the first, thus asking the participants to identify the elements that they find most motivating in the game, given the chance to select more than one aspect (Figure 6.7). The biggest percentages of the responses indicated that interactivity and the storyline are the most motivating elements in the game (scoring 67% and 61% respectively), followed by the games' challenges (49%).
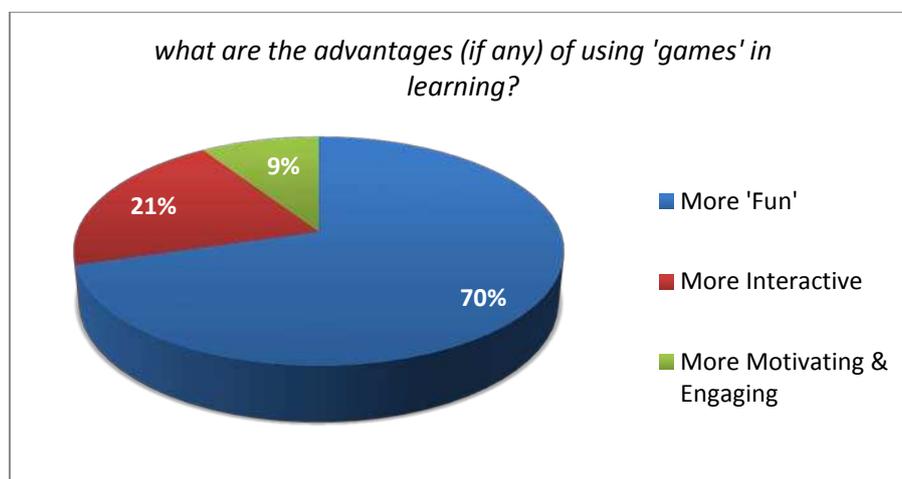
Figure 6.8: Categorisation of the participants' responses on the advantages of using games in learning.

Around 47% of the participants indicated that they have experienced –at some point- using game in an educational context to support their learning process, mainly at school within the subjects of Maths, History, and Science. Those participants mentioned that using games

to support learning was positive and indeed improved their experience and overall comprehension of the presented materials. When asked about the advantages their responses were categorised into three categories (as illustrated in Figure 6.8). Around 70% of participants related the advantages of utilising games in education mainly to the fact that games are normally associated with '*fun*', thus breaking the conventional strict learning environment. Only 21% of the participants saw that games are more effective because they offer more interactivity, and 9% related the advantages to that games are more motivating and engaging, explaining that learning in this case is '*much better than just reading a book*'. When asked about the problems/challenges encountered with educational games, none of the participating students responded, and all the recorded responses were from instructors. Some felt that there can be big threats associated with using games for learning if they are not well designed and structured, and adhering to the context and scope of the learning subject. Others added that paying careful consideration to the characteristics and expectations of the users is essential; otherwise the game could be '*distracting*' and '*disadvantageous*'.
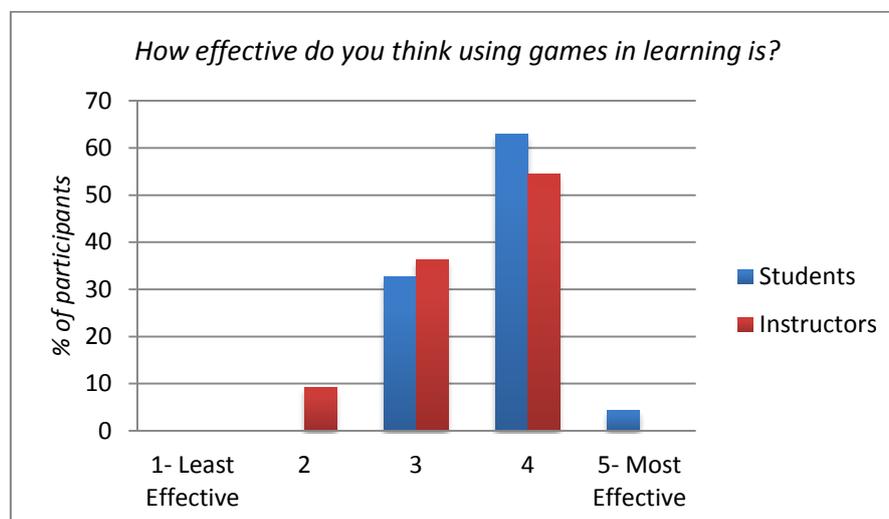
Figure 6.9: Participants' rating of the effectiveness of incorporating games
in education in general.

The participants were then asked –on a Likert scale- to rate the effectiveness of incorporating games in educational contexts. The results (depicted in Figure 6.9) show that this concept got an average score of 3.7 from participating students, and 3.45 from instructors, which are both in-between the 'neutral' and 'effective'. There is a considerably

strong neutral base, which was justified and related later to the concerns about the careful design and implementation of the game to suit the learning context and objectives (as discussed earlier in this section).

	Using Games for design representation and visualisation	
	Advantages	**Disadvantages**
A	Easy to navigate and control to explore more details about the design	Requires learning a new interface/application that is added to those already used in the design process.
B	Can set levels of interaction with various design elements.	Additional amount of work and time is required to build and run the game.
C	Can support multiple simultaneous users' connections	Can be de-motivating if programming is required.

Table 6.2: Categorisation of the participants' envisioned advantages and disadvantages for using games for design visualisation.
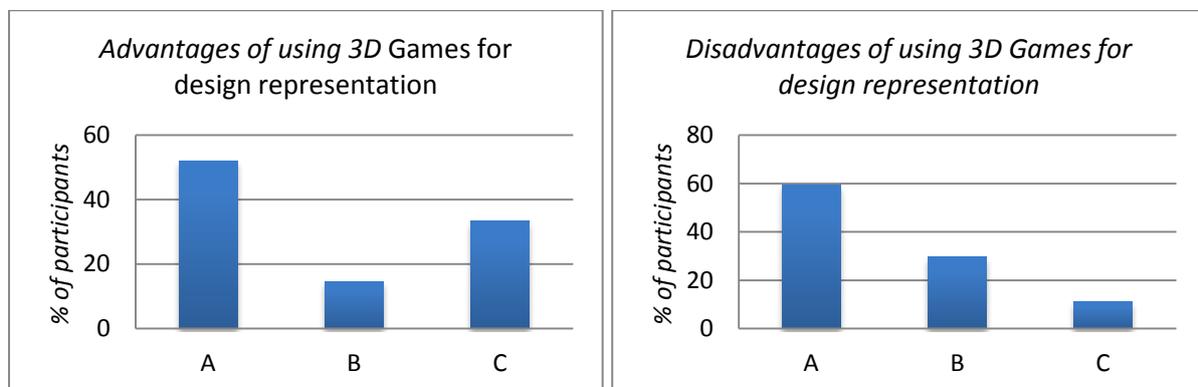
Figure 6.10: Percentages of participants' responses in relation to Table 6.2

This section concludes by criticising 3D games as a potential medium for design visualisation and representation, mentioning the envisioned (or experienced) advantages and disadvantages of this approach. The responses were collated into three categories (as presented in Table 6.2), and the percentages of participants related to these views is depicted in Figure 6.10.

6.3.2.2.   Discussion

This section discussed the notion of 'games'; with the prospect of employing it as a host medium to deliver educational materials, and as a potentially effective means for design visualisation. In so doing, this section reflects back on the second main aim of this research (aim B), and its derived objectives. The initial part of this section indicated that the current generation of students are fairly familiar with games, and that playing games is considered an important part of their life. This relates back to the literature findings discussed in chapter three (section 3.2); reflecting on the term 'gaming generation', and that the current generation can be considered 'digital natives' (Prensky, 2001; Aguilera and Mendiz, 2003). As mentioned in the analysis, this can be related to the wide availability of games' platforms, as well as the vast advances in computer processing capabilities.

The feedback provided from this section also indicates that interaction is one of the key motivational aspects for playing games, and this was an element that was deeply exploited in educational games in particular (as discussed earlier in Chapter Three). Interaction, accompanied by an effective narrative, increases the sense of control and degree of freedom offered to the players in the progression through the game and control of the events unfolding. Reflecting back on some of the literature findings from chapter three (Young and Riedl 2003; Bayon et al., 2003; Denis and Jouvelot, 2005), the interactive narrative structure of an educational game can offer higher level of engagement and involvement (where the students are more active participants), which gives educational games the edge over the conventional learning methods (where the students are more passive observers). This was reflected in the recorded participants' responses that educational games are 'fun', interactive, engaging, and motivating.

From a pedagogical perspective, the high level of motivation associated with playing games is interpreted into a series of challenges which the players/students can choose to repeat to improve their performance and/or score. As discussed earlier in chapter three, this concept has been widely exploited by educators in many disciplines, as it promotes deeper learning through reflection, self-assessment, and ultimately effective feedback. This was reflected as a key conceptual requirement for the design and implementation of the proposed tool,

where an interactive 3D virtual environment was elected to be the host medium for delivering environmental design-related learning materials and concepts. Chapter five discussed the concepts of implementing rules and challenges in the proposed tool as part of the 'gameplay', which can be related back to the concepts of 'serious' games (Zyda, 2005) and in particular those designed for education and training.

The section indicated an initial acceptance of the participants to incorporate 3D games in their design exercise, which validates the conclusions highlighted by number of researchers including Shiratuddin and Thabet (2002), Woodbury et al. (2001), and Yan and Kalay (2006). In this respect, the 3D games can be considered a familiar ground for architects to thoroughly explore and interrogate their designs, and are deemed to be an effective motivational factor which can help integrating sustainability concepts and measures.

6.3.3. Section Three: Using BPS Applications

This section seeks to address the first objective set for this research (Aim 'A', discussed in chapter one), aiming to obtain direct views and insights from design students and instructors about the utilisation of BPS applications in the design exercises, as a method for integrating sustainability into the design process. In order to attain this aim, the questions set in this section were structured to obtain the users' feedback and views on the approaches and procedures they currently follow for assessing their design's performance and fulfilling its environmental requirements. The questions focus mainly on the methods and mechanisms they employ to simulate their buildings' behaviour and use the outcomes to make further design decisions, as well as the challenges they encounter throughout this simulation (mainly through using BPS applications) to the point where they reach an understanding that they can interpret into effective design decisions. The feedback obtained from this section relates directly to the findings from the literature discussed and reviewed in chapter two, and underpins the tool's requirement specifications.

6.3.3.1. Results Presentation
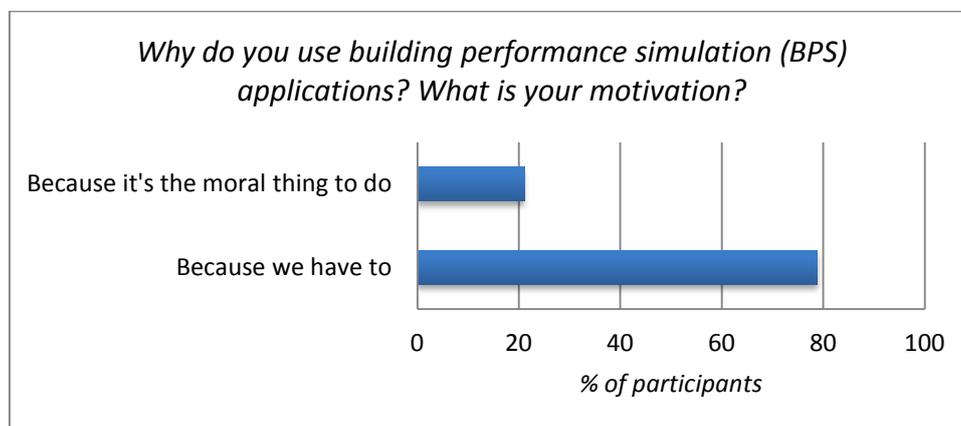
Figure 6.11: Percentages of participants' responses on the motivation to use BPS applications in the design exercise.

The section starts by obtaining the level of experience of the current participant, which is very important in analysing the responses and drawing conclusions for the rest of the questions in this session. Following that, the section probes the participants' motivation to use BPS applications in their design process. The responses for this question fell under two

main titles; moral and obligation (Figure 6.11). Around 79% of the participants explained that the main motive for integrating sustainability in the design process is the pressure to do it. They added that this pressure could be either from governments and international bodies and organisations, or –in a smaller scale- from the tutors themselves to satisfy educational requirements. Although these participants still agree that integrating sustainability is the right and ethical approach in order to preserve resources and reduce the negative effect on the environment, they noted that without the pressure, they would have probably given it a much lower priority in the process.
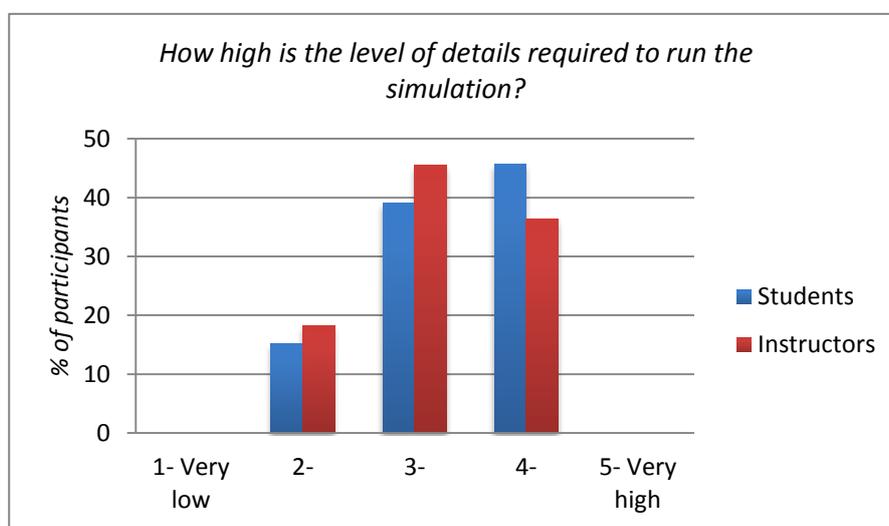
Figure 6.12: Participants' views on the level of detail required before running the simulation

Regarding the levels of detail that is normally required to be fed/input into the BPS application prior to initially running the simulation process, the average score on Likert scale for participating students was 3.3, and for instructors was 3.2 (Figure 6.12). From these figures, it can be seen that a moderate to high level of detail is normally required to run the simulation. In further discussions with the participants, they explained that the required level of detail increases as the design develops, and that towards the end of the process, a relatively high level of detail should be available and input into the BPS applications.
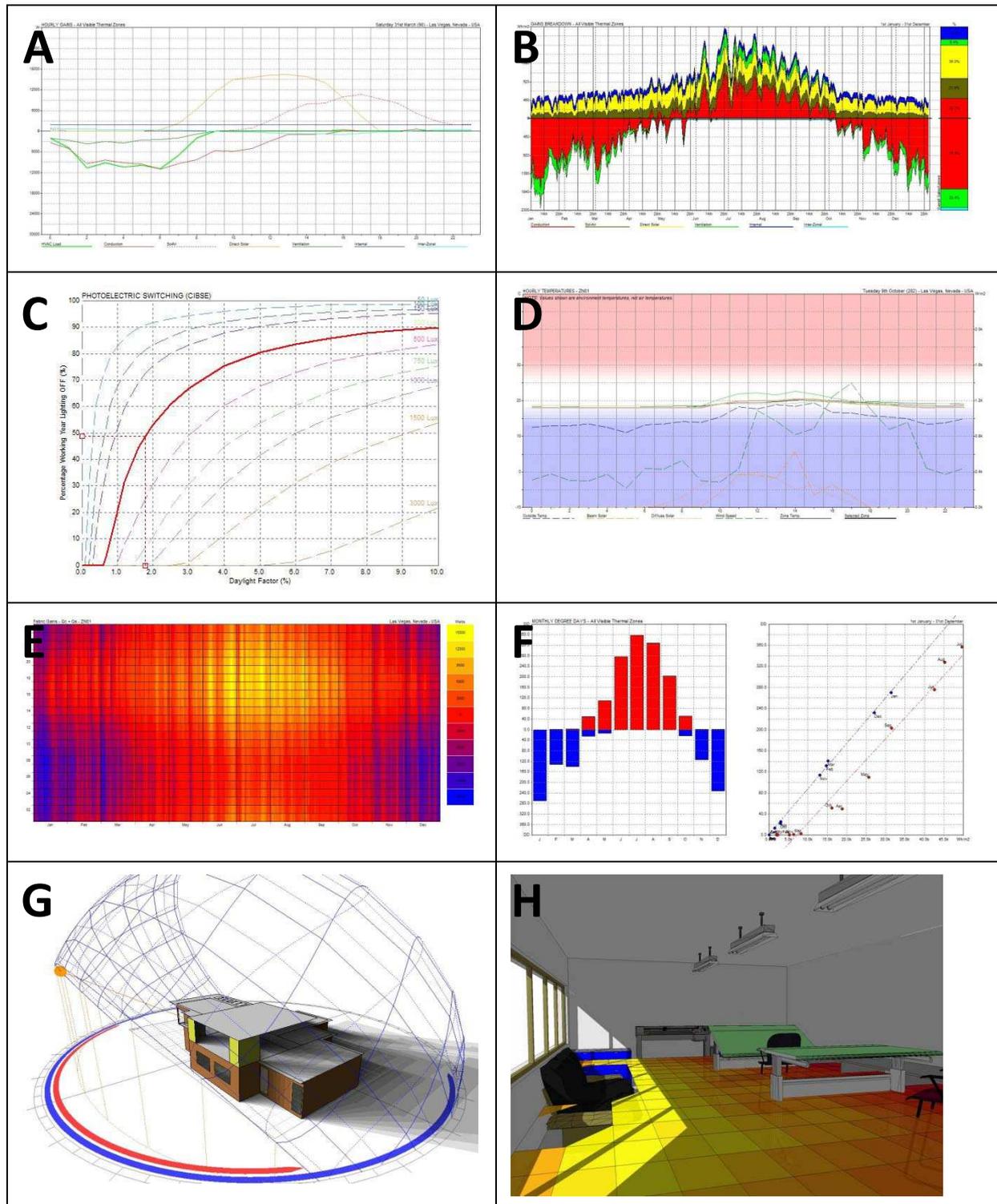
Figure 6.13: Samples of BPS data representation presented to the
participants in an interim sub-session.

During this section, the participants were presented with a printed set of sample simulation
data outcomes in different formats, including graphs, charts, numbers and tables, and 3D
representations (as depicted in Figure 6.13). At this point of the testing session, the

questioning method changed temporarily to a semi-structured interview asking the participants for their opinions on interpreting the presented sample simulation data. An important aspect in conducting this interim session was that the students wouldn't feel pressurised or biased, in order not to affect their responses and feedback. In this respect, it was the moderator's responsibility to make sure the students were comfortable, unpressurised, and uninfluenced. This was attempted through asking short, simple, clear, and fairly-worded questions, avoiding imposing any impressions and/or opinions on the participants. This part of the testing session constitutes the core base for comparison and assessment of the effectiveness of the proposed method. It has to be mentioned at this point that this process does not intend to make a comparison between the proposed tool and a BPS application, but rather a comparison between different methods and approaches for representing, interpreting, and understanding the building simulation data outcomes, for making more solid and informed design decisions. In this interim session, the participants are asked if they can:

- *Identify and describe the nature and purpose of some of the presented data/graphs*. All the participants were able to immediately identify the type and purpose, and briefly describe the data represented in a 3D visualisation format (Figure 6.13[G] and [H]). They noted that they preferred 3D data representation method (whenever it is available by the BPS application), as it integrates the data into the 3D space which is a perspective they are more accustomed to. The highest percentage of students also recognised the type and purpose and described the data for graphs [A], [D], and [E] (72%, 69%, and 75% respectively), noting that they normally come across these graphs in their simulation analysis procedure. However, the participants found it harder to identify and describe graphs [B], [C], and [F] (37%, 26%, and 41% respectively).
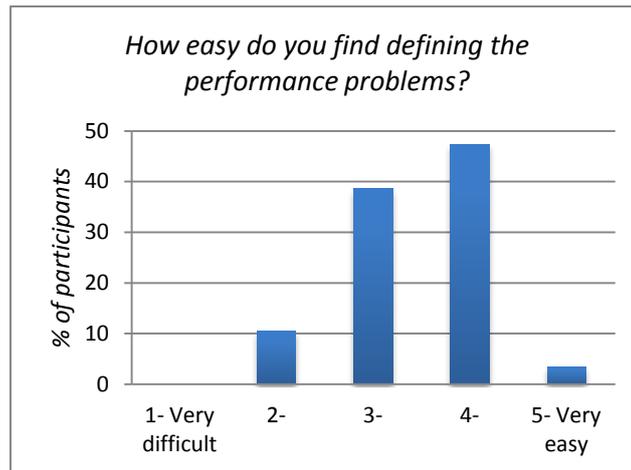
Figure 6.14: Participants' opinions on the level of difficulty for identifying a performance problem using standard BPS data representation methods.

- *Detect any highlights and/or irregularities in the presented data that can lead to identifying a potential problem*. In describing each of the graphs, the participants were asked if they can identify any problems, or any notes that can be flagged from the graphs. This discussion was coupled with presenting questions 3.9 to 3.11, which focused on the same concept of problems definition. Figure 6.14 presents the participants' feedback regarding the level of difficulty for identifying performance problems from BPS data representation. This question was asked on a Likert scale, and got an average score of 3.4, which indicates that identifying problems is close to neutrality, and leaning towards the easy side of the spectrum. In the discussion following these questions, the participants noted that the colour codes in the graphs, charts, and data grids normally gave indication of any irregularity or out-of-range values. However, some instructors noted that sometimes the colour coded indicators (presented within the BPS applications' data representation), are based on standard assumptions, which might not be necessarily accurate (for example, a standard comfort range between 18 and 26 degrees). They added that if the students didn't understand what they should consider and look for in the data, they could be easily confused and misled.
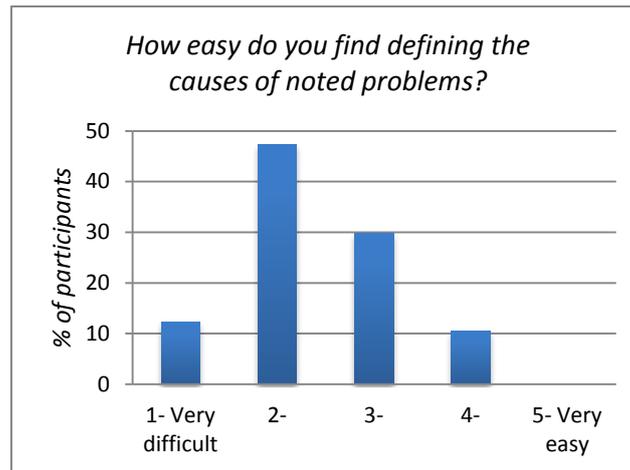
Figure 6.15: Participants' opinions on the level of difficulty for identifying problems' possible causalities, using standard BPS data representation methods.

In terms of identifying the possible causes to the identified problems (based on the graphs presented in the interim session, as well as the participants' general experience), the average score (on a Likert scale) was 2.38 (as illustrated in Figure 6.15). This indicates that – unlike identifying problems- the process of linking problems to possible causes seems to be more problematic, as it leans more to the second ('difficult') node in the scale. Later discussions revealed that in order to be able to stand upon clear causalities, large number of diagrams and data should be considered and examined, which could be itself a daunting and problematic task for inexperienced design students, and -as the discussion revealed- in many cases those students lack the motivation and urge to do so, and normally make decisions based on assumptions. On the other side of the scale, a smaller percentage (29.8%) believes that relating a problem to a set of possible causes is of moderate/neutral difficulty (or even 'easy', as 10.5% suggested). Those justified their views explaining that in many cases students could see the causes outlined in the data graph -similar to the indication of a problem- for example, a graph indicating high values of direct solar gain can give a clear clue to the problem of a particular zone's overheating periods.
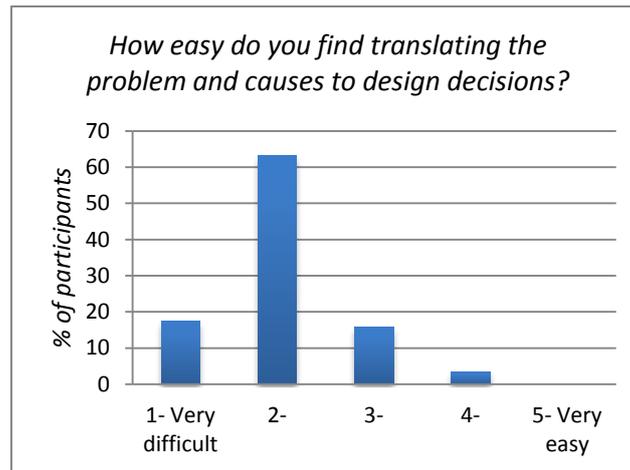
Figure 6.16: Participants' opinions on the level of difficulty for making informed design decision, based on the analysis of the simulation data.

With regards to interpreting the presented simulation data into effective design decisions (Figure 6.16), the average score on Likert scale was 2.05, indicating that the participants believed that making decisions based on their analysis of the simulation data is rather 'difficult'. The participants explained that although this is the most critical element in simulating the proposed building performance, it can be considered the most difficult aspect when dealing with the simulation data. They added that although BPS applications can give indications to problems, they offer minimum guidance and assistance on how to deal with these problems and generally improve the design performance. The participants indicated that they normally tend to seek other sources of information (like studio tutors and guidebooks) to make decisions they can actually carry out in the following design iteration. This was confirmed in question 3.16 and 3.17 in the questionnaire, where participants gave an average score (on Likert scale) of 3.68 for the frequency of relying on tutors, and an average score of 3.52 for the frequency of relying on guidebooks/rules of thumb (where a score of 5 indicated 'very frequently'). The participants, however, explained that this frequency depends on the availability of both tutors and guidebooks, and the quality of the provided information/feedback. They indicated that they preferred to consult studio tutors as they could normally provide 'case-specific' feedback, whereas guidebooks are normally generic. On the other hand, the availability of the tutors is normally restricted to tutorial sessions, whereas guidebooks can be available/handy all the time.

Using BPS applications in the architectural domain		
	Advantages	**Disadvantages**
A	Essential in getting an indication and directive regarding the building's behaviour, and simulating its performance.	Very technical in terms of operation and interpretation of outcomes (not architect-friendly).
B	Very effective in terms of the underlying calculations and algorithms, so that architects no longer have to manually carry them out.	Could be difficult in terms of defining a problem and its possible causes.
C	Constant progress in the methods of simulation data representation (particularly with 3D perspectives)	Doesn't effectively guide and/or support in further design decisions.
D		More considerable workload required (in terms of time and effort) in an already tight period of the design exercise.

Table 6.3: Categorisation of participants' responses regarding the advantages and disadvantages of using BPS application in architecture.
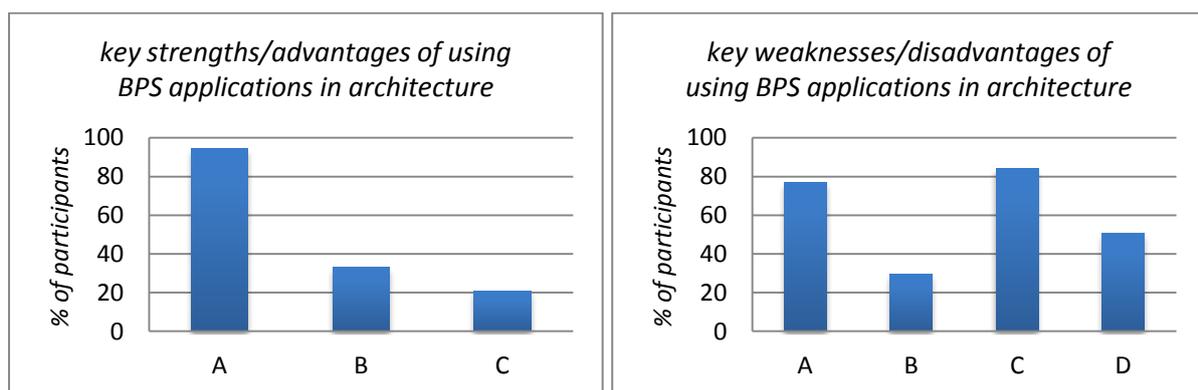
Figure 6.17: Percentages of participants' responses in relation to Table 6.3

This section concluded by asking the participants for their general views on the utilization of BPS applications in their design process, in terms of the potentials/strengths, and challenges/weaknesses. The feedback obtained on the advantages is categorised into three

categories, while that on the disadvantages is categorised into four categories, as depicted in Table 6.3. The percentages of participants who provided opinions in each of the set categories are illustrated in Figure 6.17.

6.3.3.1.1. Discussion

This section of the user testing sessions is fundamental to the research, based on two aspects; the first is that it relates directly to the literature discussed and presented throughout the previous chapters, in terms of defining the challenges that design students encounter with using BPS applications in their design exercise, and in so doing, validates the theories and concepts that were the basis for the proposed tool's development. The second aspect is that it validates and adds to the list of conceptual and functional requirements for the proposed tool, which is the base for further development and implementation.

The feedback provided in this session indicated that the majority of students tend to use BPS applications '*because they have to*'; i.e. due to the pressure enforced by governments, organisations, accreditation bodies, employers, and universities. Many of the participants noted that in the context of the design exercise, they wouldn't have approached the BPS application unless it was explicitly required as part of the module assessment process. This conclusion can be directly related to the literature findings discussed earlier in chapter two; for the case studies by Soebarto (2005), and Bambardekar and Poerschke (2009), as well as the outlined '*triangle of influences*' discussed by Hamza and Horne (2007a). It can thus be seen that putting the time and effort to integrate sustainability in the design studios is implemented based more on the pressure and obligations (the 'stick' approach), than merely the moral aspects of preserving the environment and its resources (the 'carrot' approach).

The majority of participants (78%) referred the lack of motivation to integrate sustainability mainly to the highly technical nature of the BPS applications, and that most of them are not designed for architects; i.e. the interface and outcomes are not architect-friendly (as presented in table 6.3). This feedback validates the literature finding for the challenges that designers encounter when using BPS applications (discussed in Chapter two, section 2.4),

and the surveys and studies carried out by number of researches (including Attia et al., 2009; Rutherford and Wilson, 2006; Struck and Hensen, 2007; and Srivastav et al., 2009). From a pedagogical perspective, the complexity of the BPS application's outcomes can thus stand as a barrier against attaining deeper levels of learning (Biggs, 1999), as it doesn't match the visual cognitive approach that designers are accustomed to for learning and problem solving (Altomonte, 2009)

Regarding the level of detail required for running a simulation, the feedback obtained indicated that the higher levels of detail can be more effective and reliable in terms of obtaining more reasonable simulation outcomes. This high level can only be available towards the end of the design process, and thus students tend to leave simulation to these later stages. These responses indicate that the design students, although they believe that BPS applications assist them in understanding and assessing their projected proposed design performance, they might not include it in every design iteration, and might use BPS applications once or twice towards the end when enough detail is available. This feedback supports the arguments discussed in number of studies (including Maassen et al., 2003; Mahdavi, 2005; Punjabi and Miranda, 2005). However, students should be motivated and/or encouraged to incorporate BPS applications in earlier design stages to give them directives and indicatives that can assist the development of the design as early as possible when decisions are more critical, and more flexible/subjective to change. Reflecting back on the implementation of the proposed tool, it can be seen that a key conceptual foundation of the tool is to deal with early design information when minimum details are available, and use the indicative resulting values and feedback to direct the students to higher levels of detail in the following design iterations. In other words, the tool is designed to act as the motivator and director of the design development (from a sustainability perspective), by helping the students to add more detail in every iteration (this is done after the first simulation run, where abstract and default values can be used, and later change according to the tool's feedback).

On presenting the printed Ecotect sample data, it was clearly noticed that all participants instantly identified the type and purpose of the data presented spatially; i.e. in a 3D format. This supports the conclusions outlined from the previous section as well as the literature

discussed throughout chapters two and three, in that design students prefer –and feel more comfortable- with 3D spatial (qualitative) data representation. Though the proposed tool doesn't use the same mechanism of representation –layered colour coding in a 3D perspective, like that presented by Herkel et al. (1999)- it employs an interactive 3D concept, with presentation of the abstract knowledge embedded in the simulation data (using DM techniques), relevant to the contextual conditions of the experience.

Based on the participants' feedback from this section, it is clear that the main challenge they are facing in analysing the simulation data outcomes is not just identifying the performance problems, but also (and mainly) correlating the data to link the identified problems to a set of possible causalities, and later on use the gained knowledge to formulate informed decisions. In essence, it was indicated during this section that students tend to make decisions based on default values and/or personal assumptions, which could be very problematic to the design process. These comments match the conclusions of studies carried out by Soebarto (2005), and Bambardekar and Poerschke (2009), and discussed in chapter two. The approach to resolve these challenges (reflected in the implementation of the proposed tool), was to help students find the relations between data, and present possibilities that can be affecting the noted problems. The tool also adopts the concept of engaging the students in a discussion to present alternatives and possible solutions. The next section of the users' testing analysis investigates these concepts –among others- and represents the participants' feedback and views on the effectiveness of implementing these concepts in the proposed tool.

6.3.4. Section Four: The Tool's Conceptual and Pedagogical Aspects

The set of questions in this section was presented to the participants after introducing the proposed tool / game, with a brief description about its methodology, settings, controls, and the different features and functionalities it comprises. After this introduction, the participants are offered to explore the game themselves and start 'playing' it, aiming for them to get a better understanding of how it works and what it is offering. During this part of the testing session, the participants are free to enquire about any aspect of the game, or seek help and support from the session's moderator. It is important -by the end of this

introductory session- for the participants to understand the main pedagogical objectives for using this game, and the scope of service it presents. It is also important for them to understand that this game is not an independent performance simulation software, but relies primarily on the data extracted from a BPS application (Ecotect).

This section is considered the core of the testing session, as it includes a set of questions that directly assess the main hypothesis of the research and the concepts formulating its proposed method. Moreover, the feedback obtained in this section contributes directly - to a great extent- to the research's general findings and conclusions, as well as the formulation of further conceptual (technical and pedagogical) specifications for the proposed tool's development. The section aims to acquire the participants' views on the research's proposed tool in number of aspects, including:

1. The suitability of the tool for the architectural design and education domain, in terms of speaking to the designers in their own language and moulding the technical nature of sustainability into the architects' cognitive schemata. In other words, it investigates if the tool can help the environmental design process to become more architect-friendly.

2. The quality, efficiency, and relevance of the tool's outcomes, including descriptive and informative zone-specific reports, communication and interrogation routines, problems and possible causalities identification, and the proposed guidelines and further design strategies.

3. The value of 'knowledge' that the proposed tool adds to the students' learning experience, compared with that gained from conventional methods.

6.3.4.1. Results Presentation

6.3.4.1.1. *Rating the Proposed Method*

In light of the outlined section's objectives, the section starts by asking the participants to rate the proposed tool under four different criteria; the tool's support for understanding the

building's behaviour, the tool's intuitive and instructive nature, the tool's support for environmental design education, and the quality and relevance of the tool's outcomes (questions 4.1 to 4.4). The results of the participants' rating for these four criteria are presented in figure 6.9. The following set of questions (4.5 to 4.10) is directly related to the rating, aiming to obtain further details and in-depth analysis of the participants' views of the current system's conceptualities and scope of service, and obtain any recommendations for improvements. This set of questions (along with the informal discussion that followed) also provided a deeper understanding of the participant's rationale and justification for their rating of the tool. It is important to mention at this point that in their rating, the participants were asked to assess the tool as a concept and a methodology rather than a final implementation.
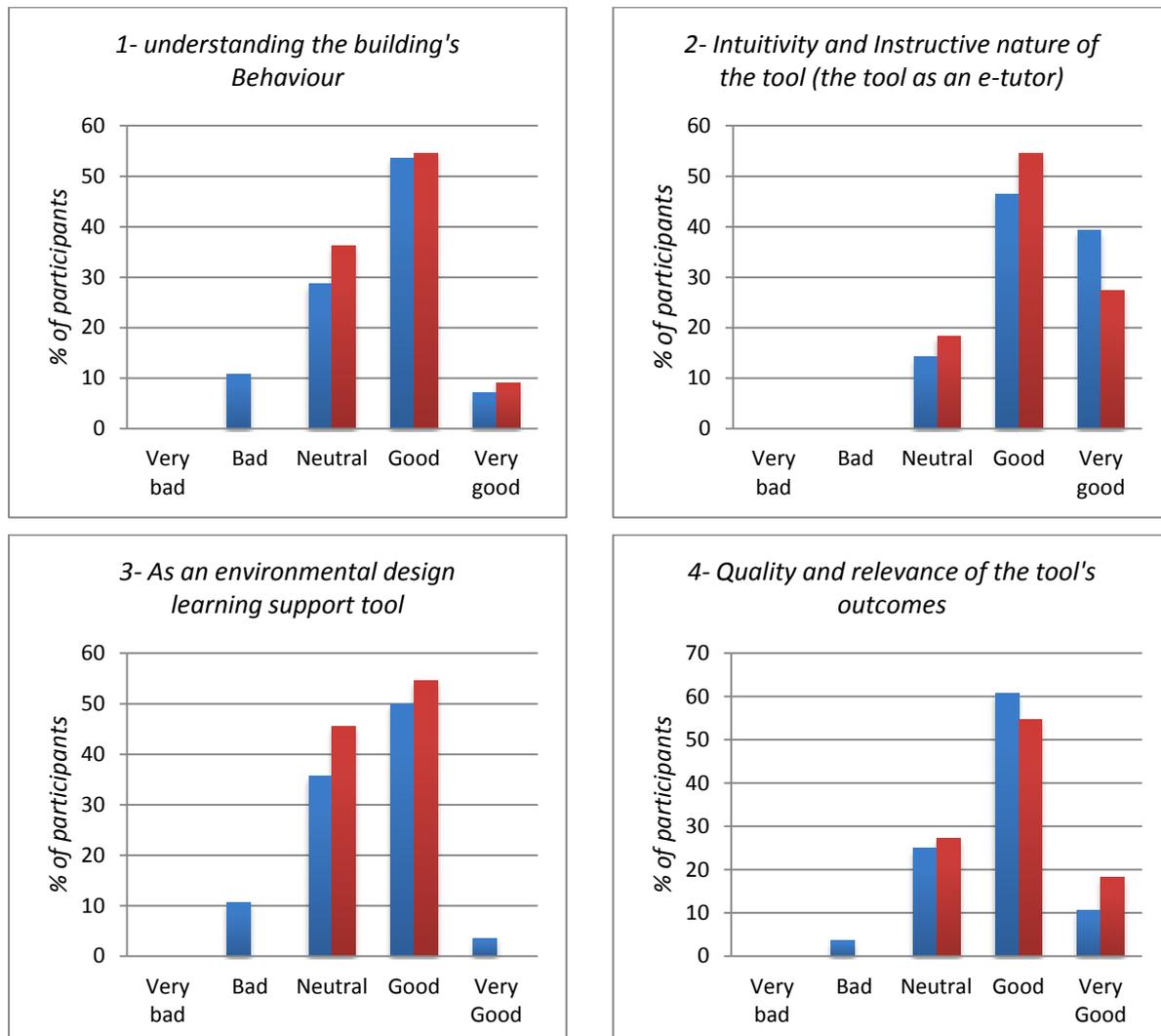
Figure 6.18: A compilation of the participants' rating for the proposed tool
(in comparison to conventional methods) based upon four different
criteria. The blue bars indicate the participating students, and the red bars
indicate the instructors.

The first criterion is based on the understanding of the general building's behaviour and the performance measures for its various entities, in comparison to using BPS applications on their own (Figure 6.18 [1]). The average score for this question (on a Likert scale) was 3.6 and 3.7 for students and instructors respectively, which is between the 'neutral' and the 'good' nodes. From the discussion that followed this section and the analysis of related questions, the rationale for this score can be related to three aspects:

- The tool attempts to explain the implications of design decision on the behaviour of the building, and explore what-if scenarios (38%).

- The tool presents the users with summarised brief reports about the building and thermal zones' behaviour within the virtual experience (62 %). This '*can save the student the confusion of where and what to look for*' (as quoted by one of the participants)

- The tool attempts to walk the student through the process until reaching a solution/decision (28%)

There was, however, a strong neutrality base (as depicted in Figure 6.18 [1]), where some participants deemed that there were shortcomings in the tool as a method for understanding building behaviour. They mentioned that there should be clearer link and reference to the materials provided in the lectures and the building physics laws in general, which should be explicitly presented within the game (for example, accompanying the reports with relevant graphs that students expect to see in the BPS application, and relating numbers to actual physics laws and rules-of-thumb).

The second rating criterion was the 'intuitive and instructive nature of the tool'; in other words, the performance of the tool as an e-tutor (Figure 6.18 [2]). The general feedback on this criterion was positive, as the average recorded score on Likert scale was 4.2 and 4.1 for students and instructors respectively, which is just above the fourth 'good' node. Further discussion with the participants indicated that the justification for their ratings lies within two categories:

- The tool attempts to create a conversation with the students, similar to that happening within a tutorial or design studio (around 48%). This is particularly reflected in the interrogation routines that investigate different paths to solve each particular zone-specific problem.

- The tool presents a list of design specific guidelines that can assist the student in developing his/her ideas (67%).

Although the feedback on this element was generally good, there were, however, concerns from some of the participants. Around 58% of them mentioned that the tool should incorporate more information and details about the specified aspects that the users are examining, and/or links to further information and details (which can be built-in within the tool, or situated externally on a web-page for example).

The third criterion for rating the tool was the quality and effectiveness of the game as an environmental design learning support tool; i.e. the quality of the tool to introduce aspects of environmental design effectively in a manner that improves the students' overall level of understanding and perception (Figure 6.18 [3]). The average score for this question (on a Likert scale) was 3.4 and 3.5 for students and instructors respectively, which is again between the 'neutral' and the 'good' nodes. Subsequent discussions with the participants, and feedback provided on related questions in this section indicated that there are clear positives and negatives with the proposed tool as a method for supporting environmental design education. The noted positives can be categorised into two aspects:

- The tool incorporates environmental data and represents them within the a 3D interactive virtual environment which can help the students attain a higher level of engagement and contribution within the learning process, and subsequently better understanding of the presented materials (around 73%).

- The tool speaks to the design students in a language that they are more familiar with, making the whole process more architect-friendly (around 32%).

On the other hand, the noted negatives/concerns for the proposed tool as an environmental design learning support method can be categorised into three aspects:

- The students may spend much time in-between the BPS application and the game; i.e. they can spend a lot of time just preparing the game, which is a time they can make better use of (around 55%).

- Interactive elements in the 3D world could end up distracting the students from the main purpose of the game. The student may concentrate more on visualisation and

interaction with his/her building rather than thoroughly investigate its performance (around 19%).

- The students may simply accept the suggestions/guidelines as they are, without questioning why (around 16%). This again relates to linking the outcomes with the underlying building physics.

The fourth rating criterion in this questionnaire's section was the quality and relevance of the materials and information presented within the tool in its different features, for examples, zone reports, identified problems, possible causes for problems, proposed guidelines and design strategies (Figure 6.18 [4]). On a Likert scale, the average score recorded for this question was 3.78 for the students' cohort and 3.9 for the instructors', which is between the 'neutral' and 'good' nodes, leaning more to the 'good' side. The rationale behind this rating was made clear throughout the subsequent discussions and within the related questions in this section. The rationale was based on two views:

- The tool refines the data to present the relevant bits back to the users (like in the case of reports), instead of bombarding them with extensive amount of information, and they have to do the refinement themselves (around 64%).

- The speciality of the presented information to include design-specific details (like for example the recommended depth of the overhang, or the effective area of opening in a particular zone), is a positive aspect in the game that can add more personalisation and can thus contribute to better engagement from the students, and subsequently improved performance (48%).

Some participants, on the other hand, repeated one of the concerns pointed out in the previous criterion, explaining that the process of presenting specified information and details should have an extra dimension where the students can understand the rationale behind the presented figures; i.e. how and why such details and decision have been reached, and the theory and physics behind them (for example, the utilised ventilation equations).

6.3.4.1.2.   The Proposed Tool as a Decision Support System
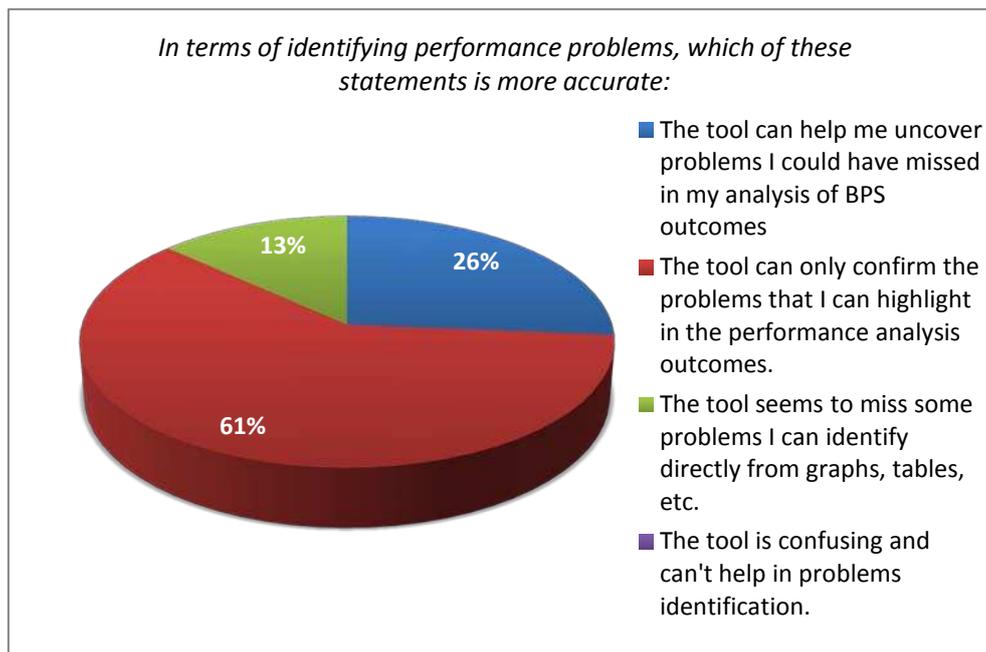
Figure 6.19: Percentages of participants' responses for their views on the
proposed tool' effectiveness in identifying performance problems.

In assessing the concepts of problem definition, identifying possible causalities, and presenting solutions and guidelines (as the base for being a decision support system), the participants were asked to select an answer that they felt appropriately describing the tool's capability and aptitude. In terms of problem identification (Figure 6.19), the highest percentage of the participants (around 61%) believe that the tool can only confirm the problems that they can highlight in the simulation data outcomes, while fewer participants (around 26%) believe that the tool can actually uncover some problems that they might have missed from interpreting the data. In the discussion that followed this section, the first group confirmed the previously acquired feedback, in that the challenge in using and analysing BPS data does not lie in problem identification, confirming that '*problems can be seen, what to do with them can't*' (as quoted by one of the participants). The latter group believe that -in comparison to conventional methods of problem identification- the tool can omit the risk of personal errors in reading and interpreting graphs and tables and thus making false decisions. On the other hand, around 13% of participants indicated that indicated that there were some problems that the tool could have missed, particularly in

lighting analysis. It has to be mentioned in the analysis of this question (and the other two that follow in this section), that the participants' level of experience and competence with using BPS applications has been a significant factor in their responses. In other words, the tool might be more useful for students who are less experienced and find it more difficult to analyse and correlate the simulation data, and subsequently form design decisions.
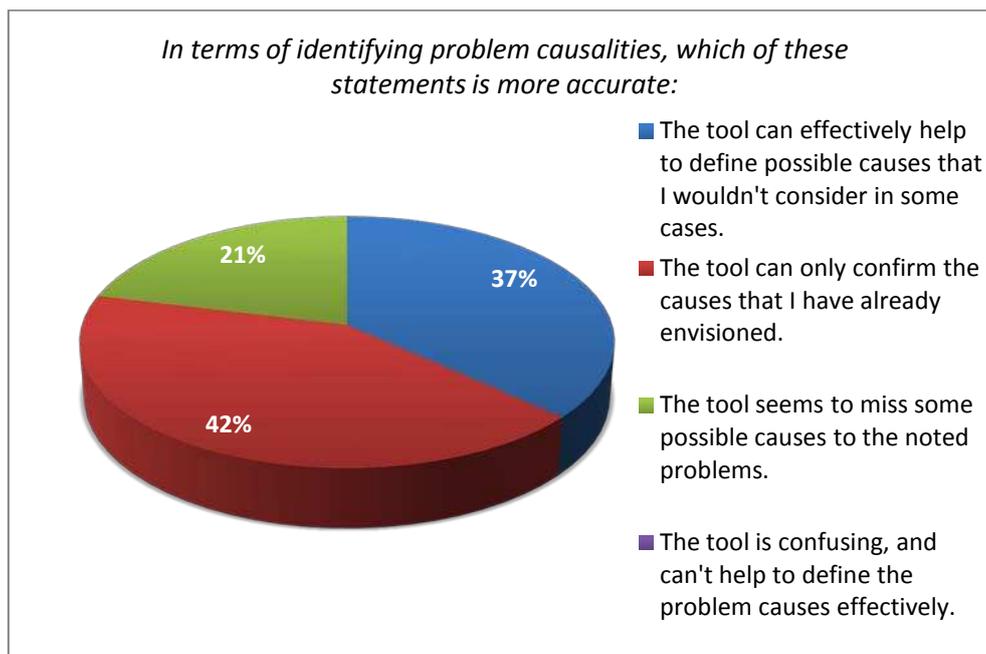
Figure 6.20: Percentages of participants' responses for their views on the proposed tool' effectiveness in identifying problems' causalities.

In terms of identifying the possible causes of noted problems, there was a clear split in the participants' views (Figure 6.20). The majority of responses (around 42%) suggested that the tool could only confirm the possible causes that the users might have already envisioned, while 37% noted that the tool can effectively help in defining possible causes that the students could actually miss. In the discussions with the latter group, they highlighted the fact that identifying a problem and its possible causes normally involve reviewing multiple data sources, and relating different figures. They added that this could be a daunting task, particularly if the examined data is for prolonged periods of time (like annual data). The first (majority) group justified their opinions based these aspects:

- In many cases causes can be linked to the problems; if the performance problems can be identified, it can be directly linked to one or more possible causes (around 64% of this group).

- The tool is restricted to only three possible causes, which could eliminate some other possible causes (36% of this group). This view was shared with another group (21% of participants) who indicated that the tool might miss some –possibly significant- problem causalities.

Some participants (12% of the second group), however, indicated that even if the tool doesn't uncover new possible causes for a certain problem, it can still be considered effective because it confirms the students' uncertain analysis, and in many cases assumptions.
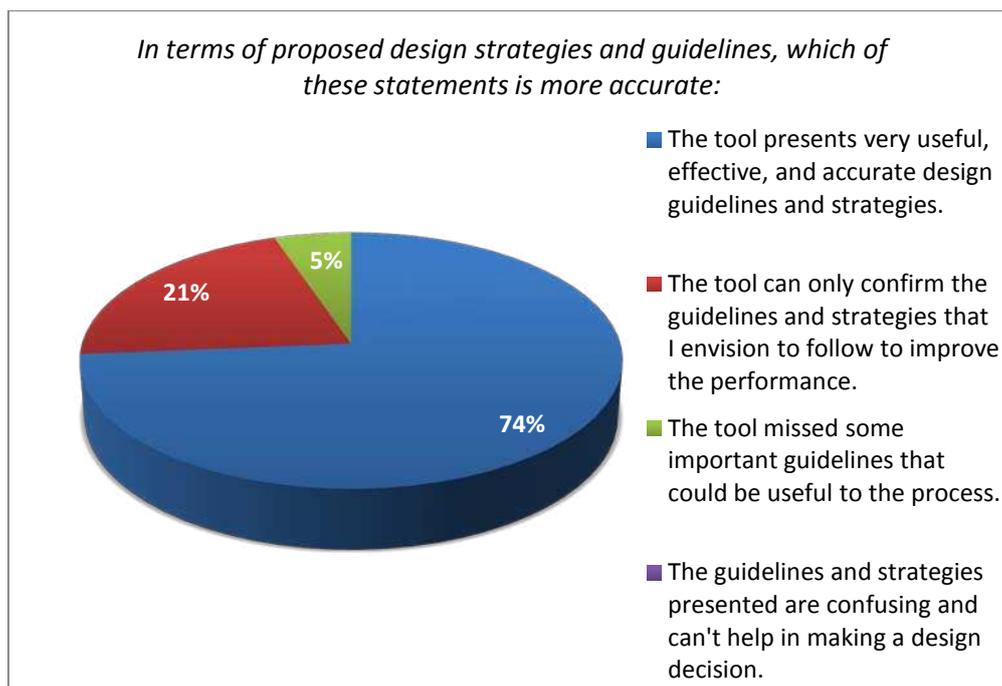
Figure 6.21: Percentages of participants' responses for their views on the proposed tool' effectiveness in proposing design strategies and guidelines

Finally, in terms of presenting effective design strategies and guidelines (Figure 6.21), the highest percentage of participants (around 74%) suggested that the tool could indeed present useful and accurate directives towards effective development of the designs. Fewer

participants (around 21%) believe that the tool can only confirm the strategies that they might have envisioned to improve the overall building performance. The former group justified their choices based on two aspects:

- The zone-specific strategies and guidelines presented in the game can be a very constructive and beneficial to the students' learning experience, and can be considered another useful element in making informed and effective decisions (58% of this group)

- The tool communicates with the users attempting to reach a decision on what is the best method to adopt and that is also suitable to the designers' preferences (42% of this group).

These responses confirm -in general- the conclusion derived from the third section of this questionnaire; that the students find the process less problematic when it comes to identifying the performance problems, and more challenging and problematic in correlating data to stand upon the causes for these problems, and also in addressing these problems, and interpreting their findings to conversant design decisions.

6.3.4.1.3.   General overview of the Proposed Method's Conception

The final part of this section sought the participants views on the effectiveness of the proposed tool based on two more rating criteria (Figure 6.22), as well as their general opinions (including discussion of the advantages and disadvantages) on the tool's effect on the students' environmental design learning experience. These are considered to be of a more generic nature than the previous four criteria introduced at the start of this section, and thus can constitute a concluding part for this section. The justification of these ratings is based on the feedback provided in previous questions within this section, along with that obtained in the post session discussions.

1- Using the proposed tool as part of the design exercise

6- Effect on students' motivation to integrate sustainability
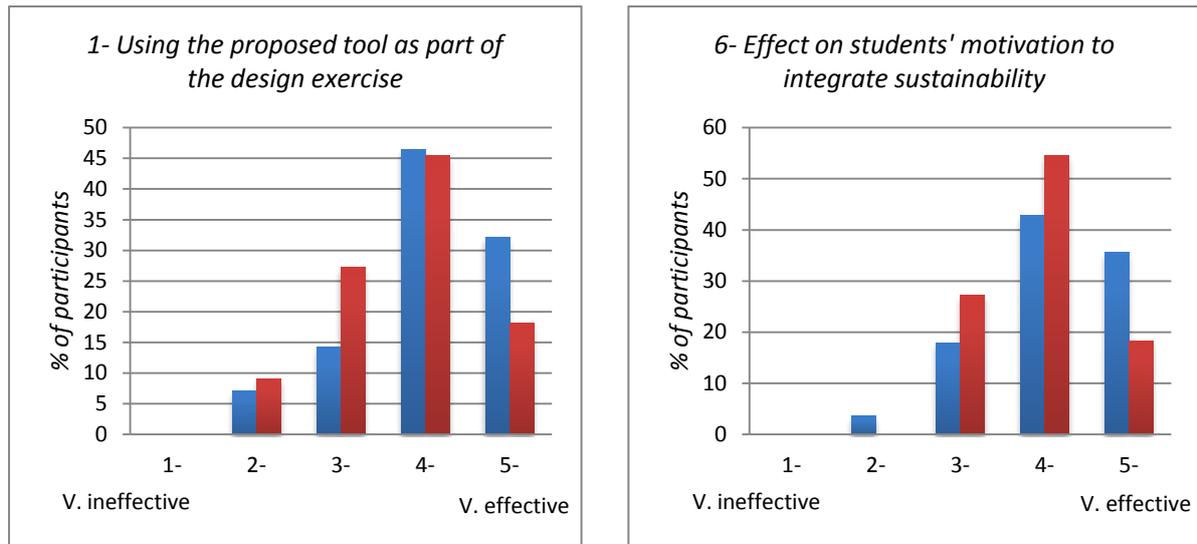
Figure 6.22: The participants' views on incorporating the tool in the design exercise (1), and its effect on the students' motivation to integrate sustainability aspects into the design process (2).

The first of those two concluding criteria aimed to acquire the participants' views on the effect of implementing the proposed method to be part of the design studios (Figure 6.22 [1]). The feedback yielded mixed views on this issue, but the average score on Likert scale was 4.03 and 3.72 for participating students and instructors respectively, which revolves around the fourth 'effective' node. The biggest percentage of participants (46.5% of students and 45.5% of instructors) agreed that the implementation would be effective and constructive for the students. This was based on three aspects:

- The tool can help students to evaluate (reflect on) their ideas and decisions applied to their design through providing effective feedback (48%).

- The tool can help students in the process of decision making, particularly through interrogation routines and zone-specific guidelines (38%).

- The tool can motivate students because it is within 3D environment (game), which they are more likely to accept (66%).

However, another proportion of the participants believed that there are some concerns and shortcomings for the current version of the tool, that wouldn't allow it to achieve the

desired objectives, and might indeed cause further problems to the process. These views were mainly justified based on three aspects:

- The additional amount of work and time needed to learn the game's world editor, update the 3D model, and modify the game's world editor whenever there is a modification or update in the developing design (58%).

- The need to have a 3D model of the design prepared before it would be possible to run the game (24%).

- The need to transport the design and its data among multiple platforms, where it is initially between the CAD software and the BPS application, and this tool demand further transportation of data to a third entity (18%).

The second concluding rating criteria was to evaluate the potential effect of the proposed method on the students' overall motivation to incorporate and integrate sustainability measures into their design process (Figure 6.22 [2]). On Likert scale, the average score for this question was 4.1 for participating students, and 3.9 for instructors, which are both again revolving around the fourth 'effective' node. The justification of this score was based on three aspects:

- The 'game' element; where students explore aspects of their design within an interactive narrative virtual environment, walking through and experiencing the designed buildings as their normal occupants. This is a medium that is more suitable to the design students than the BPS applications (72%).

- The sense of control and personalisation offered through the game, adding that incorporating learning materials in this context is of great potential (46%). One student quotes "*It could be like having a tutor on-demand*".

- The tool can negates -to some extent- the possible risk arising from the interpretation (or misinterpretation) of the data generated from the BPS applications (around 11%). In other words, it can confirm any assumptions that could have been

made from analysing the simulation data, which makes the students more confident in their future analysis.

However, some participants believed again that the additional time and effort required before running the game in every design iteration, could actually have a negative effect on the students' motivation, and could result in a high risk that they will skip this step from their design procedure.

This session concludes by asking the participants' views for the main advantages and disadvantages of using the proposed tool -in the design process- on the students' overall environmental design learning experience. In some cases these are views that the participants have provided earlier in previous questions in this section, but this is repeated in order to confirm, validate, compile and collate these views, as well as to obtain any opposing views from all the participants; whether they were in favour or against using the proposed tool to support environmental design education. These views are compiled and presented in Table 6.4, and the breakdown on percentages of participants providing these views is presented in Figure 6.23.

	The effect of the proposed tool on the students' learning experience	
	Advantages	**Disadvantages**
A	The method has a positive effect in motivating the students, as they explore learning interactively in a game, which can raise their level of engagement. In other words, the tool is designer-friendly and can speak to the architects in their own language.	The method requires learning a new application/interface, which can reflect in consuming a lot of valuable time and effort before running the game
B	The method can assist and guide the students to ask appropriate effective questions (i.e. investigate more into the simulation data) which give them better understanding of environmental design aspects	The tool currently offers abstract level of information, and there is a need for more links to the theory and the underlying building physics, to allow students to exploit the information in more depth.
C	The tool can direct the design process by presenting zone-specific guidelines that assist the students in their decisions.	The method requires the students to have a developed 3D model before running the game, which can be de-motivating for some students.
D	The method exploits the cause-effect relationships and describes the implications of some decisions and strategies that the students can elect to follow.	There is also additional effort required for transforming data across another (a third) application in the design process, which can be distracting for the users.
E	The method provides the students with a tutoring system, which they can exploit in their own time and conveniences.	

Table 6.4: A compilation of the participants' views on the effect of the proposed tool on the students' learning experience

Advantages of the proposed tool on the students' learning experience

% of participants

Disadvantages of the proposed tool on the students' learning experience
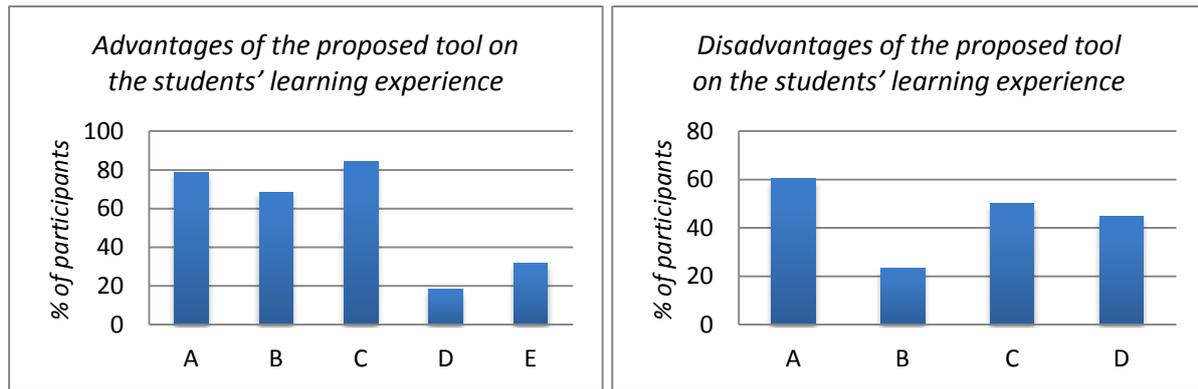
% of participants

Figure 6.23: Percentages of participants' responses in relation to Table 6.4

6.3.4.2. Discussion

The main objective for this session was to assess the conceptual basis that the proposed tool was built upon. From a pedagogical perspective, it was important to investigate if and how the proposed tool can promote 'deep learning' (Biggs, 1999). From the feedback obtained throughout this section, there is an indication that the proposed method can promote deep learning through engaging the students in interrogation routines (or a walkthrough), reflection, and feedback for developing their designs. One of the positive aspects presented in the results of this section, is the presentation of the tool to the possible implications to design decisions through the interrogation routines, and giving the students a sense of freedom and control to make decisions. The tool thus attempts to create a meaningful conversation between the student and the design to create a better and deeper understanding of its current performance, the reasons behind that performance, and the strategies to improve it. This was reflected in the feedback provided on the advantages of the proposed tool in a design exercise (Question 4.20), and in particular the responses in categories B, C, and D (as presented in Table 6.4, and Figure 6.23).

The tool can thus support 'reflection in action' (Schon, 1984), as the students need to think within the 'action' to choose the most suitable and effective decisions (sustainably, aesthetically, socially, economically, etc). After electing appropriate decisions, the students need to apply the changes to the design model, run the simulation, and return to the tool to 'reflect on' their action through evaluating the effect of their decisions on the overall building performance. This method can also promote 'Experiential Learning' (Kolb, 1984), as

the students can thus make sense of the presented materials through direct experience and with reflection in and on actions.

During the discussions carried out in and after this section, there was a clear split in the opinions as to what level of detail –in terms of the underlying building physics- that the design students should be subjected to. While some instructors believed that there should be more links to the laws governing the environmental measures of design, others believed that the students only need to know the effect and implication of a decision on the performance, with basic reference to the general rules-of-thumbs followed. For example, a student only needs to know that this room is gloomy (low DF), and that he/she needs to increase the area of the room's window to a minimum value to overcome this problem (without having to know what were the equations that lead to this decisions). As an approach to resolve this, the tool employed the 'layering' approach of data representation, like that presented by Srivastav et al. (2009). In this representation approach students are subjected to information in a layered hierarchical structure, moving from one layer to another to investigate more details. In this respect, the tool refrains from bombarding students with too much information at one instance, which could be off-putting and de-motivating for them to explore in depth, but rather walk them through the process from one level (layer) to another. For example, the game presents a zone brief reporting that the current zone is cold, the students then investigate more about the periods within which this zone is cold, and the possible reasons for that, and in the next level they can explore more about each of the possible reasons, and finally review the suggestions on how to overcome this problem and resolve any possible causes. Within this process, the tool communicates with the students presenting the physics basis (or rules-of-thumb) that can be related to a design performance problem, for example, the depth of the room is more than double the height, and thus single sided ventilation would not be effective.

The tool thus attempts to communicate with the designers in a more architect-friendly (Attia et al., 2009) non-technical manner, which can address and build upon their cognitive schemata (Gelernter, 1988; Altomonte, 2009). It also brings forward a more problem-focused strategy to the way the designers deal with the design, rather than just relying solely on the common solution-focused approach (Rutherford and Wilson, 2006). The way

this is done in the proposed method is that it resolves the complexity and high technicality surrounding the problem, thus giving the designers a chance to analyse the complexity of the problem and perform critical investigation that feeds into design solutions. In so doing, the tool attempts to move sustainability measures from being marginal in the design process to a more central position, and encourage the students to adopt a more 'conjecture analysis' approach (Hillier et al., 1984) to develop their designs. This was reflected in the feedback provided during this session; noting that the tool can guide the students to 'ask better questions' and investigate more into their design, exploring the questions 'What', 'why', 'how', and 'what if'. In so doing, the tool attempts to incorporate 'revelatory' activities (Warburton, 2003), to develop the students' knowledge and awareness, and thus promotes deeper learning.

Another key advantage highlighted from the feedback and discussions in this session was the motivational factor of this game, which is reflected in two aspects:

- Motivation by resolving the complexity of data: One of the noted challenges for using BPS in a design exercise is the complexity of data and the extensive amount of effort required from the students to link and to interpret this data (Soebarto, 2005; Bambardekar and Poerschke, 2009). This ultimately leads to more frustration and de-motivation, leading students in-turn to make unconfident assumptions, and also accept values/numbers -as they were- without thorough investigation. This challenge/shortcoming was confirmed with the feedback provided from the participants from both; this section and the previous one. The proposed tool attempts to address this challenge by resolving the complexity of data, and extract abstract/useful knowledge (using implemented DM techniques) to be presented to the user. In so doing, the DM techniques work on the users' behalf to do all the linking from multiple data sources and present the findings back to the users in the form of reports.

- Motivation by learning within a common context: As previously discussed in the previous sections, the interactive 3D context and the manner of presenting data (like

in the form of conversation) is relating more to the designers, and can thus improve the students' motivation and acceptance to the presented learning materials.

Some participants indicated that the nature and experience of the game imitates a normal tutoring session, but having an advantage in that it can be exploited in the students' own time and under their preferences and convenience. Another popular advantage mentioned in the sections results and discussions was the presentation of specified guidelines. In this respect, the proposed tool can combine the advantages of both aspects; tutoring and guidebooks (as discussed earlier in section 6.3.3.1), to present the students with design-specific guidelines in an interactive session mimicking a tutorial, and incorporating assessment and feedback on the design with directives/guidelines to improve its performance.

On a more negative note, some (conceptual and pedagogical) disadvantages and concerns were raised during this section, which could affect the students' motivation to incorporate this method in their design process. These concerns were (namely) the additional time and effort required to export data from the BPS application to the game (and the risk of losing data during its transformation), and to prepare the model within the game editor in order to get the game ready for 'playing'. This was highlighted after a short demonstration from the session moderator on how models are imported in the game engine's world editor (Figure 5.2), and what is required to prepare the model for running the game.

The negative impact of these concerns was addressed in the design of the proposed method (as explained earlier in chapter 5), where a template LUA code was developed in order to be directly used in the BPS application (Ecotect in this case) to export the required data directly to the game (which negates the time and effort concerns, as well as the risk accompanying it). A game world template was also prepared in the game engine utilised in this project (C4 Engine), where the users can directly import their 3D models into the game world, and thus can play the game with minimum adjustments required. The next section will look more into the assessment/evaluation of the technical interpretation of the conceptual aspects for the development and implementation of the proposed method and its tool.

6.3.5. Section Five: The Tool's Technical and Functional Aspects

After evaluating the conceptual and pedagogical aspects of the proposed tool, it was important to examine how effective the implementation of these concepts was within the developed features, and how these features could be improved to systematically address the main aim and objectives of this tool. In this respect, this section investigates the functional and technical aspects of the proposed method, and also probes some of the general usability issues that can affect –to a great extent- the overall efficiency and motivation to use the tool. The questions set in this section aim to assess the feasibility of the implemented features and highlight any problems in their implementation (for further development of the tool). Also, it draws attention to any missing necessary/required features that students or instructors deem important to be present to enrich the tool's overall experience and value.

6.3.5.1. Results Presentation
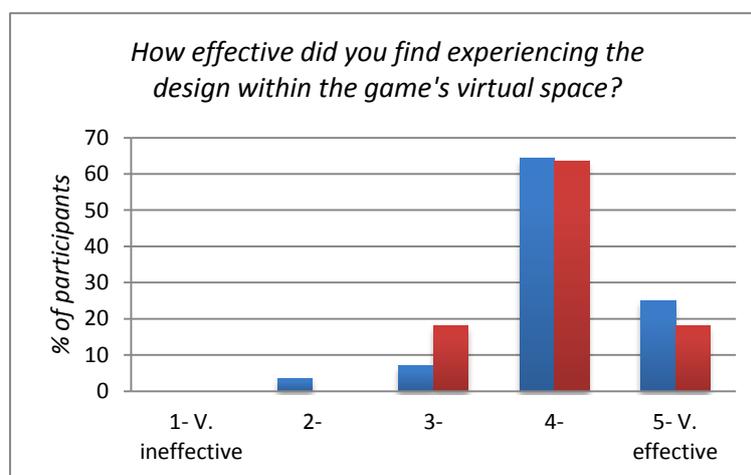
Figure 6.24: Participants' opinions on the effectiveness of experiencing the design within a 3D game's context.

The section starts by examining the efficiency of visualising the design in the game's 3D virtual environment. The feedback provided by the participating students indicates that they find the interactive walkthrough style of design visualisation (presented by the game) very effective, appealing, engaging, and motivating (as expressed in Figure 6.24). The average scores recorded for this question on Likert scale was 4.1 and 4.0 for students and instructors

respectively. Some of the participating students noted that it is a great asset to be able to experience the building from the eyes of the occupants, in various stages of its design development. One of the students also noted that '*it gives the designers a chance to relate more to the building, and its space and geometry*'. Although this doesn't directly affect the environmental design process, it relates more to the acceptance and motivation of students to incorporate the 3D game into their design exercise, not just as an environmental design learning medium, but also a medium where they can interrogate interactively various geometric elements of their design. Another group of participants, on the other hand, argued that there is still the burden of building the experience in another application (the game engine). They added that the recent releases of CAD software are implementing features similar to the walkthrough, though they fall short in terms of graphical quality, rendering time, and ease of control.

Regarding representing the sun position within the game's world, the participants noted that it could be a sensible element that enriches the overall game's experience, as it gives an actual indication of the solar access to the building's zones throughout the year. The average (Likert scale) score for students in this question was 3.6, and for instructors the average score was 3.45, which is between the 'neutral' and 'effective node'. Around 70% of the participants indicated that it is an important aspect of the design that affects a lot of decisions made (including windows, overhangs/sun-breakers/louvers, building zoning, building orientation, etc.). However, around 46% of the participants noted that they expect to see more lighting analysis for the zones, similar to that presented on data grids in Ecotect, but not necessarily using colour-coded representation, but rather a method to relate directly to specific parts of a zone. For example, one of the participants suggested implementing an indicator (somewhere beside the temperatures) that changes the colour according to the 'gloominess' of some parts in each zone.

Regarding the temperature representation within the game's GUI, the average score on Likert scale was 3.6 for participating students and 3.45 for instructors; i.e. between 'neutral' and 'effective'. The justification for this score fell under two aspects:

- It is effective to compare indoors and outdoors temperature.

- It is effective to compare temperature (both indoors and outdoors) to the comfort range.

On the other hand, some participants suggested that it would be more useful if the whole current comfort range of temperatures is explicitly and visually displayed, to give an instant indication as to how far the current temperature is from the comfort range (without having to read it in the zone brief).
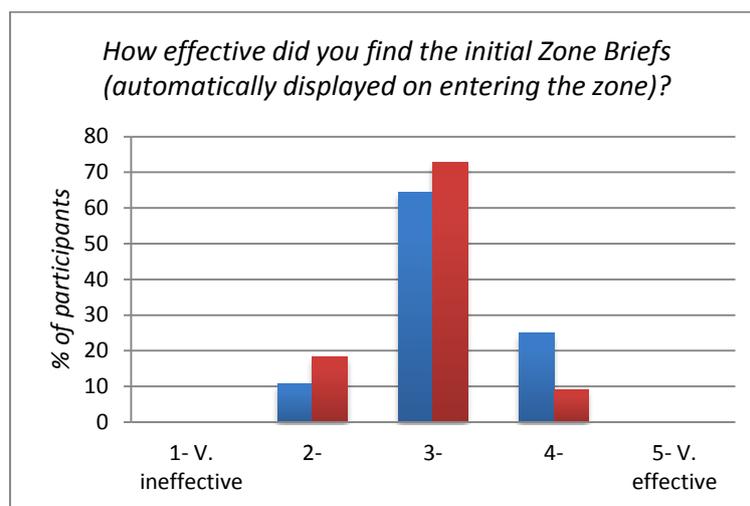
Figure 6.25: Participants' opinions on the effectiveness of the initial 'Zone Briefs',

On evaluating the effectiveness of the initial zone briefs (represented at run-time when the player changes a zone, or some of the game settings), the average score on Likert scale was 3.14 for the participating students, and 2.9 for the instructors (Figure 6.25). As a justification for this rating, the participants noted that although it gives an instant indication of the current state of the experienced zone, the presented text can be substituted by more graphical or visual in-game and/or GUI elements. Some students suggested incorporating a character (computer avatar) in the game that would physically accompany the player (student) throughout exploring the building, and this particular character can give the indication presented in a text format in the zone brief (for example, the character taking off an item of clothing or shivering to represent the current state of the zone's temperature). They believe this will give an 'extra edge' to the game and make the players more engaged, as well as offering wider variation in the method of presenting information.

How effective did you find the interrogation routines (asking questions and getting your views on relevant design strategies)?
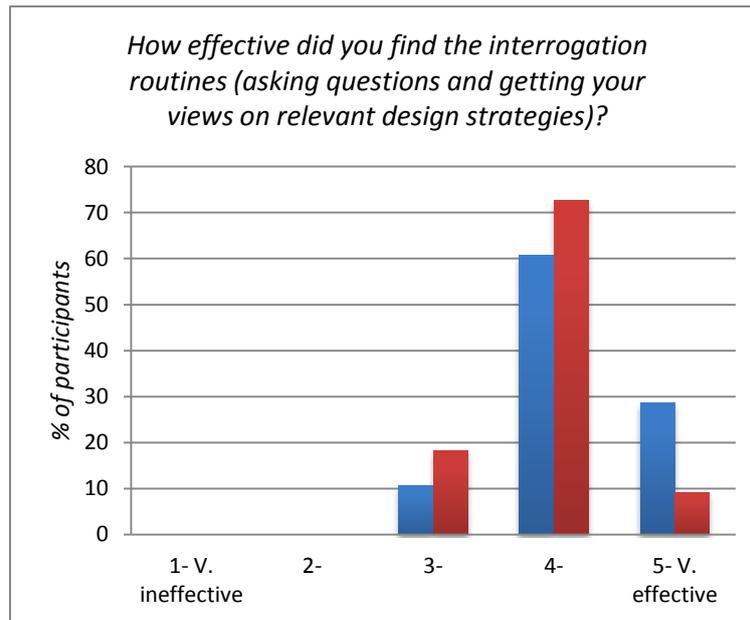
Figure 6.26: Participants' opinions on the effectiveness of the 'Interrogation Routines'.

Regarding the participants' opinion on the effectiveness of the implemented interrogation routines (located within the 'Zone Overview' tab), the average score on Likert scale was 4.18 and 3.9 for the participating students and instructors respectively (Figure 6.26), which indicate that they see this as an 'effective' feature in the tool's design and implementation. The justification of the participants' views can be categorised in two aspects:

- The 'branching' of the process; presenting an option to the students and awaiting their responses/input to make a decision or branch to the next level (46%).

- The dynamic nature of the generated questions, which is based on the condition of the currently experienced zone (62%). This gives more specialisation to the experience, and making the process more interesting to the students as these routines resemble actual cognitive conversation.

Some participants explained that although they liked the presence of a button in the routine questions area that provides additional information on the keywords used in the question, they thought that there should be more room for information expansion (see Figure 5.16). They suggested that there should be more details on the recommended strategies, with

more explanation on their nature and implication (for example, why and how can a particular strategy improve the performance in the current specified zone), and supporting the discussion more visually with relevant examples and/or diagrams.
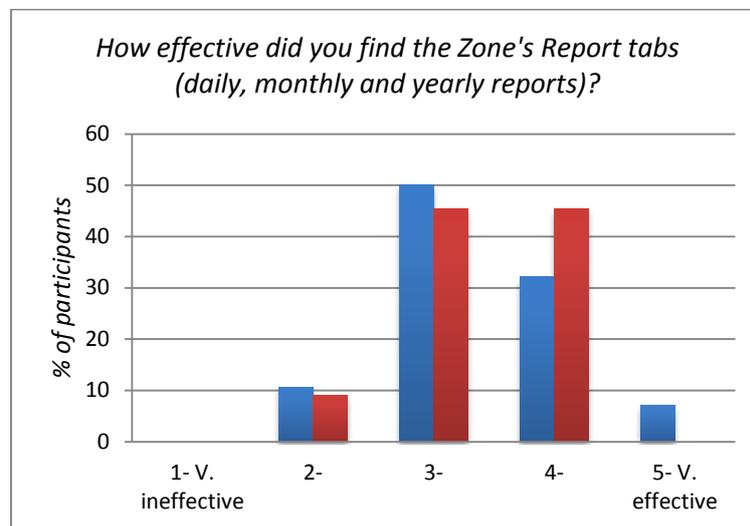
Figure 6.27: Participants' opinions on the effectiveness of 'Zone Reports'.

This section concluded by evaluating the effectiveness of the 'zone reports' tabs (Figure 6.27), in which the average score on Likert scale was 3.4 for participating students and 3.3 for instructors, meaning that they found the effectiveness of the zone reports just above 'neutral'. The participants' justification for that score was based on two aspects:

- The highlighting of the periods where there are specific problems (in the daily report tab).

- The presentation of possible causes of these noted problems (which subsequently relate to the guidelines).

However, some students suggested that it would be helpful if the numbers (for dates, periods, and energy consumption) are explicitly highlighted to be more accessible and '*swiftly glanced*' (for example, placing the overall energy consumption in an independent frame similar to that of the temperatures). More students also noted that it would be more effective to offer a link in the monthly and yearly reports tab to get the game to jump directly to the dates and times specified for highest energy consumption.

6.3.5.2. Discussion

The feedback obtained from this section validates number of conclusions and findings from both the literature review and the previous sections in the testing sessions. In the results and discussions that followed this section, it was clear that the participants have shown extensive enthusiasm to use 3D games to explore and visualise designs. This confirms and validates the discussion from section two (presented earlier in this chapter), which probed the acceptance and motivation to use interactive narrative 3D game's environment as a medium for learning and incorporating environmental design and sustainability concepts. This can be related directly to the main aims and objectives of this research (particularly objective [B] and its derived tasks). Around 88% of the participants indicated that they liked the presentation of environmental data in the 3D interactive environment of the game rather than in the BPS application itself. This also validates the literature findings that incorporating 3D games in the design experience is gaining more ground and becoming increasingly popular throughout the architecture and construction disciplines (Shiratuddin and Thabet, 2005; Tong et al., 2009).

In the discussion about the effectiveness of the implemented 'zone briefs', the participants suggested that it would be more effective to have an NPC in the game that can act like a companion throughout the experience, and someone who they can physically have a conversation with. This can be related back to Tallyn et al. (2005), Fielding et al. (2004), and Madden and Logan's (2007) findings –among others- about the merits and advantages of embodied agents in a game on the game's narrative; i.e. to report and communicate with the players. However, as a design decision in the game's implementation, the embodiment was decided to be limited in the form of a conversation through briefs and reports without physical representation of the reporting agent (as discussed previously in chapter five). However, physical embodiment is an aspect that can be investigated and considered in further development and future versions of the proposed tool.

Another aspect discussed within this section, is the effectiveness of the interrogation routines in the learning process. This aspect was discussed and covered from a conceptual and pedagogical point of view in the discussion of the previous section, however, the results

and feedback obtained in this section validates previous findings, and confirms the effectiveness of these routines to explore various environmental aspects of the students' designs. The participants noted that they liked the sense of personalisation/specialisation in the questions asked, which relate to the specified design with specified numbers. They also noted the effectiveness of the 'branching' of these routines exploring one aspect after another, which can be related to the effectiveness of DM techniques (discussed earlier throughout Chapter Four), and in particular the decision tree technique (Han and Kamber, 2001; Dunham, 2003); Zaiane, 2004). The 'decision tree' DM technique was responsible for constructing these routines, based on the contextual settings, and the students' preferences and input, which were reflected in the rules that governed the generation of these routines' questions.

6.4. Chapter Summary and Discussion

This chapter discussed the user-centred approach for the proposed tool's development process, and the general methodology outlined to obtain the potential users' and stakeholders' evaluation review and feedback at different stages in the design development. The chapter also presented a general analysis of the participants' feedback in the post-development detailed testing sessions (with its supplementary questionnaire), aiming to attain the potential users' level of acceptance and readiness to accommodate the proposed tool in their design exercises, and their suggestions for the means to improve its services and functionalities (Objective [E] in the main research's objectives). The chapter also sought to obtain an initial indication of the potential effectiveness of the proposed method and its tool to promote deeper learning and to improve the design students' level of comprehension of the environmental design concepts and rules (Objective [D]). This section of the chapter presents a summary of the feedback obtained in the different sections of the testing sessions (discussed earlier throughout this chapter), in sight of the research's main aims and objectives, and also the literature findings from earlier chapters.

The first aspect of feedback obtained in the interviews and testing sessions, was directed to address objective [B] of the main research's objectives; investigating the effectiveness of exploiting interactive narrative virtual environments as a method and context for learning in

general, and for environmental design education in particular, and probe the utilisation of "3D Games" as the potential hosting medium for this method. This was mainly reflected in the questions from the first two sections of the questionnaire, and some questions in later sections to validate the earlier feedback in the context of environmental design. The general feedback on this aspect indicated that design students are very familiar and accustomed to 3D environments, and that many of them actually use 3D modelling applications at the earliest (conceptual) stages of design, and develop their ideas in parallel to developing the model. This validates the literature findings discussed within chapters two and three; that designers tend to think spatially and visually (Srivastav et al., 2009), and use this to develop their ideas and build upon their cognitive schemata (Gelernter, 1988). This was an important aspect in the concept of the proposed method, as it is based upon having a 3D model ready to be imported to the game engine.

The feedback from the second section also addressed one of the derived objectives in objective [B], and verified Prensky's (2001) classification of younger generations as 'digital natives', where games are an integral aspect of their lives (Zyda, 2005; Oblinger and Oblinger, 2005). Later feedback and discussions in sections four and five of the post-development questionnaire confirmed the findings in the context of 'education' and 'environmental design', where there was a strong indication that exploring the design and integrating learning materials in an interactive narrative 3D virtual environment (a 3D game) is a strong motivational aspect for design students. In this respect, the 3D games can potentially create a more familiar and architect-friendly context, where students can show more acceptance to the unfamiliar highly-technical nature of environmental design concepts and data.

Section three of the questionnaire addressed the first aim of the research and its derived objectives; seeking to identify the current pedagogical and technical challenges and pragmatic issues -as well as potentials and opportunities- for integrating sustainability and environmental parameters in architectural design curricula. The feedback obtained supported and confirmed the literature findings (discussed throughout chapter two), and confirmed that one of the main challenges for architects is the motivation to integrate sustainability. The highest percentage of participants indicated that they use BPS

applications in their design exercise simply because 'they have to', which can be related to Hamza and Horne's (2007) 'triangle of influences'. The participants indicated that a major factor for their de-motivation is the size and complexity of simulation data, particularly when running the simulation over long periods (like annual data). They explained that the main challenge doesn't lie in identifying the performance problems, but in fact in linking these problems to possible causes, and subsequently to confident informed design decisions. This was reflected in the interim session where they were asked to identify and describe the types and purposes of number of graphs and diagrams representing samples of simulation data representation.

The final two sections of the post-development questionnaire focussed on the concepts that the proposed tool was built upon, and reflection of these concepts in the implemented features and functionalities. In so doing, these sections address objective [D] (developing an interactive narrative virtual learning environment that acts as a proof of concept for integrating the educational and technical theories and methodologies), and objective [E] (testing the proposed method among number of stakeholders, and evaluate the potential feasibility and effectiveness of such method within architectural design education).

The biggest percentage of participants has provided a generally positive feedback on the tool as a means for supporting environmental design education. Those confirmed that there is potential in the proposed method to improve the design students' acceptance and motivation to integrate sustainability and environmental design measures. Many of the participants also expressed that this proposed method -in comparison to conventional ones- can potentially be more effective in guiding students throughout the process, helping them to formulate the right set of questions to ask, exploring the questions 'what', 'why', and 'how', and exploring different 'what if' scenarios, and understanding various cause-effect relationships, which can be related back to the literature findings leading to the conceptual requirements for the development of this tool (as discussed in chapter two). In this respect, there were potentials seen in the tool to promote:

- Deep Learning: through the presentation of data in a hierarchical (layered) manner which takes the students from one level to another providing them with more

details, and walking them through the process from identifying the problems till formulating decisions. In so doing, the tool presents formative assessment and feedback to the students on their ideas and 'feed-forward' to how to improve them.

- Experiential Learning: this is done through building upon their experience through exploring solutions and possible design directives and thus making sense of learning materials individually, through reflection in and on action. This is done through offering the students a degree of freedom to make decisions (like within the interrogation routines and guidelines), and in so doing, they have to investigate the implications of each of the presented options, which promotes reflection in the actions that they are doing (to take/make decisions), and reflection on the actions they have done in the previous design iteration.

It was clearly noticed that there is a debate and conflicting views, particularly between the participating students and some of the instructors. This revolved around the level of detail that the designer should reach in terms of knowledge of building physics and environmental equations. While most of the students seem to agree that they only demand the outcomes of the simulation, and that the algorithms behind the simulation should be kept hidden, some instructors believe that the designers need to exploit this 'black box' on some occasions, as this kind of knowledge will help them understand more the behaviour of the building, and how to make effective decisions to improve it. The tool thus attempts to resolve this conflict through implementing the 'layered' approach to information presentation, therefore motivating students to explore the next (deeper) layers. In so doing, the tool attempts to create a meaningful conversation between the student and the design. The feedback obtained in section four of the questionnaire indicates that the participants find potential in this approach in improving the students' motivation to investigate in-depth information, and to further explore the laws and physics that directly affect the decisions they are asked to make.

One of the positives mentioned during the testing sessions and the questions that followed that the game/tool does the 'dirty work' on behalf of the students, and look into the multiple resources and data sets to extract abstract knowledge that can help them in their

design process. Though the participants were not directly informed or subjected to the implemented technology behind knowledge extraction, their feedback directly addressed objective [C] and its derived tasks; which is based on the investigation of the effectiveness of utilising MAS technology and DM techniques -within the game engine's technology- as potential mechanisms for BPS information analysis, knowledge extraction, and data representation. This can also be directly related to the literature findings (Morbitzer et al., 2003; Wilson et al., 2006), that there is good potential in employing these technologies to improve the designers' experience with BPS applications and their data outcomes.

However, there were some concerns, limitations, and shortcomings noted from the participants evaluation and feedback. Some of these limitations have been interpreted into further specifications for the development of the tool, and have already been applied in the demo version. For example, one of the main concerns for the proposed method is the additional workload and time required from the students, particularly in transferring data and preparing the game's world editor. This case has been addressed through preparing game templates with most of the required settings ready, as well as preparing template for LUA script to be used in Ecotect to facilitate and automate running the simulation, and transporting the output data directly to the game engine. Transporting data has been an issue that has been raised on multiple occasions during the testing sessions, noting that the process needs more centralisation of data. In this respect, BIM systems would be a potential ground for the future versions of the tool, and a main specification in this case would be to have the data warehouse centralised in the BIM system, and directly link the generated reports to constantly update the stored information. Another prospect to investigate for future versions is expanding the utilisation of the 3D modelling applications in the design process. The newer versions of some of these applications (like 3ds Max, and Blender) incorporate built-in 3D game engines, and some of them have their own script editor which might make it possible in the future to exploit this CAD application itself to be the host of this research's proposed method, making use of the modularity of the tool's implemented features (like the MAS and mining techniques, as discussed in the previous chapter).

There was also an almost unanimous requirement for a generalised compilation of the information (including reports, guidelines, and strategies) presented in the experience. The

participants believe that it would be useful to export and/or print this collective complied report to use it as a reference in their next iteration of design (and possible present it to the tutors as part of the project's documentation). Another aspect that was highlighted in the trials for further improvement was the actual 'gaming experience' of the tool. Although it was understandable that the narrative, gameplay, and challenges has to relate directly -and professionally- to the geometric and non-geometric data brought to the game (as discussed in chapter five), a big percentage of the participating students believe that the overall virtual experience would improve if it was more 'gamey'. They suggested that using more graphical and visual content will be more effective, for example, presenting some of the reports by an automated avatar that follows the player in the game. In other words, they suggested more physical embodiment of the reporting agent in the game run-time environment, which could enrich the overall experience.

The next chapter presents an aggregation and summarisation of the whole development process, and a reflection upon the main aims and objectives of the research. It also presents a review of the proposed method's limitations, and the proposed recommendations for expanding the scope and improving the quality of service offered by the tool in further development iterations.

Chapter Seven:

Conclusion

7. Conclusion

This chapter presents a reflection on the overall experience of undertaking this research and developing the associated tool. It presents a summary of the various phases that the research has gone through, reflecting back on the hypothesis of the research study and the main aims and objectives set earlier in chapter one of this thesis. In so doing, this chapter summarises the conceptual, functional, and pedagogical aspects that have been addressed and achieved through this research study. The chapter also reviews the shortcomings and limitations noted throughout the development process of the research tool, and from the feedback provided by the participants through the testing and evaluation phases. Based on these limitations, the chapter finally presents recommendations for further development, aiming to overcome and resolve these limitations and improving the overall learning experience.

7.1. Reflective Review

7.1.1. Objective [A]: Challenges Surrounding Sustainability Integration

The first aim of the research focused on identifying the current pedagogical and technical challenges and pragmatic issues that stand as a barrier in front of effective exploitation of the opportunities and potentials of integrating sustainability concepts and measures within the architectural design curricula. This aim and its derived objectives were addressed throughout Chapter Two, and also validated through the different phases of interviews and user trials (discussed throughout Chapter Six).

In order to address this aim, the research started by investigating the approaches for integrating sustainability. As such, the research discussed the approach for raising awareness for preserving natural resources (the moral/carrot approach), particularly when the building sector is responsible for around third of all the current energy related carbon emission (Price et al., 2006), and that the effective integration of sustainability (reflected in making good use of the BPS applications) can result in 50-75% reduction in the overall building's energy consumption (Clarke, 2001). The research also discussed the pressure

(stick) approach for motivating/enforcing this integration in design curricula; i.e. the pressure from governments, international organisations, and accreditation bodies, as well as the pedagogical principles set by some researchers and movements, like the EDUCATE project (2009), and HEA (2005), and Warburton (2003).

Aiming to propose an effective methodology for integrating sustainability in the design educational process, the research initially investigated the architects' approach to learning and problem solving, and how the technical nature of sustainability can be incorporated and accepted by design students. The research discussed the conceptual/spatial/visual means that the designers are accustomed to, and that feed into and build upon their cognitive schemata (Gelernter, 1988), and that design students mostly adopt a solution-focused rather than a problem-focused approach to resolve design questions (Rutherford and Wilson, 2006). The research also presented the Hillier et al. (1984) integrative learning process that can accommodate both the cognitive aspect of design and analytical aspects of sustainability; the 'Conjecture Analysis' approach. This yielded another set of pedagogical principles and directives to consider in the proposed methodology and the associated tool. These principles focused on making the learning process 'revelatory', promoting 'deep learning' (Biggs, 1999) through formative assessment and feedback, and promoting 'experiential learning' (Klob, 1984) by building on the students' experience via reflection in and on action (Schon, 1983).

The research also probed the opportunities and potentials of utilising BPS applications in the design exercise, not just from an environmental perspective, but also as a means to develop the design. However, these opportunities were not exploited due to number of challenges presented and discussed throughout Chapter two, which fall under three questions/categories:

- *Why simulate?* This aspect focused on the motivational challenges that surround the integration of sustainability, reflected in the use of BPS applications in the design exercise. This question addressed the suitability of coupling the highly-technical nature of sustainability with the cognitive creative nature of the design process. Literature findings indicated that design students feel de-motivated to use BPS

applications, as its technical nature does not suit their method of thinking and problem solving, and thus assign environmental design issues at a lower priority (Struck and Hensen, 2007) as they perceive environmental design as a series of mathematical equations that requires extensive time and effort to resolve (Rutherford and Wilson, 2006). In this respect, students show more interest in their own experience and guidebooks that provide them with clear qualitative directives to develop their design, particularly at the earlier stages of the design development, when ideas and concepts are in constant change and update. These 'motivational' factors lead to sustainability measures being marginal/un-central to the design process and thus the potentials are not thoroughly exploited.

- *How to simulate?* This question addressed the complexity of the BPS applications, in terms of the required learning curve to be able to effectively use these applications, and the procedure required for carrying out the building simulation. This question also focused on the need to relate the terminologies and notions learnt (the sustainability theories) to the functionality implemented in the application interface, and understand how to prepare initial input information about their building design (geometric and non-geometric) to be fed into the application in order to prepare for starting the simulation process. The literature findings revealed that this is a big challenge for design students in particular, as they need thorough understanding of the nature of the performance-based inquiry to be able to make sense of the simulation process (Bambardekar and Poerschke, 2009). In this respect, many researchers called for further extensive simplification for the simulation procedure to make it more architect-friendly (Soebarto, 2005; Attia et al., 2009).

- *What to do with the simulation outcome?* This question addressed the interpretation of simulation data outcomes into informed design decisions. The literature findings indicated that the key challenge for design students is to make sense of data, and translate what they see in the graphs/charts/tables into meaningful decisions that can actually develop the design and improve its performance. The challenge is a consequence of a huge gap between design and simulation methods of visualisation (Srivastav et al., 2009); where design visualisation utilises spatial conceptual

methods to represent qualitative data, and simulation visualisation -in most cases- relies on scientific empirical methods to represent quantitative data that are of a multidimensional spatiotemporal nature. The challenge for design students is to seek and correlate the simulation data in order to identify problems, relate problems to possible causalities, and ultimately make decisions to resolve these problems. This is considered a daunting task for students due to the amount of data generated, particularly over extended periods (like annual data).

In the discussion of the challenges, the research also presented a number of case studies, research frameworks, and surveys that highlighted the same pragmatic issues, and presented suggestions and/or guidelines to resolve those issues (for example, the IPV approach by Prazeres (2006), the layered approach by Srivastav et al. (2009)), These frameworks and proposals were critiqued and taken into consideration (along with the various findings from the literature related to this aim) forming clear directives that are translated into sets of conceptual, functional, non-functional, and technical requirement specifications that were listed in the final section of Chapter Two, and continued in more detail in Appendix A.

7.1.2. Objective [B]: Effectiveness of 3D Games as Virtual Learning Contexts

The second main aim of the research sought to investigate the effectiveness of exploiting interactive narrative virtual environments as a method and context for learning in general, and for environmental design education in particular, and probe the utilisation of "3D Games" as the potential hosting medium for this method. This aim was mainly exploited within Chapter Three, and the literature findings from this chapter were later addressed and validated within the different phases of user trials (as discussed in Chapter Six).

The discussion surrounding this aim focused on the characteristics of the modern 'gaming generation', and the benefits of protecting their 'play' modalities (Bower, 1974). The literature findings indicated that gaming is a prevailing concept in modern society, to the extent that some studies indicated that adolescents tend to spend more time playing video games than playing outside. The discussion thus made a clear distinction between the

'digital immigrants' who have recently migrated to accommodate the use of digital technology in various aspects of their lives, and 'digital natives' who have grown up well accustomed to the technology, making it an integral part of their lives (Prensky, 2001). Literature also indicated that this shift in paradigm reflected in the approaches and methodologies employed in various fields to exploit these play modalities, particularly in the field of education.

Chapter Three introduced the term 'Serious Games', which are games developed for purposes that go beyond sole entertainment (Zyda, 2005; Sawyer and Smith, 2008), with particular emphasis on serious educational games. The benefits of using games in the educational context were drafted along a number of axes; motivational factor for learning, interactivity, engagement by effective narrative structure, learning content, which is reflected into the game narrative, diversity of approaches to learning outcomes, and addressing cognitive and affective learning issues (O'Neil et al., 2005; Dondlinger, 2007). Games directed for educational purposed promote *"strategizing, hypothesis testing, or problem-solving, usually with higher order thinking rather than rote memorization or simple comprehension"* (Dondlinger, 2007, pp. 22).

The research concentrated on some of the key aspects that justify the effectiveness of educational games (particularly within the architectural domain); namely:

- *The motivational nature of game* (Denis and Jouvelot, 2005; Gee, 2003; Amory et al., 1999): This aspect of gaming was linked to a number of factors including the story unfolding, the goal-oriented structure of games, the implementation of extrinsic and intrinsic challenges, and to the graphical visual quality of the game world. This was a key aspect of games, and in particular 3D gaming, as it can be related to the motivational challenge discussed with relation to integrating sustainability and using BPS applications in the design exercise, particularly when many researchers suggested exploiting interactive virtual environments as a means to resolve this challenge and accommodate the spatiotemporal nature of the simulation data (Bambardekar and Poerschke, 2009; Yan and Liu, 2007).

- *The interactive narrative structure of 3D games* (Waraich, 2004; Dicky, 2006; Laurillard, 1998; Mantovani, 2003; Shiratuddin and Thabet, 2005; Horne and Thompson, 2008): This aspect focused on exploiting 3D game virtual worlds for interrogating the design and interacting with it, and making the game actually tell the story of the building. Research revealed that narrative structure is one of the most effective means by which the instructional message comes to be delivered and comprehended, particularly when accompanied with a sense of freedom and control through 'interaction', which transforms the linear nature of narrative to more effective non-linear experiment, where students are active participants rather than passive observers. The literature presented a number of experiments/case studies this approach has proven to be very effective in improving the design students' sense of space and geometric relations.

Chapter three also presented a number of examples where serious games have been used within the architectural domain, including design collaboration and communication, urban design and planning, environmental impact assessment, simulation of indoors and outdoors human behaviour and adaptation to the built environment, cultural heritage studies and research, form generation, algorithmic design and autonomous architecture, and design education. The discussion explored the technology behind employing games in these fields, with particular emphasis on the 'game engines', which incorporate the basic standard technology that needs to be implemented in any game (like collision detection, physics, lighting, rendering techniques, sounds, user interaction, and basic artificial intelligence). The chapter thus concluded with criteria to elect an appropriate game engine for the scope of the project, as well as a set of technical and conceptual requirements for incorporating utilising the games technology in the development of the research's proposed tool, and improve the students' motivation and acceptance to approach and comprehend the presented environmental design learning materials (these requirements are also presented in Appendix A).

7.1.3. Objective [C]: MAS and DM for Knowledge Extraction and Data Representation

The third main aim of the research sought to investigate the utilisation and integration of MAS and DM techniques -within the game engine's technology- as potential mechanisms for BPS information analysis, knowledge extraction, and data representation. This aim was mainly exploited within Chapter Four, and the technology specified within this chapter was later used in the development and implementation of the research's proposed tool (as discussed throughout Chapter Five).

The Literature in this chapter discussed the justification and rationale of electing the agent-based technology and coupling it with DM techniques to address some of the challenges noted and presented in earlier discussions relating to the integration of sustainability and subsequently the effective utilisation of BPS applications within the design process. This aim focused primarily on the aspects of knowledge extraction and data representation. As such, the research undertook a comprehensive review of the benefit and opportunities associated with utilising MAS technology in general, and its relevance and prospect within this research project in particular. It started by introducing the main characteristics of a MAS (autonomous, situated, flexible), and probed the effectiveness of a MAS in breaking down complicated problems and delegating responsibilities and cooperation to achieve each of the agents' goals which ultimately contribute towards the achievement of the overall generic goal(s) of the system.

Literature findings suggested that the structure and scope of the MAS can effectively suit the objectives set within this research to attempt to resolve the challenges surrounding BPS usage in the design domain (Lesser, 1999). In this respect, the research investigated the utilisation of MAS from two perspectives:

- *MAS as a modular element in the system architecture*: in terms of system development, management, and maintenance, a MAS offers a much simpler approach, due to the 'modular' nature that is produced from dividing the program into multiple functionally specific and modular components/agents (Sycra, 1998).

- *MAS as a game narrator*: This aspect was reviewed in context of embodied and embedded agents within the games' virtual environment. Literature findings indicated that the utilisation of MAS in the games industry is gaining more ground (Fielding et al., 2004), not only for its modular computing capability, but also as a key element in the game narrative, and to extend the boundaries of user interactivity within the game's world. Agents in this context are responsible for receiving, processing, and presenting information in the virtual environment, in what could be referred to as 'narrative voices' (Tallyn et al., 2005).

The MAS (as a system structural element for breaking down tasks, delegating responsibilities and scope of services, and representing information) needed to be coupled with other techniques to fulfil their general purpose outlined within the research. In this respect, the research introduced the rationale behind electing DM techniques for this purpose. The research probed the use of DM to collect and analyse the BPS data outcomes, through representing its role to extract knowledge within the KDP (Han and Kamber, 2001).

To achieve one of the derived objectives set for this aim, Chapter Three investigated some of the types and techniques utilised within the DM and KD processes, and probed their suitability within the purpose of this research's method. This investigation focused mainly on the descriptive type of DM (not the predictive one), as the purpose is to analyse existing data, extract relevant knowledge, and represent this knowledge back to the users, and there is no purpose to predict any future data or patterns. In this respect, the research presented three DM techniques that were suitable for different purposes within the proposed tool's structure; these techniques were:

- Summarisation/Characterisation: which was deemed suitable for in presenting instant zone briefs, and detailed periodic zone reports.

- Association Analysis: which was deemed suitable for linking data sets (and possibly define patterns) which is a way for correlating the data to identify problems and possible causalities.

- Decision Trees: which was deemed suitable to manage the interrogation routines between the game agents and the players, as well as generating a set of design strategies and guidelines to assist the decision-making process.

Finally, the research discussed the potential benefits of coupling MAS and DM, and incorporating these concepts and technologies within the elected game engine to expand its capabilities and scope of services, aiming to facilitate the accommodation and management of data gathering, allocation, extraction, and representation within the game world. The research also produced another set of conceptual, functional, and technical requirements, which were added to those generated from earlier reviews and discussions, and presented in Appendix A.

7.1.4. Objective [D]: Developing the Environmental Design Game

This aim sought to utilise and combine the previous findings (from literature and from interviews) to develop a method -and related tool- that addresses the challenges surrounding the integration of sustainability in the architectural design curricula (discussed and addressed in Chapter Two as part of fulfilling objective [A] and its derived tasks). The proposed method attempts to facilitate the integration of sustainability and shift it to a more central state in the design process, and ultimately enhance the perception and comprehension of its concepts and strategies within the design students. This aim was addressed throughout Chapter Five, and reflected in the development and implementation of the environmental design game that accompanies this research thesis.

For the fulfilment of this aim and its derived objectives, the research initially presented elected elements for the preparation of the development of the required tool, and the rationale behind electing them. These elements include the elected BPS application (which was Ecotect in this project), the elected game engine (which was C4 engine), and finally the elected case study (including the model and type of weather to be included in as a demo for representing the features and functionalities of the tool/game).

The research then presented the methodology outlined for the development of the proposed tool (based on Royce's (1970) Waterfall Development Model), and discussed the various stages that are incorporated in this methodology, including:

- Requirement specifications: These are the sets developed and generated from previous literature findings and from user interviews.

- Conceptual design: This stage includes the processes of abstraction and refinement of the requirements and translating them into effective design elements to be implemented in the next stage of development.

- Detailed design: This stage involves the implementation of the abstracted and refined requirements into features and functionalities within the tool.

- System testing and evaluation: This was carried out in Chapter Six, as part of the fulfilment of aim (E) and its derived objectives. This will be discussed in the next section of this chapter.

Chapter Five then presented the system architecture outlined for the proposed tool. The system architecture was based on developing a design model and using it in the game engine. This model was also used in the BPS application to run the simulation and export the resulting data. This data (with data from other resources) were passed to the game engine to be filtered, sorted, and stored in a built-in data warehouse. The system architecture also incorporated building a modular MAS within the game engine's source code, where three agents were implemented; a retrieving agent to formulate queries and get/extract the data from the data warehouse, an analysis agent to analyse the extracted data using implemented DM techniques (according to specified rules) to extract abstract knowledge, and a reporting agent to communicate with the users/students and pass/report information and knowledge, and obtain inputs and feedback.

The features and functionalities of the proposed tool were discussed, as set by one of this aim's derived objectives. These features include zone brief, zone reports, possible causes to noted problems, interrogation routines, and proposed zone-specific guidelines). The

discussion included reference to the underlying laws and/or equations that were the basis of the development of these features, and that constitute part of the 'rules' that govern many aspects of the game's underlying technology.

Within the scope of this aim, the underlying pedagogy was revisited and reflected upon, in an attempt to link and justify the implemented features in terms of their effect on the educational process and the quality of learning. In this respect, Chapter Five revisited the learning theories, approaches, and methodologies presented and critiqued earlier in Chapter Two, and discussed how these were reflected and interpreted within the proposed tool's features. For example, the chapter discussed how deep learning was addressed through formative assessment of the students' design decisions and their effect on the building performance (through presenting the impact of different aspects on the design, and the overall energy requirements), followed by effective feedback (through guidelines and strategies to develop the design and improve its performance). Another example is how the interrogation routines are planned to help the students reflect in and on action and promote experiential learning. The effectiveness of this implementation was assessed and evaluated using post-development user trials (as discussed in Chapter Six).

7.1.5. Objective [E]: Evaluate the Effectiveness of the Proposed Method

The final aim for the research sought to test the proposed method among number of potential stakeholders, and evaluate the feasibility and effectiveness of such method within architectural design education, and the effect of its tool on the learning process and students' comprehension and understanding of sustainability concepts (thus answering the main question of the research hypothesis). This aim was addressed throughout Chapter Six, and was carried out through phases of user interview and trial sessions.

In order to build a solid ground and a basis for evaluating the tool, the sessions intended to conduct a comparison with conventional methods, based on two aspects; the first was setting up the scene and questioning the participants to obtain their views on the key concepts addressed within this research (including using BPS applications in the design exercise, educational games, 3D models, etc.). The second aspect was through presenting

printed samples of BPS applications' data representation, and asking the students if they can identify and describe the type and purpose of these graphs/diagrams. Following this part of the testing session, the participants were introduced to the proposed tool/game, for thorough evaluation of its conceptual and pedagogical basis, and its effectiveness as an environmental design learning support tool. The recorded results, users' feedback and views obtained from the discussions that took place within the testing session yielded a set of important conclusions:

- Students like to think spatially and visually, and are more accepting to information representation within 3D contexts. This was validated throughout multiple sections of the testing session's questionnaire, and particularly when presenting the participants with printed samples of simulation data where they felt more positive towards data represented in a 3D format.

- Students are keen to develop 3D models for their design for visualisation and representation, and many of them use modelling software to develop their concepts and ideas at the very first stages of design.

- Students were part of the 'gaming generation' and were mostly 'digital natives'. They felt very connected and accustomed to 'games' in general, and 3D games in particular. Their feedback was very positive and showed high motivation and will to exploit representing and visualising their design in an interactive narrative virtual context like that of a 3D game.

- Most students indicated that they are using BPS applications in the design studios simply because they have to. Even if they are convinced that this is the right and moral approach to develop sustainable buildings and preserve valuable resources, the 'pressure' factor still seems to be the main purpose.

- The challenge that students face in using BPS applications does not mainly lie in identifying problems, but in linking and correlating data to relate these problems to possible causes and ultimately make informed decisions to overcome them.

- The proposed tool incorporated motivational aspects that can address the motivational challenge of incorporating BPS applications as part of their design process. These aspects include:

  o Motivation through abstraction of information: The tool used MAS and DM techniques to link and correlate data, extract abstract knowledge, and represent this back to the user. In this respect, it resolved the highly-technical aspect of simulation data, and did the 'dirty work' on the students' behalf, which is a strong motivational factor that can make the students more accepting to the process.

  o Motivation through encapsulating the experience within a 3D game context, which is a context they are more familiar with and accustomed to (more architect-friendly).

- The majority of participants (students and instructors) believe that the proposed method can help improve the students' comprehension of environmental design concepts, and thus can be an asset to the design process. This was related to number of factors:

  o The game resembled a tutoring system (particularly within the interrogation routines) which is based on creating a constant conversation with the students. This helps delve more deeply into their ideas and assess their feasibility, and direct them to strategies to improve the performance of their design (feed-forward). This in turn can promote deeper levels of learning.

  o The motivational factors that the tool incorporate (discussed in the previous point)

  o The hierarchical layered approach, where the tool refrains from bombarding the students with information at the first instance, but rather present the information in abstract format, which can motivate the students to explore more details in the following layers.

- There were concerns regarding the utilisation of this tool in the design exercise:

  o The time and effort required to learn new interface and competently use it.

  o The time and effort required to prepare the game in every design iteration

  o The risk of missing/losing data when transporting this data to a third application (the game engine).

- The implemented features and functionalities interpreted the underlying pedagogical and conceptual requirements of the proposed tool. However, these features need to incorporate more visual aspects and focal points to make the process more appealing and motivating.

The discussion that followed each of the key elements addressed throughout the testing sessions highlighted the strengths, opportunities, weaknesses and threats that surround the use of this tool as a method for supporting environmental design education. The next section of this chapter reflects more onto the limitations of the current version of the proposed tool, and reviews some effective prospects for further development.

7.2. Limitations and Recommendations for Further Development

The research's proposed method and its associated tool have been generally well received by the potential stakeholders who participated in its review and evaluation, as discussed earlier in chapter six. However, some functional, conceptual, and usability issues and concerns have been raised. This section presents and discusses the noted concerns and shortcomings of the proposed tool, and presents how they were addressed in various iterations of the tool's development, and/or recommendations for conceptual aspects and subsequent features to be implemented in further versions of the tool.

7.2.1. Functional Limitations

These are limitations related to the functionalities and features implemented within the game and experienced by the students at run-time. The noted limitations include:

- The temperature represented within a zone is based on the average distribution of temperatures in that particular zone. The scale of this limitation is felt in zones that have specific entities in parts of this zone that are influenced by environmental factors more than other parts of the zone. For example, in zone one in the presented case study, the southern-facing areas -in this zone- have relatively higher temperatures than the northern ones. In this respect, the tool should use a technique similar to the data grids used in Ecotect to divide the large-scale zones into smaller sectors that can reflect the thermal effect and temperature distribution in different parts of this particular zone more accurately.

- One of the main limitations of the proposed tool is that it is based on the formatting and specification of data generated from one BPS application (Ecotect). The tool uses techniques to initially gather, filter, and format simulation data to be ready for storage in the tool's data warehouse. The filtering process involves removing any headers and supplementary information that is added by default within Ecotect as part of the exported data (like the data exported in .csv format). In future versions, the tool could incorporate an initial screen for users to select the BPS application that they are using, and based on that, the filtering and reformatting process can prepare the data based on implementing additional techniques to deal with multiple BPS applications.

- The tool has no effect or support on the information that the students are required to provide in the very first design iteration. This means that the students need to supply initial input information in the BPS application before running the simulation for the first time. In this respect, the tool should be more ready to accommodate abstract information provided by the students in the BPS application and accommodate working with minimum levels of details. The tool should also use

default values or setting (including templates for example), with careful consideration that the students should be aware of these settings and input information used, and their implications on the performance of their designs.

- Some participants noted that the tool should offer more detailed and thorough lighting analysis. Currently the tool represents the hourly solar penetration through the different building zones, as well as an analysis of the Daylight Factor (as explained in chapter five). However, as a recommendation for further development; this analysis can be applied over a data grid for more accurate results and reflected as sub-sectors in each on the game zones.

- The tool currently performs an initial analysis on the CAD model once the game starts to detect the properties of each of the zones. This analysis includes the areas, heights, neighbouring zones, windows areas, and orientation. The tool worked effectively on the case study model and the basic zone shapes. However, there were noted intricacy and inaccuracy when testing on more complex zone shapes, which means that in the implementation process of this tool, the exploited algorithms should be updated to accommodate any complexity in the zone shapes. Moreover, as the tool serves as a proof of concept and technology in the scope of this research, the game was programmed to accommodate up to six thermal zones, which can be expanded in future versions and implementation.

- In the post-development interviews, there were recommendations to integrate more multimedia elements - like instructional sounds and/or videos- into the gameplay. These elements can be simply implemented into the game as most new game engines support 3D sound mapped to game-space components, and also support the mapping of video components into 3D elements in the experienced space. In this sense, some videos can be imbedded into the experience in elements like a TV, which the user can choose to play and select a particular channel which displays specified learning materials. This is envisioned to enhance the narrative structure of the game and generally enrich the virtual learning experience. However, integrating multimedia in this sense will pose a challenge which is the amount of effort required

to set these multimedia elements before initially running the game (for example, the students will have to position the TV screen object in an appropriate position in their design models. This will ultimately extend the amount of time required before running the simulation, and limit the dynamic aspect of the game.

7.2.2. Conceptual Limitations

These are the limitations related to the conceptual requirements of the proposed method, and their application within the learning support tool. These include:

- Concern about the amount of additional time and effort required to learn and effectively use the new interface/application (which is the game engine's world editor). Some participants noted that this was due to the fact that the proposed tool is not independent, and that it relied mainly on the data generated from BPS applications. The main consideration for further versions of this tool is to minimise the time and work required between running the simulation in the BPS application, and running the game. This concern has been addressed in the latter versions of the tool through developing game-world template to be the placeholder holding the students' 3D CAD models, while maintaining almost all the initial settings required to run the game (for example, lights, sun position, the player/character marker, etc). This concern has also been addressed through developing LUA code that the students can use directly in Ecotect's script editor to automate the exportation of data directly into the game for filtering and processing.

- One of the concerns that were raised by a number of participating instructors; is the need to integrate more explicit links back to the theory, building physics, and environmental design rules presented and discussed within the lectures. They believe that this aspect will enrich the overall learning experience, and form a solid foundation, that is based subsequently upon the learning objectives. It is thus recommended that the tool should incorporate links to further resources and information that support the learning process and create a more solid knowledge base. This can be attained by incorporating links within the game reports and

guidelines to external resources that can provide more details and thorough discussion about the specified entities that the student is investigating within the virtual experience. These resources can be extracts from particular lectures, or can refer to extended discussions presented in an online page.

- Another raised issue is the need for design students to still link their knowledge to what the BPS application presents, i.e. the students still need to be confident in understanding the graphs and charts, and even reading the numerical tables. It was thus recommended that the data exported from BPS applications wouldn't just be in textual/numerical format, but should also include images of the generated graphs and charts. These images should be presented subsequently within the game in relevant situations according to the students' experience and preferences. This is envisioned to improve the students' confidence for using BPS application in future projects.

- One of the recommendations presented in the tool's evaluation feedback was the need to generate a compiled report (possibly in a .pdf or .txt format), containing the notes and issues highlighted in each of the zones' reports, as well as any guideline or strategy suggested based on the users' inputs and preferences. This can be very useful feature in the game, as it presents the users with an overall summary of their experience, and a reference point that can help them in altering their designs.

7.2.3. Usability Limitations

These are limitations concerned about the design and look-and-feel of the interface, which contributes towards the overall efficiency and satisfaction of the users' experience. These limitations include:

- Some participants noted that the virtual learning experience is disrupted in multiple occasions, in order to read reports and guidelines, and/or modify some settings. They recommended that there should be more reliance on in-game elements that ensure the continuity of the game, similar to the zone brief window, which gives information without disrupting the virtual walkthrough. They also recommended

implementing hot-keys for swift alteration of the settings, like for example using a key to move the experience by one hour and another by one day. They believe that although this will require the students to be accustomed to more controls initially, but will eventually improve the quality of the overall experience, and focus more on the learning materials.

- It was also suggested in the concluding testing sessions that the text input fields in the settings window be replaced by scales or sliders, particularly when defining the type of activity, the number of occupants, and the hours of occupancy. This will potentially minimise the time required from the students to input/update the game's settings required information, and consequently contribute to more fluency in the virtual learning experience.

- There were several comments about the look and feel of the tool's interface menus and GUI elements. Some participants noted that it was not very appealing, and needed much work to make it look more interesting. As this tool was developed as an initial prototype rather than a release version implementation, the emphasis was directed more towards the features and functionalities of the tool that reflect and satisfy the conceptual and functional requirements, and address the research's main aims and objectives. However, an appealing GUI is an important aspect of the game and contributes towards the motivation and satisfaction of the players.

7.3. Concluding Notes

Architectural design education has been in constant change attempting to effectively accommodate the demand for integrating sustainability. However, this change was not very welcomed within the design community, and ultimately came with a set of challenges and barriers that has –in many cases- negatively affected the students' work and learning process. Although there is a clear moral motivation in preserving natural resources, and minimising the carbon footprint (the carrot), this was not the main driver for incorporating environmental measures in design. In fact, many governments, accreditation bodies, and international organisations have set laws, standards, and regulations, in an attempt to

enforce sustainability consideration, particularly in the building sector (the stick). This was clearly reflected in the educational institutions.

Studies cited throughout this thesis (mainly in Chapter Two) have shown that the complexity of the process, unsuitability to the architectural design students' learning approach and cognitive schemata, and the additional cost (time and effort) required have clearly affected the students' motivation to incorporate sustainability principles (reflected subsequently into the use of BPS applications), and their overall understanding of the process. Motivating the students is a key factor for ensuring effective integration/incorporation of sustainability concepts and measures in their design process and the design curricula. Reflecting back on the principles and objectives for sustainable development in education (discussed earlier in Chapter Two), it can be seen that keeping the students 'inspired' and 'enthused' is one of those key principles. Literature findings and users feedback supported that the design students lacked motivation to integrate sustainability, simply because of the technical nature of its methods (like BPS applications), which doesn't suit the designers' nature or the context they are accustomed to for developing their ideas and solving design problems. The research findings also supported the fact that design students tend to feel more relaxed and comfortable (and motivated) in visual and spatial contexts that rely on qualitative data representation (like 3D environment) which is much different than most BPS applications' IDE.

Extensive research is still being carried out to resolve the encountered challenges and pragmatic issues, aiming to mould the technical nature of building simulation applications into the cognitive design process, and to shift the sustainability aspects from the normally marginal position, into a more central and fundamental position within the design methodology. This research had the same directive, focusing on implementing a more architect-friendly context to accommodate sustainability, i.e. speaking to the designers in their own language. It attempted to address some aspects of the problem of integrating sustainability into the architectural design curriculum, focusing in particular on the application of BPS tools in the design process. The research thus endeavoured to create an e-tutoring environment for design students in which their work can be effectively assessed and reflected upon.

Given the massive scope and magnitude of the problem, there were considerable limitations surrounding the application of this research's proposed method and its related tool in the design curriculum (discussed earlier in this chapter). The conclusions drawn from the study, particularly in testing and evaluating the proposed method, can only be considered as an initial indication to the feasibility and acceptance of the method in an environmental design exercise. The number of participating students and instructors in the tool's trial and testing sessions is not sufficient enough to draw solid conclusions. Moreover, the proposed method has not yet been tested within an actual learning context, and thus the feedback cannot be considered decisive. For example, the students seem to be very enthused and motivated to experience their design within an interactive virtual environment (a game), and noted many great potentials and positives in this approach, however, in a real design project, there might be some negative aspects that were not clear or considered like the additional time and effort required to run the game. Further testing and trials are eminent to validate the findings and draw more solid conclusions regarding the feasibility and effectiveness of the proposed tool as a support for integrating sustainability in design education. In this respect, the tool presented within this research was developed as a proof of concept and to assess the effectiveness and feasibility of the proposed method, and was subjected to phases of user interviews and trials sessions. The outcomes of these sessions gave an indication that there is good potential to be a motivational element for integrating the use of BPS applications in the design process, as well as potential element to support better understanding of the environmental design principles and strategies.

One of the key benefits of the proposed tool is its modularity nature, which means that the MAS and DM techniques can be transferred to later versions of game engines that can support higher quality (in technical terms; i.e. rendering, graphics, GUI, lighting etc.), easier manipulation (for updating the 3D model in the game world in every iteration with minimum time and effort), and improved general users experience (in terms of interaction, navigation, effects, etc.). During and after the development of the proposed tool, a number of promising game engines have been introduced to the market, with improved features and more user-friendly interface. One of these promising game engines is Unity 3D, which can support the development/migration of the proposed tool, and offer better templates, features, and functionalities, and potentially better overall learning experience.

The learning process should allow the students to investigate into their design performance, and allow them to constantly ask 'how', 'why', and 'what-if' questions. In this respect, the process should be revelatory, and supported by number of exemplars, templates, and case studies. Incorporating sustainability in architectural teaching context should thus attempt to bridge the gap between the problem-focused and solution-focused approach, into one integrated approach that is acceptable to the mentality and background of the design students.

It was clearly highlighted throughout this research that design students show more acceptance to (and tend to rely more on) the guidebooks, rules-of-thumb, and their personal experience (built within their cognitive schemata). This is an important aspect that should be considered in designing a teaching methodology. It is important in teaching environmental design to incorporate guidebook-like mechanisms that are not generic, but indeed case-specific; addressing the design problems and students' approach to solve them. Guidelines and rules-of-thumb that are specified to the student's approach can effectively build upon his/her cognitive schemata, and improve the quality of the learning experience.

The method proposed within this thesis attempted to address these aspects throughout different features and functionalities implemented within its associated tool. However, it is envisioned that integrating the proposed method as a supplementary step in the design cycle will not come without its challenges, which can have a negative effect on the students' motivation. In an attempt to minimise these challenges, some aspects should be considered in the design and delivery of the environmental design modules, and the subsequent methods of assessment and feedback. These aspects include:

- Instructors/Studio tutors should be familiarised with any new or additional steps involved within the implementation of the proposed method in the architectural design teaching context. These steps include:

  o the ability to run and export simulation data from the utilised BPS application,

  o the ability to import models in the game engine,

- o the ability to prepare the model in the game engine's world editor and adjust any necessary settings

- o The ability to run the game and make use of its incorporated features and functionalities, and guiding students to the appropriate use of the tool/game.

- Any additional third-party plug-ins should be added/installed to the relevant CAD application to support exporting the 3D design model to a format that is acceptable by the game engine. For example, Collada plug-in must be used with 3Ds MAX and Maya applications to export models to C4 game engines. However, later releases and other game engines (like Unity 3D for example) may not require any additional plug-ins; and can read the models in the same format that is used by 3D modelling applications.

- In preparation to the updated design development process, instructors should incorporate Initial tutorials to familiarise students with the 'what's new' in the process, how to deal with it, and how to get the best out of it. This can be done through the use of subject-specific tutorials and brief workshops in order to speed up the student's acquisition of the desired skills, and minimise the learning curve and familiarise the students with the method and the game engine's interface.

- The feedback provided by the studio tutors is still essential, as the proposed tool is solely a supporting element that can guide the students through the design process and help them analyse BPS data outcomes and make meaningful decisions. These decisions should be validated and confirmed by the tutors, as they can incorrect due to either a mistake in generating the report and/or guidelines in the tool (due to a system bug, wrong input, etc.), or misinterpretation and application of the guidelines in the student's proposed design. Thus, tutors should review the tool's feedback, and how this is interpreted in the design.

- The assessment process of the students' design can incorporate supplementary reports in their design journal, which is a familiar element in developing and

presenting design projects, which "*contains both reflection and resolution that is intrinsically linked within the design process*" (Rutherford and Wilson, 2006). The supplementary reports should focus on highlighting the outcomes of simulation in every design iteration, how this was interpreted in the game's feedback and proposed guidelines, and ultimately how this was reflected in their design decisions. In this respect, the assessment process is demonstrating the students' reflection in and on action. This approach attempts to develop the students' ability of critical thinking and evaluation, as well as reflection upon the learnt theories and learning objectives, promoting the concepts of 'deep learning' and 'assessment for learning'.

It is envisioned that the tool would benefit -in further versions- from a direct relation and integration with BIM system, creating a more centralised base for data and a key reference point for knowledge extraction and decision making. There is a great prospect as BIM is gaining more ground everyday as a favoured medium for design development, collaboration, and communication between different parties and disciplines related to the building project. This medium has the potential to resolve some of the concerns raised during the user trials and testing sessions, particularly regarding the data transportation risks, and the compilation of reports and guidelines in every design iteration. Finally, a main directive for future development would be 'simplification and minimisation' associated with hierarchical layering approach for information presentation. This has been proven to be a much useful and user-friendly approach that can improve the design students' motivation and acceptance to incorporate sustainable aspects in their design process.

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Appendices

Appendices

Appendix [A] - Requirement Specifications

This section presents the formulated list of requirement specifications for the proposed tool. The presented list builds upon the preliminary conceptual requirements presented earlier in chapter two, and expands the scope and specification to include functional, non-functional, and technical requirements.

Conceptual Requirements

These requirements are the abstract specification of the proposed tool that directly address the conceptual level and the key aims and objectives of the research. They are used as a reference point for the formulation of more detailed specification. Chapter two presented some conceptual requirements based on the research findings of this particular chapter. The set presented here extends the previously presented requirements, based on further literature findings and the feedback provided in different waves of users' trials and testing. These requirements include:

CR1.   The tool should be intuitive and easy to learn and use. As the tool will be used in multiple design iteration within each project, the tool should make sure not to de-motivate the students or affect their confidence by its complexity.

CR2.   The game's outcomes should be clearly presented according to the users' preferences and input, current position within the game, and current condition of the weather zone being experienced.

CR3.   The Tool should offer approaches and methods to minimise the additional time required before actually running the game. This can be done through the automated generation and exportation of simulation data, and preparing pre-set templates that the users can simply import their 3D models into (as discussed later in the functional requirements).

CR4. The tool should be modular; enabling the migration of the programmed modules that are added to the engine's source code to updated versions of the engine, or to an entirely different engine.

CR5. The tool should use a 3D game engine as a host medium for the proposed environmental design support method. The tool should utilise the engine's technology to offer the students with 3D interactive narrative virtual learning experience.

CR6. The tool should have a high processing capacity to be able to handle the extensive amount of simulation data generated over prolonged (annual) periods. The tool should store and process this data at run-time according to the users preferences and behaviour in the virtual environment.

CR7. An implementation of a MAS is required to break down the overall problem, and delegate tasks and sub-tasks among the different implemented agents.

CR8. The tool should use 'descriptive' Data Mining techniques to traverse the simulation outcomes retrieved from the BPS application. These techniques include characterisation/summarisation, association analysis, and decision trees.

CR9. The tool should incorporate an embedded 'Reporting Agent' that will be the main 'narrator' of the building's story (in terms of geometry and performance), as well as the 'communicator' with the users to extract information and deliver the knowledge/reports.

Functional Requirements

These are the requirements that relate directly to the implementation of the features and functionalities within the game. These are considered to be a more detailed specification of the conceptual requirement, and a guide to the highly detailed technical requirements (discussed later). These requirements include:

FR1.   The tool should load the initial relevant data (including the default settings), at the start of the game.

FR2.   The tool should filter the loaded data, according to the format used when exported from the BPS application, to be ready for sorting and storing within the game's data warehouse. This process is carried out every time the game starts in order to allow for any updates in the data after every design iteration.

FR3.   The tool should include triggers to flag a message when the user enters a new/different zone. These triggers can either be based on actual entities in the game-engine's world editor, or can be defined as a function of the player's position and the zone's dimensions.

FR4.   The analysis calculations should be carried out when required at run-time, to avoid extensive delays on loading the game.

FR5.   The tool should incorporate be ready made templates in the game's world editor, which the users can use to import their designs. This will reduce the time and effort required to prepare the model in the game engine before running the game.

FR6.   The tool should facilitate data collection through providing pre-prepared LUA script to automate the process of exporting data from the BPS application. The LUA script should suit any Ecotect model file, and automatically export the simulation data to the game engine's location. The used LUA script is presented in Appendix E.

FR7.   The tool should present a daily, monthly, and yearly report when requested by the user. These reports will cover any identified problems, with its possible causalities, the ranges during the day where the zone's temperature is out of comfort range.

FR8.   The tool should be able to identify any missing or required data, and attempt to collect it through interrogating the users. The interrogation routines should also gather the users' views and opinions on some proposed design strategies, and store this opinion for further analysis.

FR9.   The tool should provide a brief description/reminder about the keywords and concepts used in the interrogation questions.

FR10.   The tool should provide a link to external resources to give the students a wider view on a specific topic, and/or lecture notes to revisit the information and formulas presented in the lectures.

FR11.   The tool should interrogate the sun-path diagram for the yearly-hourly coordinate of the sun, and reposition the sun's game object, as well as the game's Omni light source to the equivalent 3D coordinates in the game world.

FR12.   The tool should use the association data mining technique to analyse the simulation data (from multiple available resources) and identify the performance problems, and then present them in an abstract form to the user when demanded or at relevant time and space.

FR13.   The tool should present a number of possible reasons for any identified problem, with further details on terms/reasons mentioned.

FR14.   The tool should present an initial brief report (displayed at run-time), once any of the experiment settings have changed (like changing the date and time, or entering a different thermal zone).

FR15.   The tool should present a daily, monthly, and yearly report when requested by the user. These reports will cover any identified problems, with its possible causalities, the ranges during the day where the zone's temperature is out of comfort range.

FR16. The reports should also present the user with the overall required energy to accommodate the indoors temperatures of the current zone for a particular month, and for the whole year.

FR17. The tool should identify the current date and time once set/updated by the user, and subsequently update and load all the relevant data about this zone; this includes the indoors and outdoors temperature, the zone's brief and reports, interrogation routines, possible problem causalities, and the set of guidelines.

FR18. The tool should update the GUI information based on the current position of the player and the temperature condition in the zone of experience. This is done through clearly displaying both the indoors and outdoors temperature, with a clear relation to the comfort range.

FR19. The tool should comprise a 'Settings' window where the user can alter and update their virtual experience's settings and preferences. This window should be available directly from the game (independent of the engine's main menu).

Non-Functional Requirements

These are requirements that relate more to the contextual aspects of the tool, including the delivery platforms and methods, game controls, health and psychological aspects, etc. These requirements include:

NFR1. The tool should eliminate any means/features that could lead to some users suffering nausea and/or sickness. For example, head bobbing (where the game's first person perspective camera moves up and down to imitate realistic movement).

NFR2. The tool should eliminate -and refrain from using- any visual effect that could negatively affect the users and their virtual learning experience. For example, any effects that include flashing images that can affect students who suffer from

a degree of epilepsy, particularly when the tool is intended to be used in every design iteration.

NFR3. The game should focus on the educational elements, and eliminate any in-game and GUI entities that can distract the users or deviate them from the main objectives of using/playing the game (for example, the ability to fire weapons and its accompanied special effects, the built-in health indicators, the score system, etc.).

NFR4. The tool should offer control through standard keyboard movement and navigation keys, as well as standard mouse; offering the player with a six-degree-of-freedom control.

Technical Requirements

These requirements have more specific nature, and can be considered an interpretation of the conceptual and functional requirements into a technical format that can be directly considered in the game development and implementation. These requirements include:

TR1. The tool should incorporate a modular built-in DW, and attain a flexible structure for sorting, searching, and retrieving data according to the users' and agents' requirements

TR2. The tool should collect annual hourly information about each zone's indoors temperature, as well as the outdoors temperature for the selected weather file.

TR3. The tool should export data from the sun-path diagram that represent the annual hourly position of the sun (in terms of azimuth and altitude). These will be later used in the equation to position the sun object and light source in the game.

TR4. The tool should build an informational model about the imported design once the game is initialised. This information model is built upon the zone geometric and non-geometric details exported from Ecotect.

TR5.   The initial informational model should include attributes about each zone's area, height, width, depth, and volume, as well as the number of windows included in this zone, their orientation, and their dimensions.

TR6.   The tool requires a definition of a new data-type to hold the information and attributes related to each of the design model's thermal zones. This should hold the details mentioned in [TR5], and the engine can create multiple instances of this class to represent the game's informational model.

TR7.   The tool should collect information about the thermal gains breakdown -for each weather zone- in an annual hourly format, and extract, filter, and refine the information to be ready for storing in the relevant data holders in the data warehouse class.

TR8.   The MAS should communicate with the engine's source code and the users through the [Game Interface] class. This includes implementing some additional features to the existing [Display Interface] derived class, and implementing two additional derived classes for the reports and settings windows.

Appendix [B] – Interviews & Questionnaire

Pre-Development and In-Development Interviews

1.	When do you often develop a 3D model for your design?

2.	What motivates you to develop this 3D model?

3.	How confident are you with making regular updates to your 3D model as the design develops?

4.	In your opinion, what are the advantages (if any) of using 'games' in learning?

5.	In your opinion, what are the disadvantages (if any) of using 'games' in learning?

6.	Why do you use building performance simulation (BPS) applications? What is your motivation?

7.	What are the main advantages for using BPS applications in the architectural design process?

8.	What are the main challenges/problems (if any) that you/the student encounter when integrating BPS applications in the design process?
9.	How do you/the student normally identify problems (in the design performance) after running the simulation?
10.	When identifying a problem, how do you know what the possible causes of this problem are?
11.	After identifying the problem and noting its possible causes, how do you translate that into design decisions?
12.	(After explaining the intention to develop a 3D game to support environmental design education), what do you want/expect to see in this game?
13.	Would you like to add any further suggestions and/or information?

Post Development Questionnaire:

Part One: The Design Process & Sustainability

Section One:	
This section aims to get your views on design representation and visualisation methods, focusing mainly on 3D model, their application (and re-application) at different stages of design.	

1.1	What is your preferred method of design representation & Visualisation? *(you can select more than one)*

☐ Design Schematics & Sketches   ☐ 3D Models

☐ Physical Models   ☐ Animations

☐ Interactive Walkthroughs   ☐ Others (please specify) ....

1.2	Do you normally develop 3D models of your designs? *(if you answer 'No' to this question, please jump to 'Section Two')*	Yes ☐	No ☐

1.3	What motivates you to develop a 3D model? i.e. what do you use 3D models for?

1.4	*- On a scale from 1 to 5 (5 being most important)-* How important is the digital 3D models to your design process?	1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

1.5	At what stage (if any) do you normally develop a 3D CAD model?

☐ Early (minimum details available)   ☐ Intermediate (with basic details)   ☐ Later (with almost full details)

1.6	In your opinion, what are the advantages/disadvantages for developing 3D models at earlier stages of design?

advantages:

disadvantages:

1.7	How comfortable are you with constantly applying design changes into the CAD 3D model? ☐ Very comfortable ☐ fairly comfortable ☐ not comfortable ☐ very uncomfortable

Section Two:

This section aims to obtain your views on games in general (and 3D games in particular), as an educational medium, as well as a design visualisation context.

2.1	How frequently do you play games? ☐ Never (*if so, please move to 'Section Three', question 3.1*) ☐ Very rarely ☐ Once a month ☐ once a week ☐ Regular player
2.2	In general, what aspects of games do you like the most (what makes you play these games)? *(you can select more than one)* ☐ The game's storyline ☐ The added interactivity ☐ The game's challenges ☐ Measuring performance/capabilities ☐ Others (please specify) ....

2.3	Have you ever used games to support your learning process (educational games)? *(if your answer is 'No', please move to question 2.7)*	Yes ☐	No ☐

2.4	In your opinion, what are the advantages (if any) of using 'games' in learning?

2.5	*- On a scale from 1 to 5 (5 being most effective)-* In general, how effective do you think using games in learning is?	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐

2.6	What are the problems (if any) that you encounter with educational games?

2.7	Have you used any 3D game engine before? i.e. have you ever used any 3D models in a game editor? (if you answer 'No' to this question, please move to question 2.10)	Yes ☐	No ☐

2.8	what purpose did you use the game engine for? ☐ Game stage/level development ☐ Design visualisation and walkthrough ☐ Others (please specify) ....

2.9	If you have used the game engine for design visualisation and representation, what added value did the game add in comparison to other methods like 3D perspective shots and animations?

2.10	In your opinion, what are the key advantages/strengths (if any) in using 3D games to represent and visualise a design?

2.11	In your opinion, what are the key disadvantages/weaknesses (if any) in using 3D games to represent and visualise a design?

Section Three:

This section aims to obtain your views on the use building performance simulation software in the design process.

3.1	With regards to Building Performance Simulation (BPS) applications, would you consider yourself as: ☐ inexperienced user ☐ Beginner ☐ Regular user ☐ Highly experienced user

3.2	Why do you use building performance simulation (BPS) applications? What is your motivation?
3.3	What BPS application do you use to assess and evaluate your design's performance? *(you can select more than one)* ☐ Ecotect ☐ IES-VE ☐ EnergyPlus ☐ Other ....
3.4	In your views, what is/are the most important analysis aspect(s)? *(if you select more than one, please grade their importance - 1 being the most important aspect)* ☐ Thermal [...] ☐ Lighting [...] ☐ Acoustics [...] ☐ *Other* .... [...]
3.5	*- On a scale from 1 to 5 (5 being very high)-* How high is the level of detail required to run the simulation? 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐
3.6	What time period(s) do you normally consider in the assessment of your building performance? *(you can select more than one)* ☐ Daily ☐ Monthly ☐ Annual ☐ Other ....
3.7	After running the simulation, and in the results analysis, which data representation method do you prefer? *(you can select more than one)* ☐ Graphs/Diagrams ☐ Numerical/Tabular ☐ 3D Representation ☐ Other ....
3.8	Why do you prefer this/these particular method(s)?
3.9	How do you normally identify problems (in the design performance) after running the simulation?
3.10	What are the criteria/standards that you use to compare the outcome data to (for highlighting any irregularities)? ☐ BPS settings/standards ☐ Rules of thumb/guidebooks ☐ Lecture notes ☐ Other ....

3.11	*- On a scale from 1 to 5 (5 being very easy)-* How easy do you find defining the performance problems?	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
3.12	When identifying a problem, how do you know what the possible causes of this problem are?					
3.13	*- On a scale from 1 to 5 (5 being very easy)-* How easy do you find defining the causes of noted problems?	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
3.14	After identifying the problem and noting its possible causes, how do you translate that into design decisions?					
3.15	*- On a scale from 1 to 5 (5 being very easy)-* How easy do you find translating the problem and causes to design decisions?	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
3.16	*- On a scale from 1 to 5 (5 being very frequently)-* How frequent do you rely on tutors/instructors to help you in the simulation process?	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
3.17	*- On a scale from 1 to 5 (5 being very frequently)-* How frequent do you rely on guidebooks and rules-of thumb to support your 'environmental' design decision?	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
3.18	In your opinion, what are the key strengths/advantages of BPS applications in the architectural domain?					

3.19	In your opinion, what are the key weaknesses/disadvantages of BPS applications in the architectural domain?

Part Two: The Proposed Environmental Design Game

Section Four:

This section aims to get you views on the proposed tool as an medium for integrating design and environmental analysis, and its suitability to the architectural design and educational domain.

	In comparison to the BPS applications, please rate the proposed tool in the following set of questions:	*Very Bad*	*Bad*	*Neutral*	*Good*	*Very Good*
4.1	In comparison to the BPS application data outcomes, how would you rate the tool in terms of understanding the building behaviour?	☐	☐	☐	☐	☐
4.2	How intuitive/instructive is the proposed tool, in comparison to the BPS applications? i.e. rating the tool as an e-tutor (presenting feedback, assessment, guidance, etc)	☐	☐	☐	☐	☐
4.3	How do you rate the proposed game as an environmental design learning support tool? (how effective is the tool in improving the level of understanding for environmental design aspects)	☐	☐	☐	☐	☐
4.4	How would you rate the proposed tool in terms of the quality and relevance of the outcomes (reports, problems, guidelines, etc.)	☐	☐	☐	☐	☐
4.5	Do you believe the proposed game can help in directing you to ask the right set of questions (compared to the procedure you follow in BPS applications)? i.e. directing you to better investigate the design and make effective decisions.	Yes ☐			No ☐	

4.6	If you answered 'Yes' to the previous question, how can the game help in directing you to make effective decisions?
4.7	What do you think can be added to the game to help you towards more effective design decisions?
4.8	Can the proposed tool contribute to greater knowledge of environmental design principles and strategies (compared to that gained from BPS applications only)? Yes ☐ No ☐
4.9	If you answered 'Yes' to the previous question, how do you think the game can contribute to greater knowledge?
4.10	What do you think can be added to the game to help you get better knowledge of environmental design principles and strategies?
4.11	In terms of identifying performance problems, which of these statements is more accurate: ☐ The tool can help me uncover problems I could have missed in my analysis of BPS outcomes ☐ The tool can only confirm the problems that I can highlight in the performance analysis outcomes. ☐ The tool seems to miss some problems I can identify directly from graphs, tables, etc. ☐ The tool is confusing and can't help in problems identification.

4.12	In comparison to conventional methods, how can the proposed tool help you to better identify design problems (if it does)?
4.13	In terms of identifying problem causalities, which of these statements is more accurate: ☐ The tool can effectively help to define possible causes that I wouldn't consider in some cases. ☐ The tool can only confirm the causes that I have already envisioned. ☐ The tool seems to miss some possible causes to the noted problems. ☐ The tool is confusing, and can't help to define the problem causes effectively.
4.14	In comparison to conventional methods, how can the proposed tool help you to better identify the possible causes of noted design problems (if it does)?
4.15	In terms of proposed design strategies and guidelines, which of these statements is more accurate: ☐ The tool presents very useful, effective, and accurate design guidelines and strategies. ☐ The tool can only confirm the guidelines and strategies that I envision to follow to improve the performance. ☐ The tool missed some important guidelines that could be useful to the process. ☐ The guidelines and strategies presented are confusing and can't help in making a design decision.
4.16	In comparison to conventional methods, how can the proposed tool help you to better make informed design decisions (if it does)?

4.17	In comparison to conventional methods, what can the game help you learn more effectively/quickly?									
4.18	*- On a scale from 1 to 5 (5 being very effective)-* How effective do you believe that implementing such method/tool be in a design exercise or design studios?		1 ☐		2 ☐		3 ☐		4 ☐	5 ☐
4.19	*- On a scale from 1 to 5 (5 being very effective)-* How effective do you think this method will affect your (the students') motivation to integrate environmental design aspects?		1 ☐		2 ☐		3 ☐		4 ☐	5 ☐
4.20	What do you think are the main advantages of this supporting tool to the students' environmental design learning experience?									
4.21	What do you think are the main disadvantages of this supporting tool to the students' environmental design learning experience?									

Section Five:

This section aims to get you feedback on the features and functionalities implemented in the proposed tool.

5.1	*- On a scale from 1 to 5 (5 being highly effective)-* How effective did you find experiencing the design within the game's virtual space?	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
5.2	What did experiencing the design in a game world add to you as a designer (what are the advantages)?					
5.3	Do you have any concerns regarding running your design in a game world?					
5.4	*- On a scale from 1 to 5 (5 being highly effective)-* How effective did you find indicating if the current zone's temperature is within or outside the comfort range?	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
5.5	*- On a scale from 1 to 5 (5 being highly effective)-* How effective did you find presenting the sun position and solar access to the building zones.	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
5.6	*- On a scale from 1 to 5 (5 being highly effective)-* How effective did you find the initial Zone Briefs (automatically displayed on entering the zone)?	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
5.7	What other information (if any) do you think should be presented in the initial zone brief?					
5.8	*- On a scale from 1 to 5 (5 being highly effective)-* How effective did you find the interrogation routines (asking questions and getting your views on relevant design strategies)?	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
5.9	How can the interrogation routines help you (if they can) in making design decisions more confidently?					

5.10	*- On a scale from 1 to 5 (5 being highly effective)-* How effective did you find the Zone's Report Tabs?	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
5.11	What other information (if any) do you think should be presented in these tab?					
5.12	Finally, would you like to offer any additional reviews, comments and/or suggestions?					

Thank you for taking the time to participate and complete this questionnaire.

Appendix [C] – Selected Participants' Responses

This section presents a selected portion of the participants responses to some of the questions presented throughout the various waves of testing and users' trials (pre-development, in-development, and post-development). These were mainly open-ended questions that aimed to obtain more comprehensive views from the participants, with higher level of flexibility in expressing their thoughts and opinions. The complete set of the interview questions and the questionnaire form are presented in Appendix B.

	What motivates you/the student to develop a 3D model? i.e. what do you/the student use 3D models for?
Students	*"I find it easier to design and even sketch on modelling software, Google Sktechup in particular is very useful. So 3D models are there from the start, but different stages mean different levels of detail."* *"it's good for space reasoning, masses shaping, relations, and of course for presenting the work; in other words, communicating the design to other –the tutor in this case-"*
Instructors	*"It is an effective way of demonstrating design ideas, and can be used in multiple domains, I personally use them for CFD analysis."*
	What are the problems (if any) that you encounter with educational games?
Students	*"From what I have seen in school, they are too dull!! Simply Trivial Pursuit look alike"* *"If they are not well designed and meaningful, it's not worth the time making them."*
Instructors	*"Learning through games has been the subject of debate and criticism for decades now. There is no doubt there are clear benefits in this approach, but only if it is professionally and effectively structured. These games can easily drift from their purpose, and as a result, the students themselves can also drift into playing and further away from*

	learning."
	In your opinion, what are the advantages (if any) of using 'games' in learning?
<u>Students</u>	*"Games are always fun, and will make learning fun"* *"I only came across educational games in school; based on the math, history, and science. But it was an enjoyable experience, as it breaks the strictness of learning and makes it more 'fun' and 'challenging'."*
<u>Instructors</u>	*"Engagement, Engagement, Engagement!!"* *"Games are simply fun, and therefore challenging and motivating."*
	Why do you use building performance simulation (BPS) applications? What is your motivation?
<u>Students</u>	*"The tutor!!"* *"Simply because we have to, or we are told to"* *"To improve the performance of our designed buildings, to preserve the environment. But as the studio is short and intense, this can become a luxury, unless it is clearly made mandatory."* *"There is increasing scarcity in natural resources, and everyone on the planet should act. This is our arena -as designers- and this is how we can make a difference."*
<u>Instructors</u>	*"We incorporate it (Environmental design through BPS) as it is the 'right thing to do', not only pedagogically but morally. Yes there is pressure from governments and organisations, but the onus is on us to breed a new generation of 'responsible' practitioners."* *"It's a way of developing the design, just like any other aspect that is normally*

	considered." *"The understanding of how the building behaves within, and the passive internal comfort of the users is high on the design agenda. My main motivation in using BPS is to make sure that internal comfort of users and passive design techniques has been met to its utmost in design."*
	What are the main Challenges (if any) that you/the student encounter when integrating BPS applications in the design process?
<u>Students</u>	*"I don't always have the confidence to use Ecotect, if compared to other design applications"* *"It takes too long before getting results, most of that time I am trying to understand what I should add to the initial settings"* *"Linking the data together to make decisions. In many cases it can be assumptions and speculations, and I am not always entirely positive about what I am doing."* *"The theory and building physics can be sometimes too complex, and difficult to understand and apply."*
<u>Instructors</u>	*"Students should be guided to use these applications and their outcomes to guide them through their design decisions at different stages, and not just to produce charts and reports!!".* *"Making sense of data"* *"The main problem with students undertaking environmental analysis is their lack of understanding of why they have to do this analysis at the first instance, and then how to analyze and interpret those diagrams to inform their design decisions."* *"Architecture students find it very difficult to understand the climatic and environmental diagrams and usually pin them on the wall as fulfilling simply one of the critical requirements, without any analysis that directly informs their design decisions and this usually means that they even get the point of carrying out such analysis at the*

	first place."
	How do you/the student normally identify problems (in the design performance) after running the simulation?
Students	*"Problems can be seen, what to do about them cannot."* *"The colours from the graphs normally give indications, also the numbers for the required heating and cooling loads"* *"It depends on the nature of the problem. Sometimes it can be easily identified from graphs or charts, when there are range or colour codes."*
Instructors	*"You have to know where to look to find if there are problems. This brings us back to the point of: are the students asking the right questions?"*
	When identifying a problem, how do you know what the possible causes of this problem are?
Students	*"In most cases, I don't !!"* *"We have to look into different charts to understand the possible causes."* *"Again, it depends on the problem. If for example there's a problem noted in a graph related to high solar gains, the cause can be easily identified. However, that's not always the case."*
Instructors	*"The best way of identifying a problem and its causes is testing your main hypothesis, than it's a matter of change and error."*
	After identifying the problem and noting its possible causes, how do you translate that into design decisions?
Students	*"Lecture slides and handouts usually have sections on guidelines for passive design."*

	"If I am sure about the causes, then possibly I might know what to do" *"Studio tutors can always come handy at this stage, along with the theories and guidelines from the lectures and textbooks."*
<u>Instructors</u>	*"This is the trickiest stage of the process, and this is where it all comes down to. We tend to direct the students to refer to guidebooks and rules-of-thumb as the basis for understanding what to do next, and how this will affect the overall performance. Whether or not students follow this advice is a different matter."* *"Having known the possible causes, it's a matter of a number of changes within the design and then more testing, to see what the best solution of that problem can be."* *"Whilst some is capable of analyzing those diagrams, they find it again very difficult to pin point the main problems within their design, and thus find it difficult to take decisions based on their diagrams"*
	How can the game/tool help in directing you to make effective decisions?
<u>Students</u>	*"It helps the student to focus on a decision, rather than to focus on how to make it. It can save the time and effort spent in looking into multiple resources. It brings everything all together to the students."* *"It tells the students the expected outcome of the decisions"* *"the guidelines that the game offer are specified to the design. This can make the decision more accurate."*
<u>Instructors</u>	*"I like the fact that it speaks to the architects in their language. This can make students stand on a more familiar ground and feel more confident, which can lead to more confident decisions."* *"The game has some easy alteration techniques which can be carried out, that gives us direct results in which it will be possible to identify whether the problem has been*

	solved or other possible solutions should take place. As the game has embedded some of the main passive design principles it acts as a reminder of the roles of thumb that needs to be applied by the designer and these acts as a design guide through the process as well."
	What do you think can be added to the game to help you towards more effective design decisions?
Students	*"Combined printable report (possibly in a pdf format)."* *"Something to print out for reference, and for showing the studio tutor we actually did the work!!"*
Instructors	*"There is a big issue with the input assumptions made and the resultant output. Wrong input assumptions do not give a decent simulation. I believe the game should shed more light on this issue"* *"At the moment this can be an interesting and user friendly tool that can be used as is... frequent use will then identify if there should be some other options added."*
	How do you think the game can contribute to greater environmental design knowledge?
Students	*"It presents the terms and strategies in their appropriate place and time"* *"It is -in my opinion- a more relaxed and familiar environment, and the way the environmental data is presented is much simpler."*
Instructors	*"The game attempts to relate theory to practice, however, it needs a better link to the theory. Students should be offered much more information about an environmental concept than that presented in a small window"* *"It is presenting the data in a simple manner, and in hierarchy, in other words presenting the data when it is required."*

	"The abstraction of data can encourage students to investigate it more" *"I think the game can contribute to greater knowledge if can be used in Architecture education as a main tool for undergraduate, not only does it acts as a good visualisation tool, however, it can play a major role in understanding and applying environmental and passive design techniques effectively and efficiently."*
	What do you think can be added to the game to help you/the student get better knowledge of environmental design principles and strategies?
<u>Students</u>	*"The information presented is short and abstract. The game needs to have links to further information and online resources."* *"Probably more about lighting analysis"*
<u>Instructors</u>	*"The students still need to see the simulation graphs and numbers and understand what they mean. They are likely to use more sophisticated BPS applications in their professional career, and they need to link what they have learned with that is presented in front of them (referring to simulation outcomes)"* *"More motivational factors to push/encourage students to look back into the theory, and link to the physics."*
	In comparison to conventional methods, how can the proposed tool help you to better identify design problems (if it does)?
<u>Students</u>	*"The reports are a nice feature, and can help you find out if anything is wrong and why"* *"It pins the problems in the periods outside comfort, and the loads/energy required, which can be more useful and much easier"*
<u>Instructors</u>	*"As the tool displays direct results of internal climatic conditions of the spaces designed it aids in identifying where the problems can be, and assists in applying changes that might solve the current problems identified."*

	In comparison to conventional methods, how can the proposed tool help you to better identify the possible causes of noted design problems (if it does)?
Students	*"The game presents some possible causes with details on each"* *"It's nice to see the interface presenting the problem, and beside it some possible causes"*
Instructors	*"It states the possible causes clearly, though the game limits them to just three!!"* *"As the tool displays the main roles of thumb of passive design techniques, it works better in identifying possible causes of the noted design problems and this is something that you do not get in other conventional methods."*
	In comparison to conventional methods, how can the proposed tool help you to better make informed design decisions (if it does)?
Students	*"The design specific guidelines are very nice, and could be very effective in a design exercise"* *"It clearly presents directives on what to do, and why to do them"*
Instructors	*"Better understanding of the problem can lead to better treatment, and the game attempts to do that"* *"When you have identified problems and attempted in solving them, it gives you direct results of how better or worse this decision has made your design, in such aspect it aids in making better informed design decisions."*
	In comparison to conventional methods, what can the game help you learn more effectively/quickly?
Students	*"Strategies and guidelines to improve a building performance"* *"I Particularly like the questions asked in the game, and the fact that these are dynamically generated according to the condition of the zone. This way, the game can help me understand more about every situation and how to deal with problems with*

	different strategies and alternatives"
Instructors	*"I believe that the game helps you learning, applying and understanding more of the environmental and passive design strategies, as these are displayed along the pass of your design and hence enhances your understanding of how these strategies have a direct effect on your design."*
	What did experiencing the design in a game world add to you as a designer (what are the advantages)?
Students	*"This is my favourite part of the game. It's like playing a game without weapons"* *"I think it's important to 'live' inside the building before it is built. Then you might uncover things that you normally wouldn't in other methods".*
Instructors	*"Visualising and experiencing the spaces within your building with a thorough understanding of the internal comfort level within your spaces aided me in understanding better how those spaces will work in real life and what the effect of my design will be on its end users."*
	Do you have any concerns regarding running your design in a game world?
Students	*"Another piece of software to learn and work with."* *"It would be more useful if it could be something like a plug-in to an existing software"*
Instructors	*"My concern is that the students can be distracted by building and running the game than focusing on its main purpose"* *"Extra time and effort required in an already tight schedule"*
	How can the interrogation (Q&A) routines help you (if they can) in making design decisions more confidently?

<u>Students</u>	*"It helps in understanding what will or can happen with every suggestion."* *"They are better than just presenting guidelines. They wait for the student input/opinion before proceeding or suggesting another strategy. This creates a more personalised experience that can make the users more confident in their decisions."*
<u>Instructors</u>	*"Students can relate to this routine, as it is similar to an actual tutorial. It creates a conversation with the user to try to decide what to do next."* *"Interrogation within design process is an important aspect that makes the designer present his utmost best in reaching design decisions that provide interesting and more importantly healthy and comfortable spaces for the users"*
	What other information (if any) do you think should be presented in these tabs?
<u>Students</u>	*"The program is limited to data available in Ecotect, which may cause versatility issues as Ecotect has many noted limitations; i.e. materials, geographical location, etc."* *"More lighting analysis"*
<u>Instructors</u>	*"It is difficult to compromise our guidebooks and references. As for students to understand the outcome of their design they need to understand the physics behind environmental design and other rules-of-thumb."* *"More links to online resources, for further information."*

Appendix [D] – Environmental Design Strategies & Guidelines

This section presents the general, and zone-specific guidelines implemented within the proposed tool/game. These are generated dynamically based on the characterisation and summarisation data mining techniques that generate a report describing the currently experienced zone, and subsequently traversing through these guidelines to pick what is deemed appropriate.

Use Horizontal Overhang over windows in the southern façade
These can be structural windows overhangs (fixed throughout the year), or mechanical, where it can be expandable in summer and retractable in winter. The Depth and width of the required overhang for this zone is [*value-A*] cm depth, as the periods of overheat start from [*value-B*]. The overhang should be extended to both sides of the window by [*value-C*] cm. [*value-A*] Recommended value of the window's overhang depth, based on the calculation of the zone's periods of overheat, and the relevant sun position during this period. [*value-B*] The calculated zone's period of overheat; where temperatures start exceeding the upper limit of comfort range. [*value-C*] The measure of the extension on both sides of the window, that the overhang should adhere to in order to prevent any unrequired solar access during the zone's periods of overheat.   Figure A. 1: An illustration representing the effect of the window's overhang to prevent the unwanted summer sun and allow required winter sun. (Lechner, 2009)
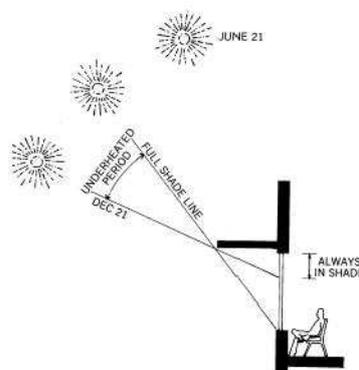
Use Vertical Fins in Eastern and western façades.

I can see that this zone has [*Eastern and/or Western*] facing windows. As the sun's altitude is relatively smaller, relying on horizontal overhangs is not efficient. It has to be understood that for these fins to be effective, they can affect the window's view. The number of vertical fins required in the window can be reduced if the depth of each fin can be increased.
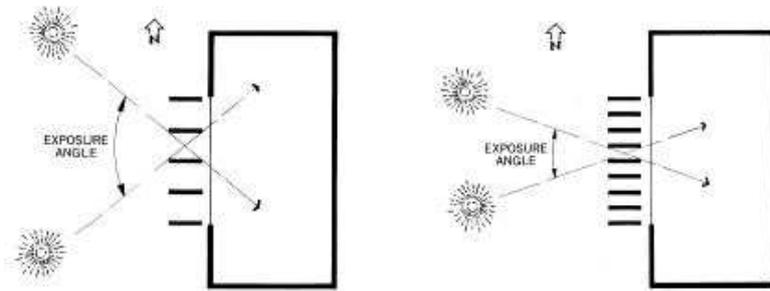
Figure A. 2: An illustration representing the relation between the depth and number of eastern/western windows' vertical fins in relevance to the exposure angle. Image from Lechner (2009)

Design eastern & western facing windows to face north or south.

You have a window area of [*value-A*] square meters, facing [*value-B*]. It is recommended to shift the windows to face north or even south to avoid direct overheat from periods of exposure in the morning and the evening and reduce summer and fall afternoon heat gain. This can be achieved by either tilting the window angle (Fig. 1) or sinking them deep in the wall. This will not affect the heat gain in winter as then the sun angle is minimal in the East and West facades.

[*value-A*] The overall area of the eastern and/or western-facing windows in the current thermal zone.

[*value-B*] The direction (East and/or West) of the existing zone's windows.
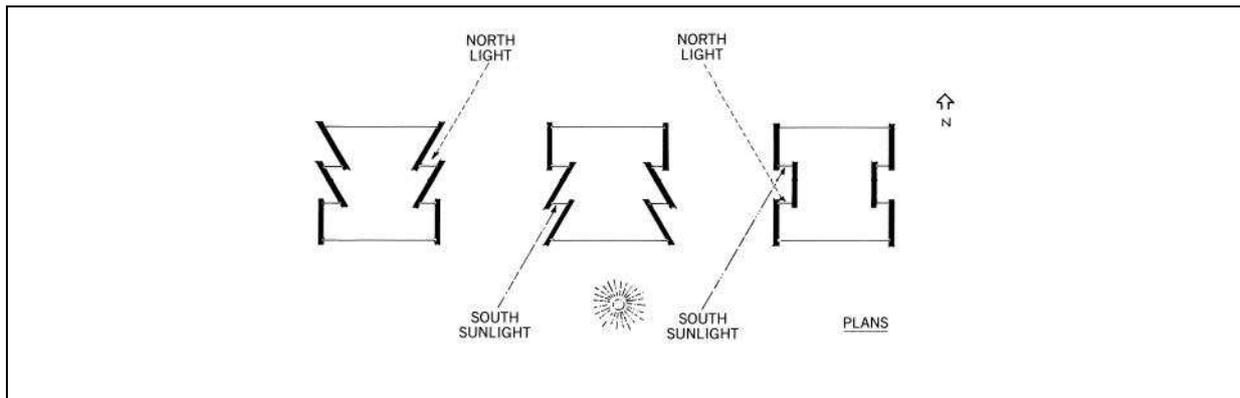
Figure A. 3: Shifting eastern and western windows to face north and south.
Image derived from Lechner (2009)

Use/Promote Evaporative Cooling.

When water evaporates, it draws a large amount of sensible heat from its surroundings and converts this type of heat into latent heat in the form of water vapour. As sensible heat is converted to latent heat, the temperature drops. This phenomenon is used to cool buildings in two very different ways. If the water evaporates in the building or in the fresh-air intake, the air will be not only cooled, but also humidified. This method is called direct evaporative cooling. If, however, the building or indoor air are cooled by evaporation without humidifying the indoor air, the method is called indirect evaporative cooling. (Lechner, 2009, pp.287)

Use high Thermal Mass

The thermal mass of a building determines its aptitude to store and control the flow of internal heat. Using high thermal mass in the building can shift its properties, allowing it to take longer periods to heat up, and to cool down. As a result, the morning heat can be absorbed during the day by thermal walls (for example), preventing the heat from the zone, and the walls can release that heat at night when temperatures fall down. I can see there are [*value*] sq m of windows in this zone, which can be a reason for heat gain/loss, you should consider converting some of this area to thermal mass walls.

[*value*] The total area of windows in the currently experienced zone.
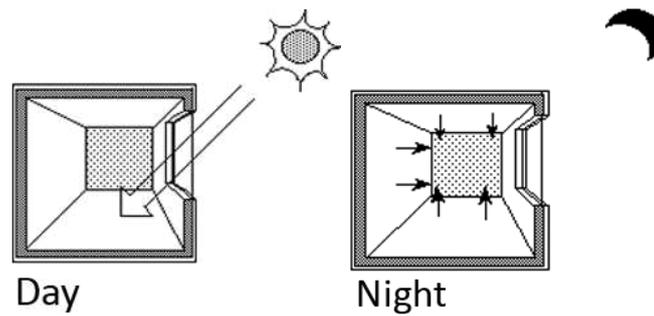
Figure A. 4: An illustration representing the concept of thermal mass in a building

Implement extended "Sunny spaces" to maximise passive gain

A "sun space" is a space or room design to be adjacent to the building's zones to collect heat and re-admit this heat to the zones (directly or indirectly). Sun space is considered one of the most popular and efficient passive heating system. It is also appealing for the occupants as it serves as a semi-outdoors space, particularly in colder conditions. However, sun spaces should be treated in summer using exterior reflective shades to block the sun and ceiling vents to get rid of indoors heated air. (Brown and Dekay, 2001; and Lechner, 2009)

(c) Isolated solar gain (sunspace)
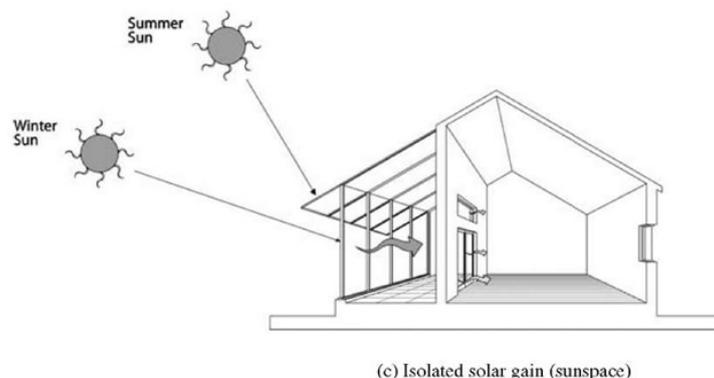
Figure A. 5: An example of an adjacent sunny space for isolated solar gains.
Image source: http://what-when-how.com/energy-engineering/solar-thermal-technologies-energy-engineering/

Optimize Building Orientation

To accommodate prevailing wind [*value*], optimise natural cross ventilation, and to avoid overheating spaces via direct solar gain. Building orientation should also be considered in designing

passive heating in winter (like areas for sunny spaces).

[*value*] The predominant wind direction throughout the year, derived from the weather file data exported from Ecotect.

Use suitable Flooring Materials and colours

Use light coloured Low emitting materials in summer, and high emitting materials in winter (like ceramics and marble flooring in summer and cover with carpets in winter). Tiles or slate (even on low mass wood floors) or a stone-faced fireplace can help store winter daytime solar gain and summer night-time 'coolth'. (Climate Consultant 4.0 - Milne et al., 2009).

Accommodate "Effective Area of Opening"

Designing an effective window opening is critical in achieving particular wind volume flow rate through a specific zone.

In case of a cross ventilation zone: In this zone I can see that there is ventilation from the north and south. According to the wind data, the prevailing wind is [*value-A*], so the [*value-A*] window is the windward and the southern is the leeward. This means that in this zone, the minimum effective opening area is [*value-B*] meters square.

In case of a single-sided ventilation zone: In this zone I can see that there is ventilation from only the [*value-C*]. This means that in this zone, the minimum effective opening area is [*value-B*] meters square.

[*value-A*] The predominant wind direction throughout the year, derived from the weather file data exported from Ecotect.

[*value-B*] The calculated effective area of opening that can support efficient stack ventilation. The calculation equations are presented in appendix F.

[*value-C*] The direction/orientation of the existing window in the current zone.
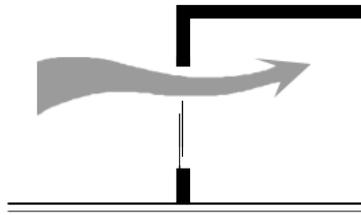
Figure A. 6: Effective Area of Opening is an important factor in the design
to attain particular wind volume flow rate through a specific zone.

Promote "Natural Cross ventilation"

This is the process of exhausting warm building air and replacing it with cooler outside air. I can see that this zone is facing [*value-A*] where the prevailing wind is coming from. It would be effective if you place a window on this side (windward) with the [*value-B*] facing window (leeward), this can create a cross-ventilation zone that can reduce the temperature in summer.

[*value-A*] The prevailing windward direction, if the current zone's orientation is facing this side.

[*value-B*] The direction/orientation of the window in the adjacent/opposite side of the zone that can support effective cross ventilation.
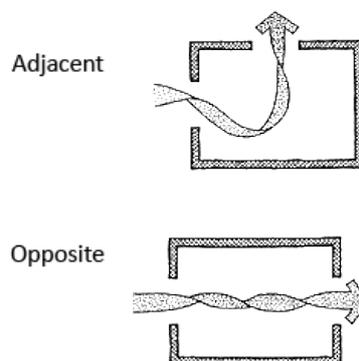
Figure A. 7: Methods of implementing and promoting natural cross
ventilation to cool down an overheated zone. Image from Brown and
Dekay (2001)

Promote "Stack ventilation"

When air warms it expands, becomes less dense than the surrounding air, and rises. This process is called convection and is the main process by which heat moves around a room and the house. Provide vertical distance between air inlet and outlet to produce stack ventilation (open stairwells, two story spaces, roof monitors) when wind speeds are low (Climate Consultant 4.0 - Milne et al., 2009). Implementing stack ventilation in this zone can benefit air flow and reduce zone temperature in summer. In this zone the effective area of the stack opening (located 1.5 meters above the windward opening) is [*value*] meters square.

[*value*] The calculated effective area of opening that can support efficient stack ventilation. The calculation equations are presented in appendix F.
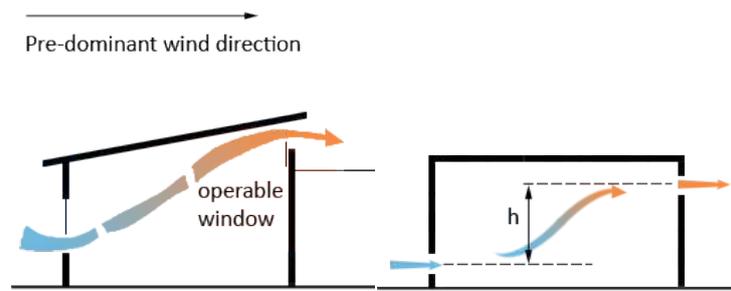
Figure A. 8: The means, effect, and benefits of implementing stack ventilation to cool down an overheated zone.

Use "Ceiling Fans" for cooling

Though Ceiling fans have the potential to add to the overall zone heat gains through its engine, Ceiling Fans have the ability to create a wind-chill effect, which affects the zone's occupants by accelerating the evaporation of moisture on their skin. On hot days ceiling fans or indoor air motion can make it seem cooler by at least 5 degrees F (2.8C). This can be coupled with Evaporative cooling to bring the indoors temperature down. Ceiling Fans can also be used to pull the lighter warmer air out of a zone, after being heated by different means.
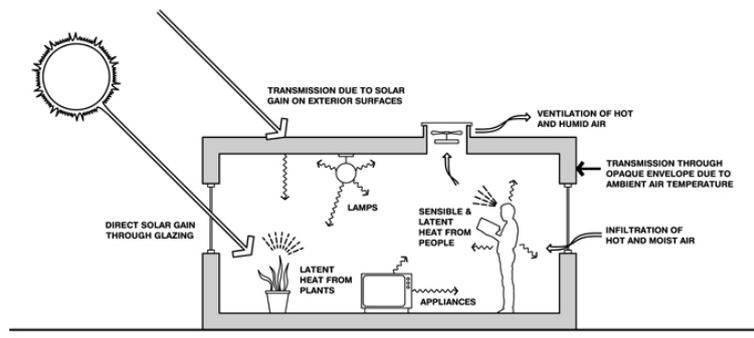
Figure A. 9: Using fans to get rid of indoors heated air. Image obtained
from Climate Consultant 4.0

Increase the "Zone Height"

Increasing the zone height is effective in reducing the heat-gain effect in the zone. This is accomplished through facilitating more efficient stack effect. The increase in zone height is also effective in case of depending on ceiling fans, which affects the zone's occupants by accelerating the evaporation of moisture on their skin. On hot days ceiling fans or indoor air motion can make it seem cooler by at least 5 degrees F (2.8C). (Climate Consultant 4.0 - Milne et al., 2009).
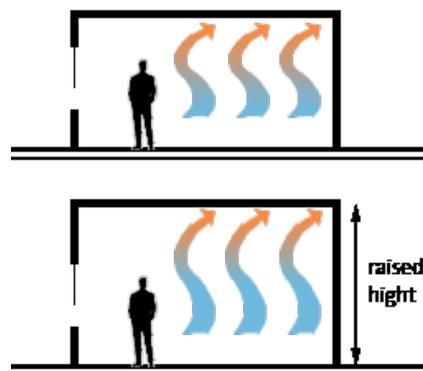
Figure A. 10: The effect of increasing the zone's height in reducing the
temperature at the lower levels.

Ensure Effective Insulation

A radiant barrier (shiny foil) will help reduce radiated heat gain through the roof in hot climates. Extra insulation (super insulation) might prove cost effective, and will increase occupant comfort by keeping indoor temperatures more uniform. It is also worth investing in proper insulation in walls,

this will prevent heat gain in overheated zones in summer, and will preserve heat indoors in cold weather (Climate Consultant 4.0 - Milne et al., 2009).

Use "Skylights" when possible

Skylights can be effective solution in many zones. It can be used in this zone as a cold air inlet (examples 1 and 2) as this zone has no openings on the [*value*], where the predominant wind is, thus help implementing stack ventilation. A skylight can be a good source of winter sun to increase the zone heat gains and raise the indoors temperature towards comfort range.

[*value*] The predominant wind direction throughout the year, derived from the weather file data exported from Ecotect.
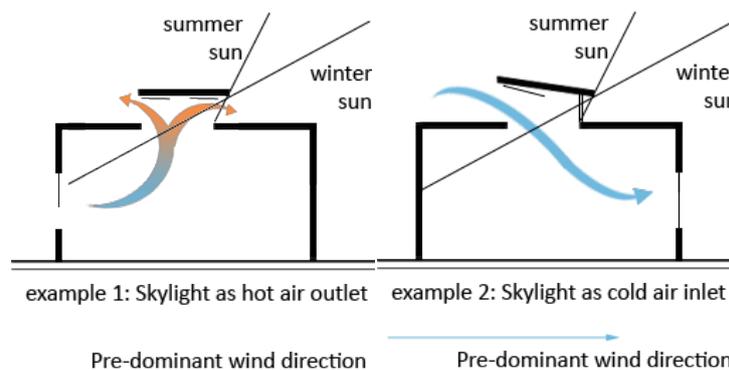
Figure A. 11: Using skylights to promote stack ventilation in hot conditions, and as a source of direct solar gains in cooler conditions.

Use Vegetation/planting near high direct solar gain zones.

Trees can be considered a natural and effective shading devices. The advantage of using such strategy is that trees are "in phase with the thermal year" – gain and lose leaves in response to temperature changes. The solar transmission can be as low as 20% in summer, and as high as 70% in winter (Lechner, 2009). Use plant materials (ivy, bushes, trees) especially on the west to shade the structure (Climate Consultant 4.0 - Milne et al., 2009). Trees can also help promote natural ventilation and distort reflected radiation (Indirect solar gain).
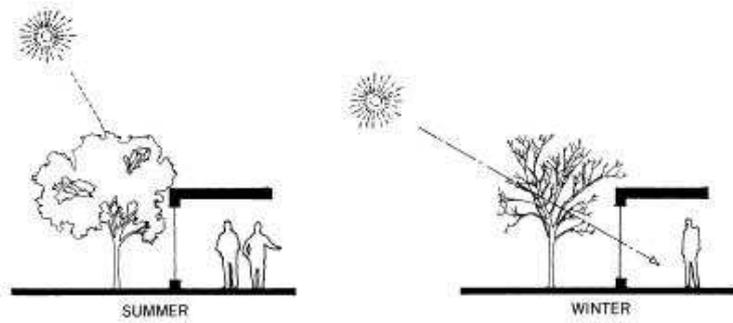
Figure A. 12: Example of using trees to block the direct solar access in the summer and allow it in winter. Image from Lechner (2009).

Use proper effective "Windows Glazing".

High performance glazing on all orientations should prove cost effective (Low-E, insulated frames) in hot clear summers or dark overcast winters (Climate Consultant 4.0 - Milne et al., 2009). Clear Glass reflects only 10% of the solar radiation and the most is transmitted to the zone, while Reflective glass on the other hand can reflect up to 50% of the solar radiation. As this zone contains a total glazing area of [*value*] square meters, effective glazing has the potential to reduce the overall loads required to accommodate this area.

[*value*] The total area of windows in the currently experienced zone.
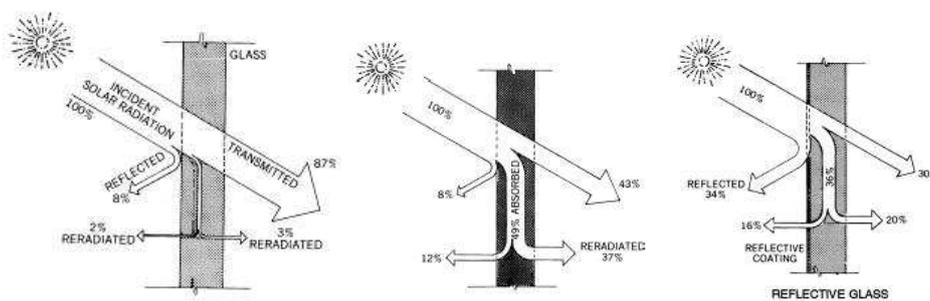
Figure A. 13: The effect of the type of glazing on the percentage of transmitted, reflected, and radiated heat. Image from Lechner, 2009.

Promote "Shading" southern walls using "Louvered Overhang"
Using Louvered Overhangs near windows in overheated zones rather than Solid Overhang is more effective in preventing hot air being trapped next to the building and windows, thus causing latent overheat. This can be an effective method for resolving indirect gains.
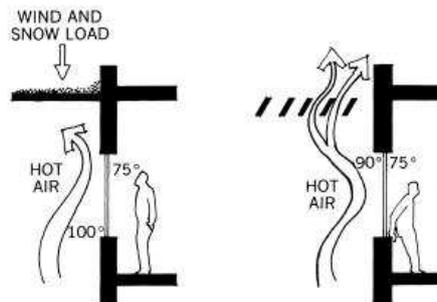
Figure A. 14: Using horizontal Louvered Overhangs to vent out the trapped hot air near the windows. Image from Lechner, 2009.

Use multiple horizontal louvers in southern facades

In some cases, using one fixed overhang for a window could be very deep and unpractical. In this zone, the window(s) require overhang of depth [*value*] meters. You might wish to consider using multiple horizontal louvers to minimise the depth, but this could affect the view. Alternatively you could use horizontal windows in southern facades, which will reduce the window's height and the needed overhang.

[*value*] Recommended value of the window's overhang depth, based on the calculation of the zone's periods of overheat, and the relevant sun position during this period.
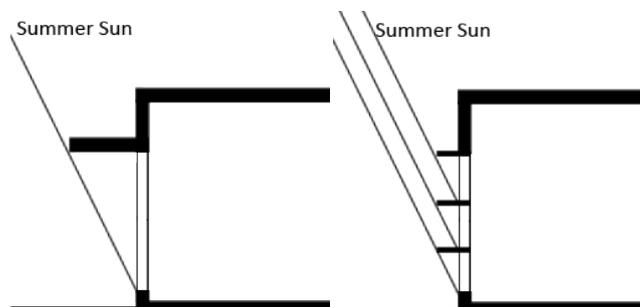
Figure A. 15: Reducing the depth of the required window's overhang via using multiple horizontal louvers.

Implement Exterior Wing-walls to promote natural ventilation.	P a g e
Wing-walls can be considered in the building design to make best use of natural ventilation through the reflection of wind from its prevailing direction into the interior of the building. This is particularly useful in overheated zones where natural cross ventilation is not possible. It can also be useful in colder conditions, as it can act as a surface for reflected solar radiations for the building zones. It can be coupled with using trees to prevent the unwanted radiation in hot periods.	

Use relatively small horizontal windows in southern facades.	
I can see this zone has south-facing windows. Use horizontally rather than vertically directed windows in this zone to minimise the direct solar gain and also minimise the required window's overhang. The recommended total area of south-facing windows should not exceed 7% of the zone's floor area to avoid overheating (Lechner, 2009). In this particular zone, the recommended total windows area is [*value*] square meters. [*value*] The calculated recommended windows area based on the zone's total floor area.	

Appendix [E] – UML Class Diagram
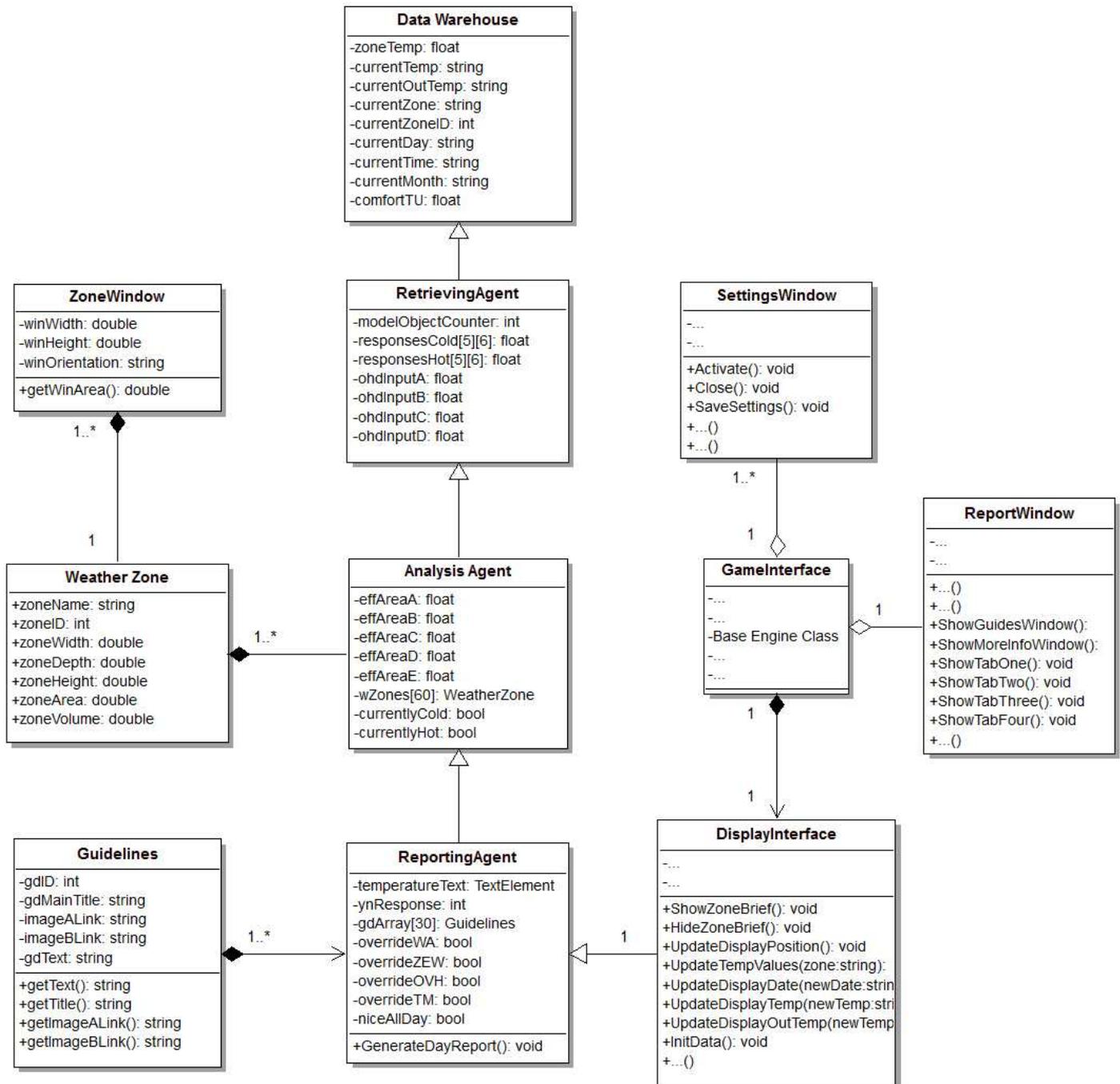
Figure A. 16: A UML Class Diagram, representing the structure of the developed classes and their connection to the core/base game engine's source code. For presentational purposes, there are only some data members, and member functions illustrated within the featured classes. The detailed classes definitions is presented in Appendix H.

Appendix [F] – Calculations Equations

Temperature Comfort Range

This process aims to identify the upper and lower bounds for the comfort range of temperatures for a specified zone. This calculation follows these steps (as explained in Szokolay, 2008, and Gagge et al., 1986):

1. Establish the mean temperature (T_{av}) of the warmest and coldest months. This is done through traversing the obtained temperature data for the whole year, aiming to detect the average temperature of every month, and hence determine the warmest and coldest months of the year.

2. Calculate the 'Neutrality Temperature' (T_n), using this equation:

$$T_n = 17.6 + 0.31\, T_{av} \ \ °\mathrm{C}$$

3. Calculate the upper and lower limits of comfort $(T_U$ and T_L), using these equations:

$$T_L \ = \ T_n - \ 2.5 \ °\mathrm{C}$$

$$T_U \ = \ T_n + \ 2.5 \ °\mathrm{C}$$

4. Obtain the Relative Humidity (RH) instance for the current zone, date, and time. This is derived directly from the data warehouse, as the annual hourly RH values can be exported from Ecotect (see Appendix G for more details).

5. Calculate the Saturation Vapour Pressure $(P_{vs}$) for both temperatures T_U and T_L , as explained in these equations:

$$P_{vsu} \ = \ 0.133322 \ \times \exp\left[18.6686 - (4030.183/(T_U + \ 235))\right]$$

$$P_{vsl} \ = \ 0.133322 \ \times \exp\left[18.6686 - (4030.183/(T_L + \ 235))\right]$$

6. Calculate the Saturation Humidity for both temperatures T_U and T_L, as explained in these equations:

$$SH_u = 622 \times P_{vsu}/(101.325 - P_{vsu})$$

$$SH_l = 622 \times P_{vsu}/(101.325 - P_{vsl})$$

7. Calculate the Absolute Humidity, which is a function of both; Relative and Saturation Humidity:

$$AH_u = RH \times SH_u$$

$$AH_l = RH \times SH_l$$

8. Determine the upper and lower Standard Effective Temperatures (SET) for the current zone and time (T_{US} and T_{LS}), which lies on the two sloping sides of the Psychrometric chart. This is a function of the Absolute Humidity, as explained in the equations below:

$$T_{LS} = T_L + 0.023 \, (T_L - 14)AH \quad °\text{C}$$

$$T_{US} = T_U + 0.023 \, (T_U - 14)AH \quad °\text{C}$$

Effective Area of Openings

Calculating the required and recommended effective area of openings in a particular zone is an important environmental design aspect. This is an assessment routine for designers who rely on natural ventilation strategies to cool down the interior of the building in periods of overheat. The recommended opening area is that required to accommodate an effective air flow rate to reduce the indoors temperature. This is applicable on zones with single-sided, cross, and stack ventilation. The calculations are used in the general zone's guidelines, as well as in the interrogation routines to examine the effectiveness of the strategy, and hence recommend increasing the effective area of opening in the currently examined zone, or

move on to discuss another strategy. Equations used for these calculations are obtained from CIBSE-Guide A (2007), and from Szokolay (2008).

Cross Ventilation

These equations aim to calculate the effective area of opening for a particular zone that has natural cross ventilation. The calculation is explained in the following procedure:

1. The first step is to calculate the total volume flow rate (q_{total}) which is a function of the air change rate (n) measured in ach^{-1}, as well as the volume (V) of the currently experienced zone, measured in m^3.

$$q_{total} = \frac{n \times V}{3600} \; m^3/s$$

The air change rate can be estimated/obtained from this table:

room / building / accommodation	air changes rate (ach^{-1})
assembly / entrance halls	$3 - 6$
bathrooms (public)	6
canteens	$8 - 12$
cinema / theatre	$6 - 10$
classrooms	$3 - 4$
restaurants	$10 - 15$
domestic habitable rooms	approx 1
hospital wards	$6 - 10$
lavatories (public)	$6 - 12$
libraries	$2 - 4$
lobbies / corridors	$3 - 4$
offices	$2 - 6$
smoking rooms	10 - 15

Table 0.1: Air-change rate values based on the zone's type and/or activity.

2. The next step is to calculate the wind pressure (p_w), which is a factor of wind velocity (v) and the density of air (d), as expressed in this equation:

$$p_w = 0.5 \times d \times v^2$$

Where v can be derived from the simulation and weather file data derived from Ecotect, and d can be assumed as 1.224 kg/m^3 at 15.5°C.

3. The next step is to work out the wind pressure difference that is acting on a particular opening (Δp_w), based on this equation:

$$\Delta p_w = p_w \times (C_{pw} - C_{pl})$$

Where C_{pw} is the pressure coefficient on the windward side of the zone (where the pressure is positive), and having a value between 0.5 and 0.8, and C_{pl} is the pressure coefficient on the leeward side (where the pressure is negative), and therefore having a value between -0.3 and -0.5.

4. The final step is to calculate the required effective area in the zone's window (A_w). This can be worked out from this equation:

$$A_w = \frac{q_{total}}{0.827 \times C_e \sqrt{\Delta p_w}} \; m^2$$

where q_{total} is the total volume flow rate calculated earlier, Δp_w is the wind pressure difference also calculated earlier, and C_e is the effectiveness coefficient that describes the impedance of the air mass contained within the zone's volume (normally with a value between 0 and 1). In this case (full cross ventilation), C_e can be assigned the value of 1. The resulting value A_w represents the required/recommended effective area of opening in the currently experienced cross-ventilated thermal zone.

5. CIBSE Guide A (2007) also explained that the effective area of opening in a cross-ventilated zone can be calculated from this formula:

$$\frac{1}{A_w{}^2} = \frac{1}{A_1{}^2} + \frac{1}{A_2{}^2}$$

where A_w is the effective area of opening, while A_w and A_w are the areas of the zone's openings in the windward and leeward sides respectively. The calculated area can be validate against the total volume flow rate (q_{total}) and subsequently the air change rate (n) to make sure that its value is sufficient and above the value presented in Table 0.1, according to the nature and type of the zone and building.

Single Sided Ventilation

These equations aim to calculate the effective area of opening for a particular zone that has single-sided ventilation. The calculation procedure is very similar to that of the cross ventilated zones. The process starts by calculating the total volume flow rate (q_{total}), the air change rate (n), and the wind pressure (p_w), using the same equation and table presented in the previous section. The wind pressure difference (Δp_w) is then calculated based on the pressure coefficient on the windward side of the zone (C_{pw}).

The value of Δp_w is then used to calculate the required effective area of opening, based on the previously calculated q_{total} and the effectiveness coefficient C_e, which is in this case assigned a value of 0.1 as the flow of air into the zone is only from one side.

$$A_w = \frac{q_{total}}{0.827 \times C_e \sqrt{\Delta p_w}} \ m^2$$

Stack Ventilation - Buoyancy Driven

This involves the calculation of the effective area of opening in a zone with stack ventilation, or where stack ventilation is recommended. This can be carried out to either suggest a system design aiming to attain a given air flow rate, or assess an existing design based on its current air flow rate. The calculations used are explained in the following steps:

1. Similar to the cross ventilation procedure, the first step is to calculate the total volume flow rate (q_{total}) which is based on the recommended air change rate (n), as presented in Table 0.1.

$$q_{total} = \frac{n \times V}{3600} \ \text{m}^3/\text{s}$$

2. Now that the total volume flow rate is known, it can be used to determine the overall required effective area of opening A_w, using this formula:

$$q_{total} = 0.61 \times A_w \times \sqrt{\frac{2(t_i - t_o) \times h \times g}{\frac{2(t_i + t_o)}{2} + 273}}$$

Where t_i is the internal temperature of the zone, t_o is the outdoors temperature, h represents the height of the stack, and g is the gravitational acceleration (given the value of 9.81). The indoors and outdoors temperatures can be derived from the exported simulation data, while the height of stack (the difference in height between the inlet and outlet) is recommended to be at least 1.5 meters.

3. Knowing the effective area of opening (A_w), the last step is to calculate the required area for the stack outlet window. This can be obtained from this equation:

$$\frac{1}{A_w{}^2} = \frac{1}{A_{in}{}^2} + \frac{1}{A_{stack}{}^2}$$

Where A_{in} is the area of the inlet window, and A_{stack} is the area of the outlet stack window.

4. The process can be reversed in case the stack is implemented, and the area of the inlet and outlet windows are known, in order to assess the air change rate (n) against the values presented in Table 0.1.

Interrogation routines

In the examination of the ventilation strategy implemented in a zone, the tool demands the effective area of opening of the existing window(s). The provided area A_w is used in this equation to calculate the total volume flow rate (q_{total}) for this zone:

$$q_{total} = 0.827 \times A_w \times C_e \times \sqrt{\Delta p_w} \quad \text{m}^3/\text{s}$$

The value of the total volume flow rate can be then used to calculate the current air change rate ($n_{current}$) for the existing zone:

$$n_{current} = \frac{q_{total} \times 3600}{V} \quad \text{ach}^{-1}$$

According to the nature and type of room/building, the value of the current air change rate is compared to the required/recommended rate (n_{req}), described earlier in Table 0.1. If $n_{current}$ is larger than or equal to n_{req}, then the current effective area is sufficient, and the tool moves on to the next strategy assessment, otherwise, the process should be reversed to calculate the recommended effective area of the zone's openings. This starts by using the value of n_{req} to calculate the required volume flow rate (q_{total}):

$$q_{total} = \frac{n_{req} \times V}{3600} \quad \text{m}^3/\text{s}$$

The value of the required q_{total} is then used to calculate the required area (A_{wreq}), in the same manner described earlier, according to the ventilation type in the current zone:

$$A_{wreq} = \frac{q_{total}}{0.827 \times C_e \sqrt{\Delta p_w}} \quad m^2$$

Appendix [G] – Ecotect's LUA Code

This appendix presents the LUA code used to automatically run the simulation process in Ecotect, and generate and export the required data in a specified format into the game engine's location for further filtering, formatting, storage, and processing.

```lua
-- ------------------------------------------------------------------
-- DETECTING AND EXPORTING GEOMETRIC DATA OF THE DESIGN MODEL
-- ------------------------------------------------------------------

-- Creating 7 Arrays to hold geometric model zones' data
-- This includes The objects inside the zone (walls, windows, etc.)
-- and their properties (type of object, orientation, etc.)


objectsArrayNUM ={}
objectsArrayZONE ={}
objectsArrayTYPE ={}
objectsArrayORIENT ={}
objectsArrayXDim ={}
objectsArrayYDim ={}
objectsArrayZDim ={}

-- Creating and opening a CSV file to store the data
ObjectsDetailsFilename = "C:\\C4_ED_Game\\EcoData\\ZDims.csv"
ODFile = openfile (ObjectsDetailsFilename, "w")

-- Detecting the total number of objects inside the design model
totalObjectsNum = get("model.objects")

-- Creating a loop to traverse different model objects
-- and retrieve their properties.
for i = 0,totalObjectsNum-1 do

        -- Populating Geometric details about the model zones --
        objectsArrayNUM[i] = i
        objectsArrayZONE[i] = get("object.zone", i)
        objectsArrayTYPE[i] = get("object.type", i)
        objectsArrayORIENT[i] = get("object.angle", i, 3)
        objectsArrayXDim[i], objectsArrayYDim[i], objectsArrayZDim[i] =
get("object.extents", i)

        -- Exporting Model data to the CSV file
        write(ODFile, format("%d,", objectsArrayNUM[i]))
        write(ODFile, format("%d,", objectsArrayZONE[i]))
        write(ODFile, format("%d,", objectsArrayTYPE[i]))
        write(ODFile, format("%d, ", objectsArrayORIENT[i]))
        write(ODFile, format("%d, ", objectsArrayXDim[i]))
        write(ODFile, format("%d, ", objectsArrayYDim[i]))
        write(ODFile, format("%d", objectsArrayZDim[i]))
        write(ODFile, "\n")

end

-- Exporting specified information on each zone, including
-- its surface area, volume, and total windows area.

-- Creating 3 arrays to hold the required data

zoneArrayNUM = {}
zoneArrayArea = {}
```

```lua
zoneArrayVolume = {}
zoneArrayTotWinArea = {}

-- Creating and opening a CSV file to store the data

zonesDataFilename = "C:\\C4_ED_Game\\EcoData\\ZData.csv"
ZDFile = openfile (zonesDataFilename, "w")

-- detecting the number of zones in the model
numZones = get("model.zones")

-- Creating a loop to traverse the zones' data
for i = 1,numZones-1 do

        -- Populating the zones' data into the relevant arrays

        zoneArrayNUM[i] = i
        zoneArrayArea[i] = get("zone.floorarea", i)
        zoneArrayVolume[i] = get("zone.volume", i)
        zoneArrayTotWinArea[i] = get("zone.windowarea", i)

        -- Exporting Model data to the CSV file

        write(ZDFile, format("%d,", zoneArrayNUM[i]))
        write(ZDFile, format("%d,", zoneArrayArea[i]))
        write(ZDFile, format("%d,", zoneArrayVolume[i]))
        write(ZDFile, format("%d, ", zoneArrayTotWinArea[i]))
        write(ZDFile, "\n")

end


-- ---------------------------------------------------------------------------
-- GENERATING & EXPORTING SIMULATION CALCULATION DATA (NON-GEOMETRIC DATA)
-- ---------------------------------------------------------------------------

-- This will automatically run the simulation calculations and export
-- the resulting data in tabular (.csv) format into the relevant data
-- Folder in the game engine for further processing, filtering, and storage.
-- ---------------------------------------------------------------
-- The first step is to export the hourly heat gains for every zone
-- along the whole year, including gains from conduction, solar, ventilation,
-- internal, inter-zonal, and total compiled gains.


-- Creating temporary variables and and array for traversing through yearly dates.

days={}
counterDay = 1
CounterMonth = 0

for i = 0,364 do

        set("model.date", counterDay, CounterMonth)
        day, month = get("model.date")

        days[i]= day

        -- checking and updating the monthly index
        if i>1 then
                if days[i] == days[i-1] then
                        CounterMonth = CounterMonth +1
                        counterDay = 1
                        days[i] = 1
                end
        end

        counterDay = counterDay +1
```

```
        -- exporting gains data to relevant files
        cmd("calc.thermal.gains", 1)
        filename = tostring(i)..".csv"
        cmd("graph.save.results", "C:\\C4_ED_Game\\EcoData\\Gains\\"..filename)
end


--
-- Generating simulation data for every zone
--


numZones = get("model.zones") -- detecting the overall number of zones

for i = 1,numZones-1 do
        set("zone.system", i, 0)

        -- Exporting annual hourly temperatures for each zone
        cmd("calc.thermal.adaptivity", i)
        tempFName = "temp_ZN0"..tostring(i)..".csv"
        cmd("graph.save.results", "C:\\C4_ED_Game\\EcoData\\"..tempFName)


        -- Exporting monthly degree days data for every thermal zone
        cmd("calc.thermal.degreedays", i)
        DDFName = "DDays_ZN0"..tostring(i)..".csv"
        cmd("graph.save.results", "C:\\C4_ED_Game\\EcoData\\"..DDFName)

end


cmd("calc.thermal.adaptivity", 0)
cmd("graph.save.results", "C:\\C4_ED_Game\\EcoData\\temp_OUTS")



-- Generating total monthly required loads for every thermal zone
for i = 1,numZones-1 do set("zone.system", i, 3) end
cmd("calc.thermal.loads")
cmd("graph.save.results", "C:\\C4_ED_Game\\EcoData\\MLoads_All.csv")

--
-- Generating and exporting information about Relative Humidity (RH)
-- for the specified weather file (in annual hourly format).
--


-- Creating and opening a CSV file to store the data

RHFilename = "C:\\C4_ED_Game\\EcoData\\Relative_Humidity.csv"
RHFile = openfile (RHFilename, "w")

for i = 1,365 do
        for j = 0,23 do

                -- Storing the RH value for every hour
                rhValue = get("weather.relhumidity", i, j)

                -- Exporting RH data to its relevant csv file
                write(RHFile, format("%d,", rhValue))
        end
        write(RHFile, "\n")
end


--
-- Generating and exporting information about the prevailing
```

```
-- wind directions (values between 0 and 16, where 0 is north)
--

-- Creating and opening a CSV file to store the data

windFilename = "C:\\C4_ED_Game\\EcoData\\wind_direction.csv"
WDFile = openfile (windFilename, "w")

for i = 1,365 do
      for j = 0,23 do

            -- Storing the wind direction value for every hour
            wdValue = get("weather.direction", i, j)

            if wdValue == 255 then wdValue = 0 end

            -- Exporting wind direction data to its relevant csv file
            write(WDFile, format("%d,", wdValue))
      end
      write(WDFile, "\n")
end


--
-- Generating and exporting information about
-- the wind speed (velocity).
--

-- Creating and opening a CSV file to store the data

windSFilename = "C:\\C4_ED_Game\\EcoData\\wind_speed.csv"
WSFile = openfile (windSFilename, "w")

for i = 1,365 do
      for j = 0,23 do

            -- Storing the wind speed value for every hour
            wsValue = get("weather.speed", i, j)

            -- convert speed from km/h to m/s
            wsValue = wsValue * 0.277777778

            -- Exporting wind direction data to its relevant csv file
            write(WSFile, format("%d,", wsValue))
      end
      write(WSFile, "\n")
end
```

Appendix [H] – Game Implementation Code

This appendix presents selected fragments of the C++ code developed within the C4 game engine's source code to implement the required features and functionalities, including the MAS taxonomy, and Data Mining techniques. The code was developed and debugged using Microsoft Visual C++ Express Edition.

Retrieving, Filtering, and Storing Simulation Data

```cpp
//*********************************************************************
//********************     THE RETRIEVING AGENT     *******************
//*********************************************************************

//*********************************************************************
//  READING,FILTERING, & STORING ZONES' ANNUAL HOURLY TEMPERATURE DATA
//*********************************************************************

void RetrievingAgent::ReadTempData(string myZone)
{
        // The data file is passed to this function as an argument
        myZone += ".csv";
        ifstream myfile (myZone.c_str()); //opening the file.
        string line;
        static string lineArray[730];
        int comIndex;
        string holder;
        int counter = 0;

        if (myfile.is_open()) //if the file is open
        {
                while (! myfile.eof() ) //while the end of file is NOT reached
                {
                        getline (myfile,line); //get one line from the file
                        lineArray[counter] = line;
                        counter ++;
                }
                myfile.close();                         //closing the file
        }
        else line = "file not opened"; //if the file is not open output
        //
        //
        int c = 0;
        //int counterY = 0;
        //

        // Separating the outdoors temperature from the internal zonal temperatures
        if(myZone.compare("EcoData\\temp_OUTS.csv") == 0){
                for(int i=0; i<730; i+=2){
                        for(int j=0; j<26; j++){
                                comIndex = lineArray[i].find(",");
                                        if((comIndex!=string::npos) && (comIndex!=-1)) {
                                                holder = lineArray[i].substr(0, comIndex);
                                                outsTemp[c][j] = holder;
                                                lineArray[i] =
lineArray[i].substr(comIndex+1, lineArray[i].length()-comIndex);
                                        }else outsTemp[c][j] = lineArray[i];
                        }
                        c++;
                }
```

```cpp
        }else{ // in case of indoors temperatures
            for(int i=1; i<731; i+=2){
                for(int j=0; j<26; j++){
                    comIndex = lineArray[i].find(",");
                        if((comIndex!=string::npos) && (comIndex!=-1)) {
                            holder = lineArray[i].substr(0, comIndex);
                            if(myZone.compare("EcoData\\temp_ZN01.csv")
== 0) zoneOneTemp[c][j] = holder;
                            if(myZone.compare("EcoData\\temp_ZN02.csv")
== 0) zoneTwoTemp[c][j] = holder;
                            if(myZone.compare("EcoData\\temp_ZN03.csv")
== 0) zoneThreeTemp[c][j] = holder;
                            if(myZone.compare("EcoData\\temp_ZN04.csv")
== 0) zoneFourTemp[c][j] = holder;
                            if(myZone.compare("EcoData\\temp_ZN05.csv")
== 0) zoneFiveTemp[c][j] = holder;
                            lineArray[i] =
lineArray[i].substr(comIndex+1, lineArray[i].length()-comIndex);
                        }else{
                            if(myZone.compare("EcoData\\temp_ZN01.csv")
== 0) zoneOneTemp[c][j] = lineArray[i];
                            if(myZone.compare("EcoData\\temp_ZN02.csv")
== 0) zoneTwoTemp[c][j] = lineArray[i];
                            if(myZone.compare("EcoData\\temp_ZN03.csv")
== 0) zoneThreeTemp[c][j] = lineArray[i];
                            if(myZone.compare("EcoData\\temp_ZN04.csv")
== 0) zoneFourTemp[c][j] = lineArray[i];
                            if(myZone.compare("EcoData\\temp_ZN05.csv")
== 0) zoneFiveTemp[c][j] = lineArray[i];
                        }
                }
                c++;
            }
        }
}

//**********************************************************************
//  READING & STORING THE GEOMETRIC ZONAL INFORMATION
//**********************************************************************

void RetrievingAgent::ReadZDimsData(void){

    string dataFile = "EcoData\\ZDims.csv";

    ifstream myfile(dataFile.c_str()); //opening the file.
    string line;
    static string lineArray[730];
    int comIndex;
    string holder;
    int counter = 0;

    if (myfile.is_open()) //if the file is open
    {
        while (! myfile.eof() ) //while the end of file is NOT reached
        {
            getline (myfile,line); //get one line from the file
            lineArray[counter] = line;
            counter ++;
        }
        myfile.close();                          //closing the file
    }
    else line = "file not opened"; //if the file is not open output

    // Storing every object in the model as a separate element in the
    // array, and assigning it with its attributes, including parent zone,
    // object type (wall, window, floor, etc.), orientation, and the
    // object's dimentions (x,y, and z). This data is used later to
```

```
        // define the thermal zones' areas, volumes, included windows area,
        // and zones and windows' orientation.


        for(int i=0; i<counter; i++){
                for(int j=0; j<7; j++){
                        comIndex = lineArray[i].find(",");
                        if((comIndex!=string::npos) && (comIndex!=-1)) {
                                holder = lineArray[i].substr(0, comIndex);
                                modelObjectsData[i][j] = holder;
                                lineArray[i] = lineArray[i].substr(comIndex+1,
lineArray[i].length()-comIndex);
                        }else{
                                modelObjectsData[i][j] = lineArray[i];
                        }
                }
        }
}

//********************************************************************
//  READING,FILTERING, & STORING ZONES' MONTHLY HEATING & COOLING LOADS
//********************************************************************

void RetrievingAgent::ReadMLoadsData(void){

        // Selecting the required target data file
        string myZone = "EcoData\\MLoads_All.csv";

        ifstream myfile(myZone.c_str()); //opening the file.
        string line;
        static string lineArray[730];
        int comIndex;
        string holder;
        int counter = 0;

        if (myfile.is_open()) //if the file is open
        {
                while (! myfile.eof() ) //while the end of file is NOT reached
                {
                        getline (myfile,line); //get one line from the file
                        lineArray[counter] = line;
                        counter ++;
                }
                myfile.close();                          //closing the file
        }
        else line = "file not opened"; //if the file is not open output

        // Selecting and sorting data after removing the automatically generated
        // data headers, and allocating data to the relevant storage arrays.

        for(int i=0; i<25; i++){
                for(int j=0; j<14; j++){
                        comIndex = lineArray[i].find(",");
                        if((comIndex!=string::npos) && (comIndex!=-1)) {
                                holder = lineArray[i].substr(0, comIndex);
                                if((i>=6) && (i<11)){
                                        mLoadsHeating[i-6][j] = holder;
                                }
                                if((i>=14) && (i<=18)){
                                        mLoadsCooling[i-14][j] = holder;
                                }
                                lineArray[i] = lineArray[i].substr(comIndex+1,
lineArray[i].length()-comIndex);

                        }else{
                                if((i>=6) && (i<11)){
                                        mLoadsHeating[i-6][j] = lineArray[i];
```

```
                                }
                                if((i>=14) && (i<=18)){
                                        mLoadsCooling[i-14][j] = lineArray[i];
                                }
                        }
                }
        }
}

//*********************************************************
//   READING,FILTERING, & STORING ANNUAL HOURLY GAINS DATA
//*********************************************************

void RetrievingAgent::ReadGainsData(int fileID){

        // Setting the required file based on the argument passed
        string fNameHolder = TheDisplayInterface->ConvertFTS(fileID)+".csv";
        string dataFile = "C:\\C4_ED_Game\\EcoData\\Gains\\"+fNameHolder;

        ifstream myfile(dataFile.c_str()); //opening the file.
        string line;
        static string lineArray[730];
        int comIndex;
        string holder;
        int counter = 0;
        int lineCounter = 0;
        int filter = 8;

        if (myfile.is_open()) //if the file is open
        {
                while (! myfile.eof() ) //while the end of file is NOT reached
                {
                        getline (myfile,line); //get one line from the file
                        if(lineCounter > filter){
                                lineArray[counter] = line;
                                counter ++;
                        }
                        lineCounter++;
                }
                myfile.close();                         //closing the file
        }
        else line = "file not opened"; //if the file is not open output

        for(int d=0; d<43; d++){
                for(int i=0; i<25; i++){
                        comIndex = lineArray[d].find(",");
                                if((comIndex!=string::npos) && (comIndex!=-1)) {
                                        holder = lineArray[d].substr(0, comIndex);
                                }

                                // Allocating data to the appropriate location
                                // according to the exported file format ...

                                if(d==0) gainsConductionZoneA[fileID][i] = holder;
                                if(d==1) gainsSAirZoneA[fileID][i] = holder;
                                if(d==2) gainSolarZoneA[fileID][i] = holder;
                                if(d==3) gainVentilationZoneA[fileID][i] = holder;
                                if(d==4) gainInternalZoneA[fileID][i] = holder;
                                if(d==5) gainIntZonalZoneA[fileID][i] = holder;
                                if(d==6) gainTotalZoneA[fileID][i] = holder;

                                if(d==9) gainsConductionZoneB[fileID][i] = holder;
                                if(d==10) gainsSAirZoneB[fileID][i] = holder;
                                if(d==11) gainSolarZoneB[fileID][i] = holder;
                                if(d==12) gainVentilationZoneB[fileID][i] = holder;
                                if(d==13) gainInternalZoneB[fileID][i] = holder;
                                if(d==14) gainIntZonalZoneB[fileID][i] = holder;
```

```
                                    if(d==15) gainTotalZoneB[fileID][i] = holder;

                                    if(d==18) gainsConductionZoneC[fileID][i] = holder;
                                    if(d==19) gainsSAirZoneC[fileID][i] = holder;
                                    if(d==20) gainSolarZoneC[fileID][i] = holder;
                                    if(d==21) gainVentilationZoneC[fileID][i] = holder;
                                    if(d==22) gainInternalZoneC[fileID][i] = holder;
                                    if(d==23) gainIntZonalZoneC[fileID][i] = holder;
                                    if(d==24) gainTotalZoneC[fileID][i] = holder;

                                    if(d==27) gainsConductionZoneD[fileID][i] = holder;
                                    if(d==28) gainsSAirZoneD[fileID][i] = holder;
                                    if(d==29) gainSolarZoneA[fileID][i] = holder;
                                    if(d==30) gainVentilationZoneD[fileID][i] = holder;
                                    if(d==31) gainInternalZoneD[fileID][i] = holder;
                                    if(d==32) gainIntZonalZoneD[fileID][i] = holder;
                                    if(d==33) gainTotalZoneD[fileID][i] = holder;

                                    if(d==36) gainsConductionZoneE[fileID][i] = holder;
                                    if(d==37) gainsSAirZoneE[fileID][i] = holder;
                                    if(d==38) gainSolarZoneE[fileID][i] = holder;
                                    if(d==39) gainVentilationZoneE[fileID][i] = holder;
                                    if(d==40) gainInternalZoneE[fileID][i] = holder;
                                    if(d==41) gainIntZonalZoneE[fileID][i] = holder;
                                    if(d==42) gainTotalZoneE[fileID][i] = holder;

                                    lineArray[d] = lineArray[d].substr(comIndex+1,
lineArray[d].length()-comIndex);
                }
            }
}

//*********************************************************************
//  READING & STORING ANNUAL HOURLY RELATIVE HUMIDITY AND WIND DIRECTION
//  DATA, AND MONTHLY DEGREE DAYS DATA FOR EACH THERMAL ZONE
//*********************************************************************

void RetrievingAgent::ReadData(string type, int zoneNum)
{
        // Checking which type of data is required, and subsequently
        // assigning the relevant data file, filter, and storage array

        string dataFile = "EcoData\\";
        string fsHolder = TheDisplayInterface->ConvertFTS(zoneNum)+".csv";

        if(type.compare("RH") == 0){
                dataFile += "Relative_Humidity.csv";
        }else if(type.compare("wind") == 0){
                dataFile += "wind_direction.csv";
        }else if(type.compare("DDays") == 0){
                dataFile += "DDays_ZN0"+fsHolder;
        }

        ifstream myfile(dataFile.c_str()); //opening the file.
        string line;
        static string lineArray[730];
        int comIndex;
        string holder;
        int counter = 0;

        if (myfile.is_open()) //if the file is open
        {
                while (! myfile.eof() ) //while the end of file is NOT reached
                {
                        getline (myfile,line); //get one line from the file
                        lineArray[counter] = line;
                        counter ++;
```

```
            }
            myfile.close();                         //closing the file
        }
        else line = "file not opened"; //if the file is not open output
        //

        int k, l;

        if(counter > 22){                   // Relative Humidity OR wind direction data
            for(k=0; k<365; k++){
                for(l=0; l<25; l++){
                    comIndex = lineArray[k].find(",");
                    if((comIndex!=string::npos) && (comIndex!=-1)) {
                        holder = lineArray[k].substr(0, comIndex);
                        if(type.compare("RH") == 0){
                            relHumidity[k][l] = holder;
                        }else if(type.compare("wind") == 0){
                            windDirection[k][l] = holder;
                        }
                        lineArray[k] = lineArray[k].substr(comIndex+1,
lineArray[k].length()-comIndex);
                    }else{
                        if(type.compare("RH") == 0){
                            relHumidity[k][l] = lineArray[k];
                        }else if(type.compare("wind") == 0){
                            windDirection[k][l] = lineArray[k];
                        }
                    }
                }
            }
        }else{                              // Degree Days Data
            for(k=8; k<counter; k++){
                for(l=0; l<5; l++){
                    comIndex = lineArray[k].find(",");
                    if((comIndex!=string::npos) && (comIndex!=-1)) {
                        holder = lineArray[k].substr(0, comIndex);

                        // Allocating data into its relevant array
                        // according to the zone data being retrieved

                        if(zoneNum == 1) DDayaZoneA[k-8][l]= holder;
                        if(zoneNum == 2) DDayaZoneB[k-8][l]= holder;
                        if(zoneNum == 3) DDayaZoneC[k-8][l]= holder;
                        if(zoneNum == 4) DDayaZoneD[k-8][l]= holder;
                        if(zoneNum == 5) DDayaZoneE[k-8][l]= holder;

                        lineArray[k] = lineArray[k].substr(comIndex+1,
lineArray[k].length()-comIndex);
                    }else{
                        if(zoneNum == 1) DDayaZoneA[k-8][l]= lineArray[k];
                        if(zoneNum == 2) DDayaZoneB[k-8][l]= lineArray[k];
                        if(zoneNum == 3) DDayaZoneC[k-8][l]= lineArray[k];
                        if(zoneNum == 4) DDayaZoneD[k-8][l]= lineArray[k];
                        if(zoneNum == 5) DDayaZoneE[k-8][l]= lineArray[k];
                    }
                }
            }
        }
}
```

Building the Game's Informational Model

```cpp
void DisplayInterface::InitData(void)
{
        // Setting the current default values when the game
        // initially starts. The player marker is positioned
        // outside the building, so the default zone is set to
        // outdoors "OUTS". The default current day and time of
        // the game is also set to the first of January at 10 am.

        currentZone = "OUTS";
        currentDay = "0101";
        currentTime = "10:00";

        string dIndex = GetDayIndex(currentDay);
        string tIndex = GetTimeIndex(currentTime);

        SetCurrentTemp(outsTemp[atoi(dIndex.c_str())][atoi(tIndex.c_str())+2]);

        UpdateDisplayDate("01 Jan, 10:00");

        currentMonth = "jan";
        UpdateDisplayTemp(GetCurrentTemp());

        // Set the sun position to its default values
        // according to the data from the sun-path diagram
        // Default Sun Position    --- set for 01/01 @ 10:00am

        float pointX=0, pointY=0, pointZ=0;
        double azmR = 180-148.8;
        double alttt = 23.9;
        //
        pointY =  -1* 500 * cos(azmR*PI/180);
        pointX =   500 * sin(azmR*PI/180);
        pointZ = 500 * tan(alttt*PI/180);

        // Updating the game object representing the sun, and the
        // Omni light of the game to be respositioned according to
        // the calculated x,y, and z position coordinates.

        Node *node= TheWorldMgr->GetWorld()->GetRootNode();
        Zone *root = static_cast<Zone *>(node);

        Point3D position = node->GetNodePosition();
        do
        {
                const char *nodeName=node->GetNodeName();
                if ((nodeName) && Text::CompareText(nodeName,"XXYY")){
                        node->SetNodePosition(Point3D(pointX, pointY, pointZ));
                        node->Invalidate();
                }
                if ((nodeName) && Text::CompareText(nodeName,"SUNN")){
                        node->SetNodePosition(Point3D(pointX, pointY, pointZ));
                        node->Invalidate();
                }
                node = root->GetNextNode(node);
        }while(node);


        // Update the game to the default values defined
        UpdateTempValues("OUTS");
```

```cpp
        //*************************************************************************
        //********************  DEFINING WEATHER ZONES  ***************************
        //*************************************************************************

        // This is a critical process that is required to be carried out once
        // the game is loaded. It basically builds an informational database
        // about the model and its multiple weather zones. This information is
        // mostly geometric, to assign attributes to the zones, based on the data
        // retrieved from the data warehouse. The tool assigns a zone name, and an
        // id, and also assigns information for the zone's area, volume, height,
        // depth, orientation, and the zone's windows (their number, dimensions, and
        // orientation). This will be the basis of assessment for developing the
        // interrogation routines and the zone-specific guidelines.


        for(int i=1; i < 6; i++){
                wZones[i].zoneID = i;
                if(i == 1) wZones[i].zoneName = "ZN01";
                if(i == 2) wZones[i].zoneName = "ZN02";
                if(i == 3) wZones[i].zoneName = "ZN03";
                if(i == 4) wZones[i].zoneName = "ZN04";
                if(i == 5) wZones[i].zoneName = "ZN05";

                wZones[i].zoneArea = atoi(modelZonesData[i-1][1].c_str());
                wZones[i].zoneVolume = atoi(modelZonesData[i-1][2].c_str());
                wZones[i].zoneHeight = wZones[i].zoneVolume / wZones[i].zoneArea;
                wZones[i].winCounter = 0;
                wZones[i].winNumber = GetZoneWinNum(i);
                wZones[i].isEast = CheckOrientation(i, "east");
                wZones[i].isNorth = CheckOrientation(i, "north");
                wZones[i].isSouth = CheckOrientation(i, "south");
                wZones[i].isWest = CheckOrientation(i, "west");

                for(int j=1; j <= wZones[i].winNumber; j++){
                        wZones[i].AddZoneWindow(getWinWidth(i, j), getWinHeight(i,j),
getWinOrientation(i,j));
                }
        }
        //...
}

// ************************************************************
// The supporting functions used to build the informational model
// ************************************************************


//********** Getting a window's ORIENTATION *********************

int RetrievingAgent::GetZoneWinNum(int zid){

        int zoneWinCounter = 0;
        for(int i=0; i<modelObjectCounter; i++){
                if(atoi(modelObjectsData[i][1].c_str()) == zid){
                        if(atoi(modelObjectsData[i][2].c_str()) == 6){
                                zoneWinCounter++;
                        }
                }
        }
        return zoneWinCounter;
}

//********** Getting a window's WIDTH **************************

float RetrievingAgent::getWinWidth(int zid, int wid){

        float wWidth;
        int occurance = 0;
```

```
        for(int i=0; i<modelObjectCounter; i++){
                if(atoi(modelObjectsData[i][1].c_str()) == zid){
                        if(atoi(modelObjectsData[i][2].c_str()) == 6){
                                occurance++;
                                // The first occurance to meet the required conditions.
                                if(occurance == wid){

                                        // detect if the window's width is assigned as the
                                        // x or y values when exported from Ecotect. This
                                        // depends on the window's orientation.

                                        if(atoi(modelObjectsData[i][4].c_str()) != 0){
                                                // retrieve the window's width data
                                                wWidth =
atoi(modelObjectsData[i][4].c_str());
                                        }else{
                                                wWidth =
atoi(modelObjectsData[i][5].c_str());
                                        }
                                }
                        }
                }
        }
        // as the values exported from ecotect are in millimeters, it is
        // thus divided by 1000 to convert the values to meters.
        return wWidth/1000;
}

//********** Getting a window's HEIGHT ***************************

float RetrievingAgent::getWinHeight(int zid, int wid){

        float wHeight;
        int occurance = 0;

        for(int i=0; i<modelObjectCounter; i++){
                if(atoi(modelObjectsData[i][1].c_str()) == zid){
                        if(atoi(modelObjectsData[i][2].c_str()) == 6){
                                // The first occurance to meet the required conditions.
                                occurance++;
                                if(occurance == wid){
                                        // retrieve the window's height data
                                        wHeight = atoi(modelObjectsData[i][6].c_str());
                                }
                        }
                }
        }
        // as the values exported from ecotect are in millimeters, it is
        // thus divided by 1000 to convert the values to meters.
        return wHeight/1000;
}

string RetrievingAgent::getWinOrientation(int zid, int wid){

        string wOrient;
        int occurance = 0;

        for(int i=0; i<modelObjectCounter; i++){
                if(atoi(modelObjectsData[i][1].c_str()) == zid){
                        if(atoi(modelObjectsData[i][2].c_str()) == 6){
                                occurance++;
                                // The first occurance to meet the required conditions.
                                if(occurance == wid){
                                        wOrient = modelObjectsData[i][3];
                                }
                        }
```

```
            }
        }

        // Assign a meaningful string to the retrieved value

        if(wOrient.compare("0") == 0) wOrient = "north";
        if(wOrient.compare("90") == 0) wOrient = "east";
        if(wOrient.compare("180") == 0) wOrient = "south";
        if(wOrient.compare("270") == 0) wOrient = "west";

        return wOrient;
}
```

Analysis Operations

```cpp
//**********************************************************
// CALCULATING THE CURRENT COMFORT RANGE OF TEMPERATURES
//**********************************************************

void AnalysisAgent::CalcComfortRange(){
        int day = atoi(GetDayIndex(currentDay).c_str());
        int time = atoi(GetTimeIndex(currentTime).c_str());
        int month = GetMonthIndex(currentMonth);

        float TAV, TL, TU;
        float Pvs_L, SH_L, AH_L, Pvs_H, SH_H, AH_H, RH;

        TAV = ((2*averageTemps[month])+15)/3;

        TU = 17.6+(0.31*TAV)+2.5;
        TL = 17.6+(0.31*TAV)-2.5;

        RH = atof(relHumidity[day][time].c_str())/100;

        Pvs_L = 0.133322*exp(18.6686-(4030.183/(TL+235)));
        SH_L = 622*Pvs_L/(101.325-Pvs_L);
        AH_L = RH*SH_L;

        Pvs_H = 0.133322*exp(18.6686-(4030.183/(TU+235)));
        SH_H = 622*Pvs_H/(101.325-Pvs_H);
        AH_H = RH*SH_H;

        TL = TL+(0.023*(TL-14)*AH_L);
        TU = TU+(0.023*(TU-14)*AH_H);

        PopulateHiComfort();
        PopulateLoComfort();

        comfortTU = tmpHi[day][time];
        comfortTL = tmpLo[day][time];
}

//**********************************************************
// POPULATING THE ANNUAL HOURLY CALCULATED UPPER BOUND
// TEMPERATURES OF THE COMFORT RANGE
//**********************************************************

float AnalysisAgent::CalcHiComfort(int day, int time, int month){

        float TAV, TL, TU;
        float Pvs_L, SH_L, AH_L, Pvs_H, SH_H, AH_H, RH;

        TAV = ((2*averageTemps[month])+15)/3;

        TU = 17.6+(0.31*TAV)+2.5;
        RH = atof(relHumidity[day][time].c_str())/100;

        Pvs_H = 0.133322*exp(18.6686-(4030.183/(TU+235)));
        SH_H = 622*Pvs_H/(101.325-Pvs_H);
        AH_H = RH*SH_H;

        TU = TU+(0.023*(TU-14)*AH_H)*0.9;

        return TU;
}

//**********************************************************
// POPULATING THE ANNUAL HOURLY CALCULATED LOWER BOUND
// TEMPERATURES OF THE COMFORT RANGE
```

```cpp
//***********************************************************
float AnalysisAgent::CalcLoComfort(int day, int time, int month){

        float TAV, TL, TU;
        float Pvs_L, SH_L, AH_L, Pvs_H, SH_H, AH_H, RH;

        TAV = ((2*averageTemps[month])+15)/3;

        TL = 17.6+(0.31*TAV)-2.5;

        RH = atof(relHumidity[day][time].c_str())/100;

        Pvs_L = 0.133322*exp(18.6686-(4030.183/(TL+235)));
        SH_L = 622*Pvs_L/(101.325-Pvs_L);
        AH_L = RH*SH_L;

        TL = TL+(0.023*(TL-14)*AH_L)*0.9;

        return TL;
}

// Populating the array for the annual high bounds of comfort ranges
void AnalysisAgent::PopulateHiComfort(void){
        for(int i = 0; i<364; i++){
                for(int j=0; j<24; j++){
                        if((i>=0)&&(i<=30))   {tmpHi[i][j] = CalcHiComfort(i, j, 0);}
                        else if((i>=31)&&(i<=58))  {tmpHi[i][j] = CalcHiComfort(i, j,
1);}
                        else if((i>=59)&&(i<=89))  {tmpHi[i][j] = CalcHiComfort(i, j,
2);}
                        else if((i>=90)&&(i<=119)) {tmpHi[i][j] = CalcHiComfort(i, j,
3); }
                        else if((i>=120)&&(i<=150)){tmpHi[i][j] = CalcHiComfort(i, j,
4);}
                        else if((i>=151)&&(i<=180)){tmpHi[i][j] = CalcHiComfort(i, j,
5);}
                        else if((i>=181)&&(i<=211)){tmpHi[i][j] = CalcHiComfort(i, j,
6);}
                        else if((i>=212)&&(i<=242)){tmpHi[i][j] = CalcHiComfort(i, j,
7);}
                        else if((i>=243)&&(i<=272)){tmpHi[i][j]= CalcHiComfort(i, j,
8);}
                        else if((i>=273)&&(i<=303)){tmpHi[i][j] = CalcHiComfort(i, j,
9);}
                        else if((i>=304)&&(i<=333)){tmpHi[i][j] = CalcHiComfort(i, j,
10);}
                        else if((i>=334)&&(i<=364)){tmpHi[i][j] = CalcHiComfort(i, j,
11);}
                }
        }
}

// Populating the array for the annual high bounds of comfort ranges
void AnalysisAgent::PopulateLoComfort(void){
        for(int i = 0; i<364; i++){
                for(int j=0; j<24; j++){
                        if((i>=0)&&(i<=30))   {tmpLo[i][j] = CalcLoComfort(i, j, 0);}
                        else if((i>=31)&&(i<=58))  {tmpLo[i][j] = CalcLoComfort(i, j,
1);}
                        else if((i>=59)&&(i<=89))  {tmpLo[i][j] = CalcLoComfort(i, j,
2);}
                        else if((i>=90)&&(i<=119)) {tmpLo[i][j] = CalcLoComfort(i, j,
3); }
                        else if((i>=120)&&(i<=150)){tmpLo[i][j] = CalcLoComfort(i, j,
4);}
                        else if((i>=151)&&(i<=180)){tmpLo[i][j] = CalcLoComfort(i, j,
5);}
```

```cpp
                          else if((i>=181)&&(i<=211)){tmpLo[i][j] = CalcLoComfort(i, j,
6);}
                          else if((i>=212)&&(i<=242)){tmpLo[i][j] = CalcLoComfort(i, j,
7);}
                          else if((i>=243)&&(i<=272)){tmpLo[i][j]= CalcLoComfort(i, j,
8);}
                          else if((i>=273)&&(i<=303)){tmpLo[i][j] = CalcLoComfort(i, j,
9);}
                          else if((i>=304)&&(i<=333)){tmpLo[i][j] = CalcLoComfort(i, j,
10);}
                          else if((i>=334)&&(i<=364)){tmpLo[i][j] = CalcLoComfort(i, j,
11);}
              }
          }
}

// *************************************************************
// CLACLUATING THE OVERHEATED PERIODS OF A PARTICULAR ZONE
// *************************************************************
// This is used as part of the characterisation data mining
// routines for generating reports and guidelines.
// *************************************************************

string AnalysisAgent::CalcOverheatPeriod(string zone){
      int startDate, endDate;
      string period = "";
      string tmpHolder = "";
      bool firstActive = false, lastActive = false;
      for(int i = 0; i<364; i++){
              for(int j=0; j<23; j++){
                      if(zone.compare("ZN01") == 0) tmpHolder =
zoneOneTemp[i+1][j+1];
                      if(zone.compare("ZN02") == 0) tmpHolder =
zoneTwoTemp[i+1][j+1];
                      if(zone.compare("ZN03") == 0) tmpHolder =
zoneThreeTemp[i+1][j+1];
                      if(zone.compare("ZN04") == 0) tmpHolder =
zoneFourTemp[i+1][j+1];
                      if(zone.compare("ZN05") == 0) tmpHolder =
zoneFiveTemp[i+1][j+1];
                      if(zone.compare("OUTS") == 0) tmpHolder = outsTemp[i+1][j+1];

                      if(atof(tmpHolder.c_str()) > tmpHi[i][j]){

                              if(!firstActive){

                                      firstActive = true;
                                      startDate = i;
                              }else endDate = i;
                      }
              }
      }
      period = GetDayName(startDate)+ " to "+ GetDayName(endDate);
      return period;
}

int AnalysisAgent::CalcOverheatIndex(string zone){
      int startDate, endDate, ohDayIndex;
      string period = "";
      string tmpHolder = "";
      string ttt = "";
      bool firstActive = false, lastActive = false;
      for(int i = 0; i<364; i++){
              for(int j=0; j<23; j++){
                      if(zone.compare("ZN01") == 0) tmpHolder =
zoneOneTemp[i+1][j+1];
                      if(zone.compare("ZN02") == 0) tmpHolder =
```

```
zoneTwoTemp[i+1][j+1];
                if(zone.compare("ZN03") == 0) tmpHolder =
zoneThreeTemp[i+1][j+1];
                if(zone.compare("ZN04") == 0) tmpHolder =
zoneFourTemp[i+1][j+1];
                if(zone.compare("ZN05") == 0) tmpHolder =
zoneFiveTemp[i+1][j+1];
                if(zone.compare("OUTS") == 0) tmpHolder = outsTemp[i+1][j+1];

                if(atof(tmpHolder.c_str()) > tmpHi[i][j]){

                        if(!firstActive){

                                firstActive = true;
                                startDate = i;
                                ohDayIndex = startDate;
                        }else endDate = i;
                }
            }
        }
        period = GetDayName(startDate)+ " to "+ GetDayName(endDate);
        return ohDayIndex;
}

// ************************************************************
// CLACLUATING OPTIMUM WINDOW'S OVERHANG DEPTH
// ************************************************************

float AnalysisAgent::CalculateOverhangDepth(float winHeight){

        int sunFileIndex = CalcOverheatIndex(GetCurrentZone());
        string mySunFile = ConvertFTS(sunFileIndex);

        if(mySunFile.length() == 1) mySunFile = "sunData\\00"+mySunFile+".txt";
        if(mySunFile.length() == 2) mySunFile = "sunData\\0"+mySunFile+".txt";
        if(mySunFile.length() == 3) mySunFile = "sunData\\"+mySunFile+".txt";

        static string sunArray[50][10];

        ifstream sunfile(mySunFile.c_str()); //opening the file.

        string sline;
        static string slineArray[50];
        int comIndex;
        string holder;
        int sdCounter = 0;

        if (sunfile.is_open()) //if the file is open
        {
                while (! sunfile.eof() ) //while the end of file is NOT reached
                {
                        getline(sunfile,sline); //get one line from the file
                        slineArray[sdCounter] = sline;
                        sdCounter ++;
                }
                sunfile.close();                        //closing the file
        }
        else sline = "file not opened";


        for(int i=0; i<sdCounter; i++){
                for(int j=0; j<7; j++){
                        comIndex = slineArray[i].find(",");

                        if((comIndex!=string::npos) && (comIndex!=-1)) {
                                holder = slineArray[i].substr(0, comIndex);
                                sunArray[i][j] = holder;
```

```
                        slineArray[i] = slineArray[i].substr(comIndex+1,
slineArray[i].length()-comIndex);
                    }else sunArray[i][j] = slineArray[i];
            }

        }

        string altAngle, azmAngle;
        float alt, azm;
        string azHolder;
        bool night = true;

        for(int i=0; i<sdCounter; i++){
                for(int j=0; j<7; j++){
                        string tmp = sunArray[i][j].substr(0,5);
                        azHolder = sunArray[i][2].substr(0, sunArray[i][2].length()-1);
                        if(atof(azHolder.c_str()) > 140){
                                azmAngle = sunArray[i][2].substr(0,
sunArray[i][2].length()-1);
                                altAngle = sunArray[i][3].substr(0,
sunArray[i][3].length()-1);
                                break;
                        }
                }
        }

        alt = 90-atof(altAngle.c_str());
        azm = atof(azmAngle.c_str());
        //myDebuggerB.SetText(altAngle.c_str());
        float ohDepth;
        ohDepth = winHeight * tan(alt*PI/180);

        return ohDepth;
}

// *********************************************
// Determining the prevailing wind direction
// *********************************************
string AnalysisAgent::CalcPrevWindDirection(){
        //windDirection

        int val = 0;
        //int avg = 0;
        int nCounter = 0;
        int eCounter = 0;
        int sCounter = 0;
        int wCounter = 0;

        for(int i = 0; i<364; i++){
                for(int j=0; j<24; j++){
                        val = atoi(windDirection[i][j].c_str());

                        if((val <= 2) || (val > 14)) nCounter++;
                        if((val > 2) && (val <= 6)) eCounter++;
                        if((val > 6) && (val <= 10)) eCounter++;
                        if((val > 10) && (val <= 14)) eCounter++;
                }
        }

        string prevailing = "";

        if((nCounter >= eCounter) && (nCounter >= sCounter) && (nCounter >=
wCounter)) prevailing = "north";
        if((eCounter >= nCounter) && (eCounter >= sCounter) && (eCounter >=
wCounter)) prevailing = "east";
        if((sCounter >= nCounter) && (sCounter >= eCounter) && (sCounter >=
wCounter)) prevailing = "south";
```

```cpp
        if((wCounter >= nCounter) && (wCounter >= eCounter) && (wCounter >=
sCounter)) prevailing = "west";

        return prevailing;
}
// Determining the current wind speed

string AnalysisAgent::GetWindSpeed(int day, int hour){
        return windSpeed[day][hour];
}

// ************************************************************
// VALIDATING THE EFFECTIVE AREA OF WINDOWS OPENINGS
// ************************************************************

float AnalysisAgent::ValidateWinEffectiveArea(string zone, float Ag, float Ce,
float DPw){
        int zID;
        float Vz, Qt, Qtr, Awr, nACH;
        if(zone.compare("ZN01") == 0) zID = 1;
        if(zone.compare("ZN02") == 0) zID = 2;
        if(zone.compare("ZN03") == 0) zID = 3;
        if(zone.compare("ZN04") == 0) zID = 4;
        if(zone.compare("ZN05") == 0) zID = 5;

        Vz = wZones[zID].zoneVolume;

        // Implementing EAO Equations
        Qt = (0.827*Ag*Ce)*Sqrt(DPw);
        nACH = (Qt*3600)/Vz;

        if(nACH >= 1){
                return 999;
        }else{
                Qtr = Vz/3600;
                Awr = Qtr/((0.827*Ce)*Sqrt(DPw));

                return Awr;
        }
}
```

Generating Reports

```cpp
//*****************************************************************
//****************** REPORTING AGENT *****************************
//*****************************************************************

string ReportingAgent::GenerateZoneBrief(string zone)
{
        /*
        This function is responsible for generating the short zone briefs
        that apprear at the game's run-time, giving a brief indication on
        two factors, dayligh factor (DF) assessment, and the indoors
        temperature assessment (against the comfort ranges).
        */

        string zoneBText="";

        if(zone.compare("OUTS") != 0){    //Only applies when inside the building

                // identifying the current Zone
                int czID;

                string cZone = GetCurrentZone();

                for(int i=1; i<MODELZONESNUM; i++){
                        if(wZones[i].zoneName.compare(cZone) == 0) czID = i;
                }

                // ********************************************
                // Check low DAYLIGHT FACTOR (Less than 5%)
                // ********************************************

                bool hasSouthWin = false;
                bool hasNorthWin = false;
                bool hasEastWin = false;
                bool hasWestWin = false;
                bool whDeep = false;
                int wCounter = wZones[czID].winCounter;

                // Defining variables for the Daylight Factor calculation equations.

                double DFav, angle=75,  Aw=0, t=0.7, MF=0.9, GBC=0.7, Atotal, Pav=0.4;

                for(int g=0; g<wCounter; g++){
                                Aw += wZones[czID].wins[g].getWinArea();
                }

                Atotal = wZones[czID].zoneArea;

                DFav = (angle*Aw*t*MF*GBC)/(2*Atotal*(1-Pav));

                if(DFav<=2){
                        zoneBText = zoneBText+ "It is so gloomy in here. The DF in this
room is "+ConvertFTS(DFav).c_str()+". ";
                }

                // ********************************************
                // THEN REPORT INDOORS TEMP (vs. COMFORT RANGE)
                // ********************************************

                int ii = atoi(GetDayIndex(currentDay).c_str());
                int jj = atoi(GetTimeIndex(currentTime).c_str());

                string tmpOut = outsTemp[ii][jj+2];
                float diff = atof(tmpOut.c_str()) - atof(currentTemp.c_str());
```

```cpp
                // Drafting the report (brief) with the extracted relevant values.

                if(atof(currentTemp.c_str())<comfortTL){       // Check if LOWER than
comfort range
                        zoneBText = zoneBText+"It feels quite cold in here.";
                        float comfDiff = comfortTL - atof(currentTemp.c_str());
                        if(atof(tmpOut.c_str()) > atof(currentTemp.c_str())){

        if((currentZone.compare("ZN03")==0)||(currentZone.compare("ZN05")==0)){
                                zoneBText = zoneBText + "It is even colder than
outside by "+ConvertFTS(diff).c_str()+" degrees. You need to consider getting more
solar radiation to this room in winter.";
                                }else zoneBText = zoneBText + "It is even colder than
outside by "+ConvertFTS(diff).c_str()+" degrees. You need to consider methods for
retaining heat inside the zone.";
                        }else{
                                zoneBText = zoneBText + "Though it is warmer than
outside, it is still "+ConvertFTS(comfDiff).c_str()+" degrees below comfort.";
                        }
                }else if((atof(currentTemp.c_str())>=comfortTL) &&
(atof(currentTemp.c_str())<comfortTU)){
                        zoneBText = zoneBText+ "It feels lovely in this room. I wish it
was like that all year long!!";
                }else{        // Check if HIGHER than comfort range
                        zoneBText = zoneBText+"It feels quite hot in here.";
                        if(atof(tmpOut.c_str()) < atof(currentTemp.c_str())){
                                zoneBText = zoneBText + "You can try openning the
window, as the temperature outside is "+tmpOut;
                        }else{
                                float comfDiff = atof(currentTemp.c_str())-comfortTU;
                                zoneBText = zoneBText + "though it is less than the
outside temperature, it is still "+ConvertFTS(comfDiff).c_str()+" degrees above
comfort range.";
                        }
                }
        }

        // SUBMIT REPORT
        return zoneBText;
}

//******** GENERATING DAYLY REPORTS *******************

void ReportingAgent::GenerateDayReport(void){

        //************************************************
        //*****  REPORTING OUT-OF-COMFORT TIMES  ***********
        //************************************************

        string cDay = GetDayIndex(currentDay);
        int cDayIndex = atoi(cDay.c_str());
        float lowest = 100.0;
        float heighest = 0.0;
        int lowIndex=0;
        int hiIndex=0;
        string fromTime, toTime, fromTimeB, toTimeB;
        bool fromSet = false;
        bool toSet = false;
        bool fromSetB = false;
        bool toSetB = false;
        float tmp = 0.0;

        string tmpString;

        for(int i=0; i<24; i++){

                if(GetCurrentZone().compare("ZN01") == 0) tmpString =
```

```cpp
zoneOneTemp[cDayIndex][i+2];
            if(GetCurrentZone().compare("ZN02") == 0) tmpString =
zoneTwoTemp[cDayIndex][i+2];
            if(GetCurrentZone().compare("ZN03") == 0) tmpString =
zoneThreeTemp[cDayIndex][i+2];
            if(GetCurrentZone().compare("ZN04") == 0) tmpString =
zoneFourTemp[cDayIndex][i+2];
            if(GetCurrentZone().compare("ZN05") == 0) tmpString =
zoneFiveTemp[cDayIndex][i+2];

            /*
            Using Characterisation (summarisation) data mining technique
            to traverse through the daily data, and highlight the areas
            of interest (out of comfort temperature range). The data mining
            is governed by 'Rules', which in this case the assessment against
            the current calculated comfort range.
            */

            tmp = atof(tmpString.c_str());

            if(tmp<comfortTL){
                if(!fromSet){
                    fromTime = GetTimeName(i);
                    fromSet = true;
                }
                if(toSet){
                    if(!fromSetB){
                        fromTimeB = GetTimeName(i);
                        fromSetB = true;
                    }
                }
            }else if(tmp>=comfortTL && tmp<comfortTU){
                if(fromSet){
                    if(!toSet){
                        toTime = GetTimeName(i-1);
                        toSet = true;
                    }
                }
                if(fromSetB){
                    if(!toSetB){
                        toTimeB = GetTimeName(i-1);
                        toSetB = true;
                    }
                }
            }else{
                if(!fromSet){
                    fromTime = GetTimeName(i);
                    fromSet = true;
                }
                if(toSet){
                    if(!fromSetB){
                        fromTimeB = GetTimeName(i);
                        fromSetB = true;
                    }
                }
            }
            if(tmp<lowest){
                lowest = tmp;
                lowIndex = i;
            }
            if(tmp>heighest){
                heighest = tmp;
                hiIndex = i;
            }
        }

    if(!toSet) toTime = "00:00";
```

```cpp
        if(!toSetB) toTimeB = "00:00";
        string drText;

        string hiStr = ConvertFTS(heighest);
        string loStr = ConvertFTS(lowest);

        // Formulating the report after obtaining the required charachterisation,
and the supplementary parameters.

        if(fromSet){
                if((fromTime.compare("00:00")==0) && (toTime.compare("00:00")==0)){
                        drText = "The zone temperature is outide comfort range for THE
WHOLE DAY. The Lowest temperature: "+loStr+" at "+GetTimeName(lowIndex)+", and
Heighest temerature: "+hiStr+" at "+GetTimeName(hiIndex);
                }else{
                        drText = "The zone temperature is outide comfort range from "+
fromTime + " to "+ toTime;
                        if(fromSetB){
                                drText = drText + ", and from "+fromTimeB+" to
"+toTimeB;
                        }
                        drText = drText + ". The Lowest temperature: "+loStr+" at
"+GetTimeName(lowIndex)+", and Heighest temerature: "+hiStr+" at
"+GetTimeName(hiIndex);
                }
        }else drText =  "The temperature is lovely all day today in this room.";

        // SUBMIT REPORT
        TheReportWindow->dayReportText.SetText(drText.c_str());
}

//******** GENERATING MONTHLY REPORTS ******************

void ReportingAgent::GenerateMonthReport(void){

        // Traversing data and retrieving relevant information
        // Identifying Required heating and cooling load for the month

        int month = GetMonthIndex(currentMonth);
        string mRepHeat = mLoadsHeating[currentZoneID-1][month+1];
        string mRepCool = mLoadsCooling[currentZoneID-1][month+1];

        float mrh = atof(mRepHeat.c_str())/1000;
        float mrc = atof(mRepCool.c_str())/1000;

        mRepHeat = ConvertFTS(mrh);
        mRepCool = ConvertFTS(mrc);

        int monthDays, startIndex;
        int hoursCounter = 0;
        string tmpString;
        float tmp;

        // Calculating month index.

        if(month == 0){
                monthDays = 31;
                startIndex = 0;
        }
        if(month == 1){
                monthDays = 28;
                startIndex = 31;
        }
        if(month == 2){
                monthDays = 31;
                startIndex = 59;
        }
```

```
        if(month == 3){
                monthDays = 30;
                startIndex = 89;
        }
        if(month == 4){
                monthDays = 31;
                startIndex = 120;
        }
        if(month == 5){
                monthDays = 30;
                startIndex = 150;
        }
        if(month == 6){
                monthDays = 31;
                startIndex = 181;
        }
        if(month == 7){
                monthDays = 31;
                startIndex = 212;
        }
        if(month == 8){
                monthDays = 30;
                startIndex = 242;
        }
        if(month == 9){
                monthDays = 31;
                startIndex = 273;
        }
        if(month == 10){
                monthDays = 30;
                startIndex = 303;
        }
        if(month == 11){
                monthDays = 31;
                startIndex = 334;
        }

        float mHiTemp = 0, mLoTemp = 40;
        int hiDayIndex, loDayIndex, hiTimeIndex, loTimeIndex;

        for (int i=0; i<monthDays; i++){
                for(int j=2; j<26; j++){
                        // Check out of comfort hours
                        if(GetCurrentZone().compare("OUTS") == 0) tmpString =
outsTemp[startIndex+i][j];
                        if(GetCurrentZone().compare("ZN01") == 0) tmpString =
zoneOneTemp[startIndex+i][j];
                        if(GetCurrentZone().compare("ZN02") == 0) tmpString =
zoneTwoTemp[startIndex+i][j];
                        if(GetCurrentZone().compare("ZN03") == 0) tmpString =
zoneThreeTemp[startIndex+i][j];
                        if(GetCurrentZone().compare("ZN04") == 0) tmpString =
zoneFourTemp[startIndex+i][j];
                        if(GetCurrentZone().compare("ZN05") == 0) tmpString =
zoneFiveTemp[startIndex+i][j];

                        tmp = atof(tmpString.c_str());

                        if(tmp<mLoTemp){
                                mLoTemp = tmp;
                                loDayIndex = startIndex+i;
                                loTimeIndex = j-2;
                        }
                        if(tmp>mHiTemp){
                                mHiTemp = tmp;
                                hiDayIndex = startIndex+i;
                                hiTimeIndex = j-2;
```

```
                }
                if((tmp<tmpLo[startIndex+i][j-2]) ||
(tmp>tmpLo[startIndex+i][j-2])) hoursCounter++;        //
            }
        }

        // FORMULATE REPORT (Wording + Variables)
        string hrsStr = ConvertFTS(hoursCounter);
        string mRepAll = "This zone's temperature is out of comfort range for ";
        mRepAll += hrsStr + " hours for this month, and needs " + mRepHeat + " KWH
heating, and "+ mRepCool+" KWH cooling. The highest temperature is ";
        mRepAll += ConvertFTS(mHiTemp)+" on "+GetDayName(hiDayIndex)+" at
"+GetTimeName(hiTimeIndex);
        mRepAll += ", and the lowest temperature is "+ConvertFTS(mLoTemp)+" on
"+GetDayName(loDayIndex);
        mRepAll += " at "+GetTimeName(loTimeIndex);

        // SUBMIT REPORT
        TheReportWindow->monthReportText.SetText(mRepAll.c_str());
}


//******** GENERATING YEARLY REPORTS ******************

void ReportingAgent::GenerateYearReport(void){

        // Retrieving relevant data from the data warehouse
        // and traversing the contents to select elements for
        // calculations and reporting.

        string yRepHeat, yRepCool, tmpString;
        float tmp, totHeatLoads = 0, totCoolLoads = 0, totLoads, totLoadsArea;
        float mHiTemp = 0, mLoTemp = 40;
        int hiDayIndex, loDayIndex, hiTimeIndex, loTimeIndex;
        double czArea;

        for (int i=0; i<365; i++){
            for(int j=2; j<26; j++){
                if(GetCurrentZone().compare("OUTS") == 0){
                        tmpString = outsTemp[i][j];
                        czArea = 1;
                }
                if(GetCurrentZone().compare("ZN01") == 0){
                        tmpString = zoneOneTemp[i][j];
                        czArea = wZones[1].zoneArea;
                }
                if(GetCurrentZone().compare("ZN02") == 0){
                        tmpString = zoneTwoTemp[i][j];
                        czArea = wZones[2].zoneArea;
                }
                if(GetCurrentZone().compare("ZN03") == 0){
                        tmpString = zoneThreeTemp[i][j];
                        czArea = wZones[3].zoneArea;
                }
                if(GetCurrentZone().compare("ZN04") == 0){
                        tmpString = zoneFourTemp[i][j];
                        czArea = wZones[4].zoneArea;
                }
                if(GetCurrentZone().compare("ZN05") == 0){
                        tmpString = zoneFiveTemp[i][j];
                        czArea = wZones[5].zoneArea;
                }

                tmp = atof(tmpString.c_str());

                if(tmp<mLoTemp){
```

```cpp
                            mLoTemp = tmp;
                            loDayIndex = i;
                            loTimeIndex = j-2;
                    }
                    if(tmp>mHiTemp){
                            mHiTemp = tmp;
                            hiDayIndex = i;
                            hiTimeIndex = j-2;
                    }
                }
        }
    }

    for(int m=1; m<13; m++){
            totHeatLoads += atof(mLoadsHeating[currentZoneID-1][m].c_str())/1000;
            totCoolLoads += atof(mLoadsCooling[currentZoneID-1][m].c_str())/1000;
    }
    totLoads = totHeatLoads + totCoolLoads;
    totLoadsArea = totLoads/czArea;
    string yRepString = "This zone needs ";

    yRepString += ConvertFTS(totHeatLoads) +" KWH overall yearly heating loads,
and "+ ConvertFTS(totCoolLoads) +" KWH overall yearly cooling loads (";
    yRepString += ConvertFTS(totLoadsArea)+" KWH/m_sq). Maximum heating is at
"+GetTimeName(hiTimeIndex)+" on "+GetDayName(hiDayIndex);
    yRepString += ". Maximum cooling is at "+GetTimeName(loTimeIndex)+" on
"+GetDayName(loDayIndex);

    // SUBMIT REPORT
    TheReportWindow->yearReportText.SetText(yRepString.c_str());
}
```

Identifying Problems' Causalities

```cpp
// *********************************************************
// GENERATING PROBLEMS' POSSIBLE CAUSALITIES LIST
// *********************************************************

// *********************************************************
// Using the 'association' data mining technique to traverse
// through the available data files, and particularly the
// annual hourly temperatures and Gains breakdown, as well as
// monthly degree days, and monthly loads for every thermal
// zone in the design model.
// *********************************************************

void AnalysisAgent::UpdatePossibleCausalitiesList(int zID, string dID){

        if(currentZone.compare("OUTS") != 0){
                int cday = atoi(dID.c_str());



                //TheDisplayInterface->myDebugger.SetText(cDayComfortOutTo.c_str());

                // Check each gains array for the relevant 'out of comfort' period ...

                // Start with the total gains

                float totalGains = 0;
                float condGains = 0;
                float solarGains = 0;
                float internalGains = 0;
                float sairGains = 0;
                float izonalGains = 0;
                float ventGains = 0;
                int xIndex = 99;
                int yIndex = 99;
                int xIndexB = 99;
                int yIndexB = 99;

                if(cDayComfortOutFrom.compare("NA") != 0){
                        xIndex = atoi(cDayComfortOutFrom.c_str());
                        yIndex = atoi(cDayComfortOutTo.c_str());
                }

                if(cDayComfortOutFromB.compare("NA") != 0){
                        xIndexB = atoi(cDayComfortOutFromB.c_str());
                        yIndexB = atoi(cDayComfortOutToB.c_str());
                }
                if(yIndex == 0) yIndex = 24;
                if(yIndexB == 0) yIndexB = 24;

                if(xIndex != 99){
                        for(int i=xIndex+1; i<=yIndex; i++){
                                if(zID == 1){
                                        totalGains +=
atoi(gainTotalZoneA[cday][i].c_str());
                                        condGains +=
atoi(gainsConductionZoneA[cday][i].c_str());
                                        solarGains +=
atoi(gainSolarZoneA[cday][i].c_str());
                                        internalGains +=
atoi(gainInternalZoneA[cday][i].c_str());
                                        sairGains +=
atoi(gainsSAirZoneA[cday][i].c_str());
                                        izonalGains +=
atoi(gainIntZonalZoneA[cday][i].c_str());
```

```
                                                ventGains +=
atoi(gainVentilationZoneA[cday][i].c_str());
                                }
                                if(zID == 2){
                                        totalGains +=
atoi(gainTotalZoneB[cday][i].c_str());
                                        condGains +=
atoi(gainsConductionZoneB[cday][i].c_str());
                                        solarGains +=
atoi(gainSolarZoneB[cday][i].c_str());
                                        internalGains +=
atoi(gainInternalZoneB[cday][i].c_str());
                                        sairGains +=
atoi(gainsSAirZoneB[cday][i].c_str());
                                        izonalGains +=
atoi(gainIntZonalZoneB[cday][i].c_str());
                                        ventGains +=
atoi(gainVentilationZoneB[cday][i].c_str());
                                }
                                if(zID == 3){
                                        totalGains +=
atoi(gainTotalZoneC[cday][i].c_str());
                                        condGains +=
atoi(gainsConductionZoneC[cday][i].c_str());
                                        solarGains +=
atoi(gainSolarZoneC[cday][i].c_str());
                                        internalGains +=
atoi(gainInternalZoneC[cday][i].c_str());
                                        sairGains +=
atoi(gainsSAirZoneC[cday][i].c_str());
                                        izonalGains +=
atoi(gainIntZonalZoneC[cday][i].c_str());
                                        ventGains +=
atoi(gainVentilationZoneC[cday][i].c_str());
                                }
                                if(zID == 4){
                                        totalGains +=
atoi(gainTotalZoneD[cday][i].c_str());
                                        condGains +=
atoi(gainsConductionZoneD[cday][i].c_str());
                                        solarGains +=
atoi(gainSolarZoneD[cday][i].c_str());
                                        internalGains +=
atoi(gainInternalZoneD[cday][i].c_str());
                                        sairGains +=
atoi(gainsSAirZoneD[cday][i].c_str());
                                        izonalGains +=
atoi(gainIntZonalZoneD[cday][i].c_str());
                                        ventGains +=
atoi(gainVentilationZoneD[cday][i].c_str());
                                }
                                if(zID == 5){
                                        totalGains +=
atoi(gainTotalZoneE[cday][i].c_str());
                                        condGains +=
atoi(gainsConductionZoneE[cday][i].c_str());
                                        solarGains +=
atoi(gainSolarZoneE[cday][i].c_str());
                                        internalGains +=
atoi(gainInternalZoneE[cday][i].c_str());
                                        sairGains +=
atoi(gainsSAirZoneE[cday][i].c_str());
                                        izonalGains +=
atoi(gainIntZonalZoneE[cday][i].c_str());
                                        ventGains +=
atoi(gainVentilationZoneE[cday][i].c_str());
                                }
```

```
                }
            }
            if(xIndexB != 99){
                for(int i=xIndexB+1; i<=yIndexB; i++){
                    if(zID == 1){
                        totalGains +=
atoi(gainTotalZoneA[cday][i].c_str());
                        condGains +=
atoi(gainsConductionZoneA[cday][i].c_str());
                        solarGains +=
atoi(gainSolarZoneA[cday][i].c_str());
                        internalGains +=
atoi(gainInternalZoneA[cday][i].c_str());
                        sairGains +=
atoi(gainsSAirZoneA[cday][i].c_str());
                        izonalGains +=
atoi(gainIntZonalZoneA[cday][i].c_str());
                        ventGains +=
atoi(gainVentilationZoneA[cday][i].c_str());
                    }
                    if(zID == 2){
                        totalGains +=
atoi(gainTotalZoneB[cday][i].c_str());
                        condGains +=
atoi(gainsConductionZoneB[cday][i].c_str());
                        solarGains +=
atoi(gainSolarZoneB[cday][i].c_str());
                        internalGains +=
atoi(gainInternalZoneB[cday][i].c_str());
                        sairGains +=
atoi(gainsSAirZoneB[cday][i].c_str());
                        izonalGains +=
atoi(gainIntZonalZoneB[cday][i].c_str());
                        ventGains +=
atoi(gainVentilationZoneB[cday][i].c_str());
                    }
                    if(zID == 3){
                        totalGains +=
atoi(gainTotalZoneC[cday][i].c_str());
                        condGains +=
atoi(gainsConductionZoneC[cday][i].c_str());
                        solarGains +=
atoi(gainSolarZoneC[cday][i].c_str());
                        internalGains +=
atoi(gainInternalZoneC[cday][i].c_str());
                        sairGains +=
atoi(gainsSAirZoneC[cday][i].c_str());
                        izonalGains +=
atoi(gainIntZonalZoneC[cday][i].c_str());
                        ventGains +=
atoi(gainVentilationZoneC[cday][i].c_str());
                    }
                    if(zID == 4){
                        totalGains +=
atoi(gainTotalZoneD[cday][i].c_str());
                        condGains +=
atoi(gainsConductionZoneD[cday][i].c_str());
                        solarGains +=
atoi(gainSolarZoneD[cday][i].c_str());
                        internalGains +=
atoi(gainInternalZoneD[cday][i].c_str());
                        sairGains +=
atoi(gainsSAirZoneD[cday][i].c_str());
                        izonalGains +=
atoi(gainIntZonalZoneD[cday][i].c_str());
                        ventGains +=
atoi(gainVentilationZoneD[cday][i].c_str());
```

```
                                }
                        if(zID == 5){
                                totalGains +=
atoi(gainTotalZoneE[cday][i].c_str());
                                condGains +=
atoi(gainsConductionZoneE[cday][i].c_str());
                                solarGains +=
atoi(gainSolarZoneE[cday][i].c_str());
                                internalGains +=
atoi(gainInternalZoneE[cday][i].c_str());
                                sairGains +=
atoi(gainsSAirZoneE[cday][i].c_str());
                                izonalGains +=
atoi(gainIntZonalZoneE[cday][i].c_str());
                                ventGains +=
atoi(gainVentilationZoneE[cday][i].c_str());
                        }
                    }
                }


            // Check if period is hot or cold
            // and create strings to hold the values, titles, and description.

            string causeA, causeB, causeC, causeD, causeE, causeF;
            string valA, valB, valC, valD, valE, valF;
            string detailsA, detailsB, detailsC, detailsD, detailsE, detailsF =
"";

            // Detailed description of the terms used are derived from
            // Ecotect Community Wiki:
            // http://wiki.naturalfrequency.com/wiki/Heat_Balance

            if(currentPeriodCold){
                    causeA = "Conduction";
                    valA = condGains;

                    causeB = "Solar";
                    valB = solarGains;

                    causeC = "Ventilation";
                    valC = ventGains;

                    causeD = "Indirect Solar";
                    valD = sairGains;

                    causeE = "Internal";
                    valE = internalGains;

                    causeF = "Inter-Zonal";
                    valF = izonalGains;

                    detailsA = "Conduction gains occur when heat from the outside
flows through the external building envelope. This occurs almost exclusively by
conduction, however some convection may occur within some cavity constructions. The
external envelope is deemed to include the walls, windows, doors, roofs and floor.
In a building element, instantaneous heat flow will depend upon the characteristics
of the materials that make up that element, as well as overall surface area and the
temperature difference between inside and outside. The Conduction Gain for the
periods outside comfort range today in this zone is: "+ valA +" W.";
                    detailsB = "Solar gains refer to additional heat flows
generated within the building by the sun. This can be directly through the windows
or indirectly through opaque elements. In the case of opaque elements, the sun acts
to heat up exposed surfaces, thereby increasing the amount of heat flowing through
the building fabric. The Direct Solar Gain for the periods outside comfort range
today in this zone is: "+ valB +" W.";
                    detailsC = "Ventilation gains occur when outside air enters the
```

```
building. This can be by natural leakage through the building fabric (infiltration)
or by the intentional opening of doors and windows (ventilation). The Ventilation
Gain for the periods outside comfort range today in this zone is: "+ valC +" W.";
                detailsD = "Indirect solar gains allow heat from a southern
facing wall to infeltrate through the building.  The heat is distributed to the
interior space by convection, conduction, and radiation. The Indirect Solar Gain
for the periods outside comfort range today in this zone is: "+ valD +" W.";
                detailsE = "Internal gains result from heat sources within the
building. These range from people to electric lights, typewriters, computers and
almost every electrical appliance. An average person adds around 70W of heat energy
to a zone, just by being there. A computer may add up to 150 Watts of heat energy,
mainly from the monitor. These values are simply summed and added to the total heat
gain. Internal gains are most often given in W/mÃ‚Â² floor area, based on the type
of activity within each zone. The Internal Gain for the periods outside comfort
range today in this zone is: "+ valE +" W.";


            }


        if(currentPeriodHot){

                causeA = "Solar";
                valA = solarGains;

                causeB = "Conduction";
                valB = condGains;

                causeC = "Internal";
                valC = internalGains;

                causeD = "Indirect Solar";
                valD = sairGains;

                causeE = "Ventilation";
                valE = ventGains;

                causeF = "Inter-Zonal";
                valF = izonalGains;


                detailsB = "Conduction gains occur when heat from the outside
flows through the external building envelope. This occurs almost exclusively by
conduction, however some convection may occur within some cavity constructions. The
external envelope is deemed to include the walls, windows, doors, roofs and floor.
In a building element, instantaneous heat flow will depend upon the characteristics
of the materials that make up that element, as well as overall surface area and the
temperature difference between inside and outside. The Conduction Gain for the
periods outside comfort range today in this zone is: "+ valB +" W.";
                detailsA = "Solar gains refer to additional heat flows
generated within the building by the sun. This can be directly through the windows
or indirectly through opaque elements. In the case of opaque elements, the sun acts
to heat up exposed surfaces, thereby increasing the amount of heat flowing through
the building fabric. The Direct Solar Gain for the periods outside comfort range
today in this zone is: "+ valA +" W.";
                detailsE = "Ventilation gains occur when outside air enters the
building. This can be by natural leakage through the building fabric (infiltration)
or by the intentional opening of doors and windows (ventilation). The Ventilation
Gain for the periods outside comfort range today in this zone is: "+ valE +" W.";
                detailsD = "Indirect solar gains allow heat from a southern
facing wall to infeltrate through the building.  The heat is distributed to the
interior space by convection, conduction, and radiation. The Indirect Solar Gain
for the periods outside comfort range today in this zone is: "+ valD +" W.";
                detailsC = "Internal gains result from heat sources within the
building. These range from people to electric lights, typewriters, computers and
almost every electrical appliance. An average person adds around 70W of heat energy
to a zone, just by being there. A computer may add up to 150 Watts of heat energy,
mainly from the monitor. These values are simply summed and added to the total heat
gain. Internal gains are most often given in W/mÃ‚Â² floor area, based on the type
of activity within each zone. The Internal Gain for the periods outside comfort
```

```
range today in this zone is: "+ valC +" W.";
                }

                //Populate Causalities Array

                causalitiesList[0][0] = "Total";
                causalitiesList[0][1] = ConvertFTS(totalGains).c_str();
                causalitiesList[0][2] = "NA";

                causalitiesList[1][0] = causeA;
                causalitiesList[1][1] = valA;
                causalitiesList[1][2] = detailsA;

                causalitiesList[2][0] = causeB;
                causalitiesList[2][1] = valB;
                causalitiesList[2][2] = detailsB;

                causalitiesList[3][0] = causeC;
                causalitiesList[3][1] = valC;
                causalitiesList[3][2] = detailsC;

                causalitiesList[4][0] = causeD;
                causalitiesList[4][1] = valD;
                causalitiesList[4][2] = detailsD;

                causalitiesList[5][0] = causeE;
                causalitiesList[5][1] = valE;
                causalitiesList[5][2] = detailsE;

                causalitiesList[6][0] = causeF;
                causalitiesList[6][1] = valF;
                causalitiesList[6][2] = detailsF;
        }
}

void ReportingAgent::UpdateCausalitiesSet(void){

        if(TheDisplayInterface->GetCurrentZone().compare("OUTS") != 0){

                // SOLAIR: Indirect solar loads through solar gains on opaque surfaces
                string cZone = GetCurrentZone();

                int czID;
                for(int i=1; i<MODELZONESNUM; i++){
                        if(wZones[i].zoneName.compare(cZone) == 0) czID = i;
                }
                float wArea = CalcCZWinsArea(cZone);

                bool hasSouthWin = false;
                bool hasNorthWin = false;
                bool hasEastWin = false;
                bool hasWestWin = false;

                //int wCounter = TheDisplayInterface->wZones[czID].winCounter;

                for(int j=0; j<6; j++){
                        if(wZones[czID].wins[j].winOrientation.compare("south") == 0)
hasSouthWin = true;
                        if(wZones[czID].wins[j].winOrientation.compare("north") == 0)
hasNorthWin = true;
                        if(wZones[czID].wins[j].winOrientation.compare("east") == 0)
hasEastWin = true;
                        if(wZones[czID].wins[j].winOrientation.compare("west") == 0)
hasWestWin = true;
                }

                float cTemp, cLowTemp, cHiTemp, wzArea;
```

```
            cTemp = atof(GetCurrentTemp().c_str());
            cLowTemp = comfortTL;
            cHiTemp = comfortTU;

            if(cTemp<cLowTemp){
                    currentlyCold = true;
                    currentlyHot = false;
            }else if((cTemp>=cLowTemp) && (cTemp<=cHiTemp)) {
                    currentlyCold = false;
                    currentlyHot = false;
            }else if(cTemp>cHiTemp){
                    currentlyCold = false;
                    currentlyHot = true;
            }

            string causeHolder, detailHolder;

            // *** REPORTING CAUSALITIES ************

            if((currentlyCold) || (currentPeriodCold)){
                    TheReportWindow->moreTwoBTN.Show();
                    TheReportWindow->moreThreeBTN.Show();
                    TheReportWindow->moreFourBTN.Show();
                    TheReportWindow->reasonTitle.Show();
                    TheReportWindow->reasonA.Show();
                    TheReportWindow->reasonB.Show();
                    TheReportWindow->reasonC.Show();

                    if((hasSouthWin)&&(hasNorthWin)){
                            if(wArea > 15){
                                    if(causalitiesList[1][0].compare("Conduction") ==
0){
                                            causalitiesList[1][0] = "Heat Loss through
Glass";
                                            causalitiesList[1][2] = "As there are large
areas of glazing in this zone, this could be a source of subtantial heat loss. The
heat loss through conduction from glass and walls of this zone is "+
causalitiesList[1][1] +" W.";
                                    }
                                    if(causalitiesList[2][0].compare("Solar") == 0)
causalitiesList[2][0] = "Low Direct Solar Gains";
                                    if(causalitiesList[3][0].compare("Ventilation") ==
0) causalitiesList[3][0] = "High loss through Ventilation";

                            }else{

                                    if(causalitiesList[1][0].compare("Conduction") ==
0) causalitiesList[1][0] = "High Conduction Heat Loss";
                                    if(causalitiesList[2][0].compare("Solar") == 0)
causalitiesList[2][0] = "Low Direct Solar Gains";
                                    if(causalitiesList[3][0].compare("Ventilation") ==
0) causalitiesList[3][0] = "High loss through Ventilation";
                            }
                            if(moreInfoReqID == 1){
                                    causeHolder = causalitiesList[1][0];
                                    detailHolder = causalitiesList[1][2];
                            }else if(moreInfoReqID == 2){
                                    causeHolder = causalitiesList[2][0];
                                    detailHolder = causalitiesList[2][2];
                            }else if(moreInfoReqID == 3){
                                    causeHolder = causalitiesList[3][0];
                                    detailHolder = causalitiesList[3][2];
                            }
                    }
                    if(((hasSouthWin) && (!hasNorthWin))||((!hasSouthWin) &&
(hasNorthWin))||(hasEastWin)){
```

```
                            if(hasSouthWin){
                                    if(causalitiesList[1][0].compare("Conduction") ==
0) causalitiesList[1][0] = "High Conduction Heat Loss";
                                    if(causalitiesList[2][0].compare("Solar") == 0)
causalitiesList[2][0] = "Low Direct Solar Gains";
                                    if(causalitiesList[4][0].compare("Indirect Solar")
== 0){
                                            causalitiesList[3][0] = "Low Indirect Solar
Gain";
                                            causalitiesList[3][1] =
causalitiesList[4][1];
                                            causalitiesList[3][2] =
causalitiesList[4][2];
                                    }
                                    if(moreInfoReqID == 1){
                                            causeHolder = causalitiesList[1][0];
                                            detailHolder = causalitiesList[1][2];
                                    }else if(moreInfoReqID == 2){
                                            causeHolder = causalitiesList[2][0];
                                            detailHolder = causalitiesList[2][2];
                                    }else if(moreInfoReqID == 3){
                                            causeHolder = causalitiesList[4][0];
                                            detailHolder = causalitiesList[4][2];
                                    }
                            }else{
                                    if(hasNorthWin){

      if(causalitiesList[1][0].compare("Conduction") == 0) causalitiesList[1][0] =
"High Conduction Heat Loss";
                                            if(causalitiesList[2][0].compare("Solar")
== 0) causalitiesList[2][0] = "Low Direct Solar Gains";

      if(causalitiesList[3][0].compare("Ventilation") == 0) causalitiesList[3][0]
= "High loss through Ventilation";

                                            string tmpA, tmpB, tmpC;

                                            tmpA = causalitiesList[2][0];
                                            tmpB = causalitiesList[2][1];
                                            tmpC = causalitiesList[2][2];

                                            causalitiesList[2][0] =
causalitiesList[1][0];
                                            causalitiesList[2][1] =
causalitiesList[1][1];
                                            causalitiesList[2][2] =
causalitiesList[1][2];
                                            causalitiesList[1][0] =
causalitiesList[3][0];
                                            causalitiesList[1][1] =
causalitiesList[3][1];
                                            causalitiesList[1][2] =
causalitiesList[3][2];
                                            causalitiesList[3][0] = tmpA;
                                            causalitiesList[3][1] = tmpB;
                                            causalitiesList[3][2] = tmpC;

                                    }
                                    if(hasEastWin){

      if(causalitiesList[1][0].compare("Conduction") == 0) causalitiesList[1][0] =
"High Conduction Heat Loss";
                                            if(causalitiesList[2][0].compare("Solar")
== 0) causalitiesList[2][0] = "Low Direct Solar Gains";
                                            if(causalitiesList[4][0].compare("Indirect
Solar") == 0){
```

```
                                                            causalitiesList[3][0] = "Low
Indirect Solar Gain";
                                                            causalitiesList[3][1] =
causalitiesList[4][1];
                                                            causalitiesList[3][2] =
causalitiesList[4][2];
                                                    }
                                            }
                                    if(moreInfoReqID == 1){
                                            causeHolder = causalitiesList[1][0];
                                            detailHolder = causalitiesList[1][2];
                                    }else if(moreInfoReqID == 2){
                                            causeHolder = causalitiesList[2][0];
                                            detailHolder = causalitiesList[2][2];
                                    }else if(moreInfoReqID == 3){
                                            causeHolder = causalitiesList[3][0];
                                            detailHolder = causalitiesList[3][2];
                                    }
                            }
                    }
            }else if((currentlyHot) || (currentPeriodHot)){
                    TheReportWindow->moreTwoBTN.Show();
                    TheReportWindow->moreThreeBTN.Show();
                    TheReportWindow->moreFourBTN.Show();
                    TheReportWindow->reasonTitle.Show();
                    TheReportWindow->reasonA.Show();
                    TheReportWindow->reasonB.Show();
                    TheReportWindow->reasonC.Show();
                    if((hasSouthWin)&&(hasNorthWin)){
                            if(wArea > 15){
                                    if(causalitiesList[1][0].compare("Solar") == 0)
causalitiesList[1][0] = "High Direct Solar Gains";
                                    if(causalitiesList[2][0].compare("Conduction") ==
0) causalitiesList[2][0] = "High Conduction Heat Gain";
                                    if(causalitiesList[4][0].compare("Indirect Solar")
== 0){
                                            causalitiesList[3][0] = "High Indirect
Solar Gain";
                                            causalitiesList[3][1] =
causalitiesList[4][1];
                                            causalitiesList[3][2] =
causalitiesList[4][2];
                                    }
                            }else{
                                    if(causalitiesList[1][0].compare("Solar") == 0)
causalitiesList[1][0] = "High Direct Solar Gains";
                                    if(causalitiesList[2][0].compare("Conduction") ==
0) causalitiesList[2][0] = "High Conduction Heat Gain";
                                    if(causalitiesList[5][0].compare("Ventilation") ==
0){
                                            causalitiesList[3][0] = "High Ventilation
Gains";
                                            causalitiesList[3][1] =
causalitiesList[5][1];
                                            causalitiesList[3][2] =
causalitiesList[5][2];
                                    }
                            }
                            if(moreInfoReqID == 1){
                                    causeHolder = causalitiesList[1][0];
                                    detailHolder = causalitiesList[1][2];
                            }else if(moreInfoReqID == 2){
                                    causeHolder = causalitiesList[2][0];
                                    detailHolder = causalitiesList[2][2];
                            }else if(moreInfoReqID == 3){
                                    causeHolder = causalitiesList[3][0];
                                    detailHolder = causalitiesList[3][2];
```

```cpp
                                }
                        }
                        if(((hasSouthWin) && (!hasNorthWin))||((!hasSouthWin) &&
(hasNorthWin))||(hasEastWin)){
                                if(hasSouthWin){
                                        if(causalitiesList[1][0].compare("Solar") == 0)
causalitiesList[1][0] = "High Direct Solar Gains";
                                        if(causalitiesList[2][0].compare("Conduction") ==
0) causalitiesList[2][0] = "High Conduction Heat Gain";
                                        if(causalitiesList[4][0].compare("Indirect Solar")
== 0){
                                                causalitiesList[3][0] = "High Indirect
Solar Gain";
                                                causalitiesList[3][1] =
causalitiesList[4][1];
                                                causalitiesList[3][2] =
causalitiesList[4][2];
                                        }
                                }else{
                                        if(causalitiesList[2][0].compare("Conduction") ==
0){
                                                causalitiesList[1][0] = "High Conduction
Heat Gain";
                                                causalitiesList[1][1] =
causalitiesList[2][1];
                                                causalitiesList[1][2] =
causalitiesList[2][2];
                                        }
                                        causalitiesList[2][0] = "High Internal Gains";
                                        causalitiesList[2][1] = causalitiesList[3][1];
                                        causalitiesList[2][2] = causalitiesList[3][2];

                                        causalitiesList[3][0] = "High Indirect Solart
Gain";
                                        causalitiesList[3][1] = causalitiesList[4][1];
                                        causalitiesList[3][2] = causalitiesList[4][2];
                                }
                                if(moreInfoReqID == 1){
                                        causeHolder = causalitiesList[1][0];
                                        detailHolder = causalitiesList[1][2];
                                }else if(moreInfoReqID == 2){
                                        causeHolder = causalitiesList[2][0];
                                        detailHolder = causalitiesList[2][2];
                                }else if(moreInfoReqID == 3){
                                        causeHolder = causalitiesList[3][0];
                                        detailHolder = causalitiesList[3][2];
                                }
                        }
                }
                TheReportWindow->moreInfoTitle.SetText(causeHolder.c_str());
                TheReportWindow->moreInfoText.SetText(detailHolder.c_str());
                TheReportWindow->reasonA.SetText(causalitiesList[1][0].c_str());
                TheReportWindow->reasonB.SetText(causalitiesList[2][0].c_str());
                TheReportWindow->reasonC.SetText(causalitiesList[3][0].c_str());
        }
}
```

Implementing Interrogation Routines

```cpp
//***********************************************************************
//************* INTERROGATION ROUTINES *********************************
//***********************************************************************
//
// This is carried out using the decision tree datamining techniques based
// on the 'rules' specified by building physics equations, as well as the
// input and preferences of the users. The Q&A routine is dynamicaly generated
// for everyzone, according to the current settings and state of the experience.
//***********************************************************************

int ReportingAgent::UpdateInterrogationData(void){

        if(GetCurrentZone().compare("OUTS") != 0){

                // ****** FIRST DO THE MATH *********

                string cZone = GetCurrentZone();
                int czID;
                for(int i=1; i<MODELZONESNUM; i++){
                        if(wZones[i].zoneName.compare(cZone) == 0) czID = i;
                }
                float wArea = CalcCZWinsArea(cZone);
                if(overrideWA) wArea = 0;
                float southWinArea = 0;
                float nonSouthWinArea = 0;

                int nWinArea = 15;

                bool hasSouthWin = false;
                bool hasNorthWin = false;
                bool hasEastWin = false;
                bool hasWestWin = false;
                bool whDeep = false;
                float effArea;

                int wCounter = wZones[czID].winCounter;

                for(int j=0; j<wCounter; j++){
                        if(wZones[czID].wins[j].winOrientation.compare("south") == 0){
                                if(czID == 5) TheDisplayInterface-
>myDebugger.SetText(TheDisplayInterface->ConvertFTS(j).c_str());
                                hasSouthWin = true;
                                if(wZones[czID].wins[j].winHeight > 1.3) whDeep = true;

                                // calculate the south facing windows area...
                                southWinArea += wZones[czID].wins[j].getWinArea();
                        }else{
                                // calculate the non-south facing windows area...
                                nonSouthWinArea += wZones[czID].wins[j].getWinArea();
                        }
                        if(wZones[czID].wins[j].winOrientation.compare("north") == 0)
hasNorthWin = true;
                        if(wZones[czID].wins[j].winOrientation.compare("east") == 0)
hasEastWin = true;
                        if(wZones[czID].wins[j].winOrientation.compare("west") == 0)
hasWestWin = true;
                }

                if(czID == 3) hasWestWin = false;

                // get the zone's depth

                float zDepth = 0;
                float tmpX, tmpY;
```

```cpp
            for(int k=0; k<modelObjectCounter; k++){
                if(atoi(modelObjectsData[k][1].c_str()) == czID){
                    if(atoi(modelObjectsData[k][6].c_str()) == 0){
                        tmpY = atoi(modelObjectsData[k][5].c_str());
                        zDepth = tmpY/1000;
                    }
                }
            }

            // Get the zone's height
            float zHeight = wZones[czID].zoneHeight;

            float cTemp, cLowTemp, cHiTemp, wzArea;

            cTemp = atof(GetCurrentTemp().c_str());
            cLowTemp = comfortTL;
            cHiTemp = comfortTU;
            string intMessage;
            bool cLevelA, cLevelB, cLevelC, cLevelD, cLevelE, cLevelF;
            string inputResponse;

            if(cTemp<cLowTemp){
                currentlyCold = true;
                currentlyHot = false;
            }else if((cTemp>=cLowTemp) && (cTemp<=cHiTemp)) {
                currentlyCold = false;
                currentlyHot = false;
            }else if(cTemp>cHiTemp){
                currentlyCold = false;
                currentlyHot = true;
            }

            // Check which level of interrogation ..
            // and recording users' responses...

            float response;

            float ohd = response;
            string tmpZone="";
            string cmpZN="";
            float whHolder, ovhDepth;
            tmpZone = GetCurrentZone();
            for(int i=1; i<7; i++){
                cmpZN = wZones[i].zoneName;
                if(tmpZone.compare(cmpZN) == 0){
                    if(wZones[i].isSouth){
                        for(int j=0; j<4; j++){

    if(wZones[i].wins[j].winOrientation.compare("south") == 0){
                                whHolder =
wZones[i].wins[j].winHeight;
                            }
                        }
                    }
                }
            }
            ovhDepth = CalculateOverhangDepth(whHolder);


            //****************************************************
            // IN CASE OF TEMPERATURES WITHIN COMFORT RANGE
            // ************************************************
            if(cTemp<cLowTemp){
                int cCounter = 0;
                if(overrideWA) cCounter++;
```

```cpp
                        // Check if the zone is facing south (prevailing sun)
                        if(wZones[czID].isSouth){

                                if(wArea > nWinArea){
                                        // Check NON-SOUTH facing windows area
                                        // Reduce NON_SOUTH facing windows ...

                                        string intMessage = "";
                                        intMessage = "I noticed there is "+
ConvertFTS(nonSouthWinArea)+ "sq m non-south facing windows' area in this zone,
which could be a main cause for heat loss. Can you reduce these window's total
area?";
                                        TheReportWindow-
>qText.SetText(intMessage.c_str());
                                        TheReportWindow->qInfoTitle.SetText("More
Information:");
                                        TheReportWindow->qInfo.SetText("Reducing the area
of non-south facing windows will minimise the heat loss through these windows.");
                                        ShowYesNoGUI();

                                        response = responsesCold[czID-1][cCounter];
                                        cCounter++;

                                        if(response == 1){
                                                TheReportWindow-
>qText.SetText("Reduce these windows area to reduce the amount of heat loss through
them. Using small size windows with appropriate effective area of opening can help
bring the indoors temperature to comfort in both hot and cold periods.");
                                                HideInterrogationGUI();
                                                TheReportWindow->qInfo.Show();
                                                TheReportWindow-
>qInfo.SetText("Please press the 'Guidelines' button for more detailed overview and
suggestions for this zone.");
                                        }else if(response == 2){
                                                overrideWA = true;
                                                UpdateInterrogationData();
                                        }
                                }else{          // normal non south windows area...

                                        string intMessage = "";
                                        intMessage = "Though there are "+
ConvertFTS(southWinArea)+ "sq m south-facing windows area, the 'Direct Solar Gain'
is not enough to bring the temperature towards comfort range. Is it possible to
increase the windows area?";
                                        TheReportWindow-
>qText.SetText(intMessage.c_str());
                                        TheReportWindow->qInfoTitle.SetText("Information
about Direct Solar Gain:");
                                        TheReportWindow->qInfo.SetText("This is the heat
aquired by a zone from solar radiation, due to direct access of sun heat from the
zone's windows.");
                                        ShowYesNoGUI();

                                        response = responsesCold[czID-1][cCounter];
                                        cCounter++;

                                        if(response == 1){
                                                TheReportWindow->qText.SetText("It is
recommended to use larger south facing windows' area to allow more solar heat in
winter. Use appropriate overhand on these windows to prevent the unwanted summer
heat.");
                                                HideInterrogationGUI();
                                                TheReportWindow->qInfo.Show();
                                                TheReportWindow->qInfo.SetText("Please
press the 'Guidelines' button for more detailed overview and suggestions for this
zone.");
```

```
                                }else if(response == 2){
                                        intMessage = "I noticed there is "+
ConvertFTS(CalcCZWinsArea(cZone))+ "sq m windows in this zone, which could be a
main cause for heat loss. Are you using 'Heat Absorbing Glass'?";
                                        TheReportWindow-
>qText.SetText(intMessage.c_str());
                                        TheReportWindow-
>qInfoTitle.SetText("Information about Heat Absorbing Glass:");
                                        TheReportWindow->qInfo.SetText("HAG is high
performance glazing (Low-E, insulated frames), and has the potential to absorb 80%
of the solar radiation falling on it (43% transmitted and 37% radiated).");
                                        ShowYesNoGUI();


                                        response = responsesCold[czID-1][cCounter];
                                        cCounter++;

                                        if(response == 1){
                                                TheReportWindow->qText.SetText("Can
you please input the depth of the overhang you are using on the southern window (0
if no overhang used)?");
                                                TheReportWindow-
>qInfoTitle.SetText("Information about Windows Overhang:");
                                                TheReportWindow-
>qInfo.SetText("Windows overhangs are built extrusions commonly used above southern
facing windows to prevent any solar access during periods of overheat.");
                                                ShowOKInputGUI();

                                                response = responsesCold[czID-
1][cCounter];
                                                cCounter++;
                                                ohd = response;

                                                if((response != 1) && (response !=
2) && (response != 99)){
                                                        if(ohd>ovhDepth){
                                                                string ss = "The
overhang depth is too deep that it is blocking even the winter sun. The recommended
depth for the southern window in this zone is "+ConvertFTS(ovhDepth)+" meters.";
                                                                TheReportWindow-
>qText.SetText(ss.c_str());
                                                                HideInterrogationGUI();
                                                                TheReportWindow-
>qInfo.Show();
                                                                TheReportWindow-
>qInfo.SetText("Please press the 'Guidelines' button for more detailed overview and
suggestions for this zone.");
                                                        }else{
                                                                TheReportWindow-
>qText.SetText("This depth you provided seems to be sufficient to allow solar
access in the winter cold period. Are you using 'Thermal Mass'?");
                                                                TheReportWindow-
>qInfoTitle.SetText("Information about Thermal Mass:");
                                                                TheReportWindow-
>qInfo.SetText("Thermal mass is any surface that absorbs solar energy and heat
during the day and releases it night. Using thermal mass can moderate temperatures
and minimise energy consumption.");
                                                                ShowYesNoGUI();

                                                                response =
responsesCold[czID-1][cCounter];

                                                                cCounter++;

                                                                if(response == 1){
                                                                        // Tree
branching stops, show guidelines.
```

```cpp
        HideInterrogationGUI();
                                                    TheReportWindow-
>qText.SetText("Please press the 'Guidelines' button for more detailed overview and
suggestions for this zone.");

                                            }else if(response ==
2){
                                                    TheReportWindow-
>qText.SetText("It is recommended to use thermal mass in your design to shift the
temperature passively towards the comfort ranges.");

        HideInterrogationGUI();
                                                    TheReportWindow-
>qInfo.Show();
                                                    TheReportWindow-
>qInfo.SetText("Please press the 'Guidelines' button for more detailed overview and
suggestions for this zone.");
                                                    }
                                            }
                                    }
                            }else if(response == 2){
                                    TheReportWindow->qText.SetText("It
is recommend to use the 'Heat Absorbing Glazing' to allow more heat gain during the
cold periods in this zone. make sure to use a suitable overhang that blocks the sun
access during hot periods.");
                                    HideInterrogationGUI();
                                    TheReportWindow->qInfo.Show();
                                    TheReportWindow-
>qInfo.SetText("Please press the 'Guidelines' button for more detailed overview and
suggestions for this zone.");
                            }
                    }
            }
        }else{          // IF NOT SOUTH-FACING ZONE

                    // install skylight
                    intMessage = "This zone doesn't have south-facing
windows, which can be a factor for reducing the solar gains/heat. Can you use a
skylight in this zone?";
                    TheReportWindow->qText.SetText(intMessage.c_str());
                    TheReportWindow->qInfoTitle.SetText("Information about
Skylights:");
                    TheReportWindow->qInfo.SetText("Skylights are formed
from a shift in the hight on the zone's cieling, which allows more direct solar
access to this zone which helps in increasing the heat gains, and also improve the
lighting performance.");
                    ShowYesNoGUI();

                    response = responsesCold[czID-1][cCounter];
                    cCounter++;

                    if(response == 1){
                            TheReportWindow->qText.SetText("Great, a skylight
can be quite effective in zones like this, as it will promote stack ventilation in
hot periods, and allow sun heat access in winter.");
                            HideInterrogationGUI();
                            TheReportWindow->qInfo.Show();
                            TheReportWindow->qInfo.SetText("Please press the
'Guidelines' button for more detailed overview and suggestions for this zone.");
                    }else if(response == 2){

                            if((nonSouthWinArea>3)&&(!overrideZEW)){
                                    intMessage = "I noticed there is "+
ConvertFTS(nonSouthWinArea)+ "sq m non-south facing windows' area in this zone,
which could be a main cause for heat loss. Can you reduce these window's total
area?";
                                    TheReportWindow-
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>qText.SetText(intMessage.c_str());
                                        TheReportWindow-
>qInfoTitle.SetText("Information about Heat Absorbing Glass:");
                                        TheReportWindow->qInfo.SetText("Reducing
the area of non-south facing windows will minimise the heat loss through these
windows.");
                                        ShowYesNoGUI();

                                        response = responsesCold[czID-1][cCounter];
                                        cCounter++;

                                        if(response == 1){
                                                TheReportWindow-
>qText.SetText("Reduce these windows area to reduce the amount of heat loss through
them. Using small size windows with appropriate effective area of opening can help
bring the indoors temperature to comfort in both hot and cold periods.");
                                                HideInterrogationGUI();
                                                TheReportWindow->qInfo.Show();
                                                TheReportWindow-
>qInfo.SetText("Please press the 'Guidelines' button for more detailed overview and
suggestions for this zone.");

                                        }else if(response == 2){
                                                overrideZEW = true;
                                                UpdateInterrogationData();
                                        }
                                }else{
                                        if(overrideZEW) cCounter++;
                                        TheReportWindow->qText.SetText("Can you
implement sunspaces in the building?");
                                        TheReportWindow-
>qInfoTitle.SetText("Information about Sunspaces:");
                                        TheReportWindow->qInfo.SetText("A sunspace
is like an 'attached greenhouse' which is a thermally separated area attached to
the building, and collects and stores solar energy to be circulated among the
colder zones.");
                                        ShowYesNoGUI();

                                        response = responsesCold[czID-1][cCounter];
                                        cCounter++;

                                        if(response == 1){
                                                TheReportWindow-
>qText.SetText("Sunspace is an isolated gains system based on passive solar
heating. It is isolated thermal zone, but can pass heated air to the colder areas
of the building. This needs to be treated by reflectors, or opening shaft during
hot periods.");
                                                HideInterrogationGUI();
                                                TheReportWindow->qInfo.Show();
                                                TheReportWindow-
>qInfo.SetText("Please press the 'Guidelines' button for more detailed overview and
suggestions for this zone.");

                                        }else if(response == 2){

                                                TheReportWindow->qText.SetText("Can
you change the windows orientation to face South, while using appropriate windows'
overhangs?");
                                                TheReportWindow-
>qInfoTitle.SetText("More Information:");
                                                TheReportWindow->qInfo.SetText("This
will allow more direct solar gain in the colder periods, as well as prevent the
eastern and western unwanted direct solar access in overheated periods.");
                                                ShowYesNoGUI();

                                                response = responsesCold[czID-
1][cCounter];
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                                              cCounter++;

                                    if(response == 1){
                                              TheReportWindow-
>qText.SetText("Change the orientation on eastern or western windows to face south
whenever possible, and use a appropriate overhang to prevent unwanted solar access
during overheated periods.");
                                              HideInterrogationGUI();
                                              TheReportWindow->qInfo.Show();
                                              TheReportWindow-
>qInfo.SetText("Please press the 'Guidelines' button for more detailed overview and
suggestions for this zone.");

                                    }else if(response == 2){
                                              // Tree branching stops, show
guidelines.
                                              HideInterrogationGUI();
                                              TheReportWindow-
>qText.SetText("Please press the 'Guidelines' button for more detailed overview and
suggestions for this zone.");
                                    }
                             }
                      }
               }
        }

        //****************************************************
        // IN CASE OF TEMPERATURES WITHIN COMFORT RANGE
        // ****************************************************

        }else if((cTemp>=cLowTemp) && (cTemp<=cHiTemp)) {
               // Feels good now
               TheReportWindow->qText.SetText("It feels quite nice now,
however,  this is not the case for the whole year. You can change the date and time
settings to investigate more into out of comfort periods.");
               HideInterrogationGUI();

        //****************************************************
        // IN CASE OF TEMPERATURES ABOVE COMFORT RANGE
        // ****************************************************

        }else if(cTemp>cHiTemp){

               int hCounter = 0;

               // Check if the zone is south-facing
               if((wZones[czID].isSouth) && (!overrideOVH)){
                      if((wArea > nWinArea) && (!overrideTM)){
                             intMessage = "This zone has"+ ConvertFTS(wArea)+
"sq m of windows. Can you reduce the glazing area and depend more on 'Thermal
Masses'?";
                             TheReportWindow-
>qText.SetText(intMessage.c_str());
                             TheReportWindow->qInfoTitle.SetText("Information
about Thermal Mass:");
                             TheReportWindow->qInfo.SetText("The thermal mass
is a measure of its capacity to store and regulate internal heat. Buildings with a
high thermal mass take a long time to heat up but also take a long time to cool
down.");
                             ShowYesNoGUI();

                             response = responsesHot[czID-1][hCounter];
                             hCounter++;

                             if(response == 1){
                                    TheReportWindow->qText.SetText("'Thermal
Mass' can be an effective passive cooling strategy, and it can also be effective in
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colder conditions as it absorbs solar heat during the day and release it at
night.");
                                    HideInterrogationGUI();
                                    TheReportWindow->qInfo.Show();
                                    TheReportWindow->qInfo.SetText("Please
press the 'Guidelines' button for more detailed overview and suggestions for this
zone.");

                        }else if(response == 2){
                                overrideTM = true;
                                UpdateInterrogationData();
                        }
                }else{

                        if(overrideTM) hCounter++;

                        // Check overhang depth
                        TheReportWindow->qText.SetText("I noticed this
zone has south-facing windows. Can you please input the depth of the overhang you
are using on the southern window (0 if no overhang used)?");
                        TheReportWindow->qInfoTitle.SetText("Information
about Windows Overhang:");
                        TheReportWindow->qInfo.SetText("Windows overhangs
are built extrusions commonly used above southern facing windows to prevent any
solar access during periods of overheat.");
                        ShowOKInputGUI();

                        response = responsesHot[czID-1][hCounter];
                        hCounter++;

                        ohd = response;

                        if((response != 1) && (response != 2) && (response
!= 99)){

                                if(ohd<ovhDepth){
                                        string tsRes = "This depth might be
enough to allow the winter sun, but is not deep enough to block the unwanted solar
access during the zone's overheated periods. The recommended depth for the southern
window in this zone is "+ConvertFTS(ovhDepth)+" meters.";
                                        TheReportWindow-
>qText.SetText(tsRes.c_str());
                                        HideInterrogationGUI();
                                        TheReportWindow->qInfo.Show();
                                        TheReportWindow-
>qInfo.SetText("Please press the 'Guidelines' button for more detailed overview and
suggestions for this zone.");
                                }else{
                                        // override to skip overhang check
                                        overrideOVH = true;
                                        UpdateInterrogationData();
                                }
                        }
                }
        }else{
                // Check Ventilation type
                if(overrideOVH) hCounter++;

                // Check for cross ventilation
                if((hasSouthWin && hasNorthWin)||(hasSouthWin &&
hasEastWin)||(hasSouthWin && hasWestWin)||(hasNorthWin && hasEastWin)||(hasNorthWin
&& hasWestWin)||(hasEastWin && hasWestWin)){

                        TheReportWindow->qText.SetText("I can see this
zone has Cross Ventilation. Can you tell me the 'Effective Openning Area' of the
windows in this zone?");
                        TheReportWindow->qInfoTitle.SetText("Effective
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Openning Area:");
                                    TheReportWindow->qInfo.SetText("This term refers
to the actual area of the window which is allowed to be opened for air flow and
ventilation.");
                                    ShowOKInputGUI();

                                    response = responsesHot[czID-1][hCounter];

                                    effArea = response;
                                    float val = ValidateWinEffectiveArea(cZone,
effArea, 1.0, 0.55);

                                    if((response != 1) && (response != 2) && (response
!= 99)){
                                        if(val != 999){
                                            string icc = "The effective area you
provided is not enough to maintain the required air change per hour. The minimum
required area is "+ConvertFTS(val)+" m Sq.";
                                            TheReportWindow-
>qText.SetText(icc.c_str());
                                            HideInterrogationGUI();
                                            TheReportWindow->qInfo.Show();
                                            TheReportWindow-
>qInfo.SetText("Please press the 'Guidelines' button for more detailed overview and
suggestions for this zone.");
                                        }else{

                                            response = responsesHot[czID-
1][hCounter];

                                            hCounter++;

                                            TheReportWindow->qText.SetText("The
Effective Area seems to be acceptable to maintain the air change per hour. Is it
possible to increase the zone's height?");
                                            TheReportWindow-
>qInfoTitle.SetText("Increasing Zone Height:");
                                            TheReportWindow-
>qInfo.SetText("Increasing the height of the zone will allow the lighter hot air to
occupy the higher levels of the zone, leaving the much cooler air at the bottom
levels.");
                                            ShowYesNoGUI();

                                            if(response == 1){
                                                TheReportWindow-
>qText.SetText("Increasing the zone's hight will allow the hot air to travel
upwards, leaving the cooler air down.");
                                                HideInterrogationGUI();
                                                TheReportWindow->qInfo.Show();
                                                TheReportWindow-
>qInfo.SetText("Please press the 'Guidelines' button for more detailed overview and
suggestions for this zone.");

                                            }else if(response == 2){
                                                // Tree branching stops, show
guidelines.

                                                HideInterrogationGUI();
                                                TheReportWindow-
>qText.SetText("Please press the 'Guidelines' button for more detailed overview and
suggestions for this zone.");
                                            }
                                        }
                                    }
                        }else{ // In case of single-sided ventilation

                                // check the depth of the zone

                                if(zDepth > (2*zHeight)){ // example --> ZONE_03
```

```cpp
                                    string sDepth = "I can see you have windows
on one side on the room. However, the depth of the zone ("+ConvertFTS(zDepth)+" m
is too big to be ventilated from one side. Can you reduce this depth?";
                                    TheReportWindow-
>qText.SetText(sDepth.c_str());
                                    TheReportWindow-
>qInfoTitle.SetText("Information on Single Sided Ventilation:");
                                    TheReportWindow->qInfo.SetText("Single
Sided Ventilation is effective in a zone with a depth no more than double the zone
hight (d=2h), and generally limited to 5 to 6 meters depth.");
                                    ShowYesNoGUI();

                                    response = responsesHot[czID-1][hCounter];
                                    hCounter++;

                                    if(response == 1){
                                            TheReportWindow-
>qText.SetText("Reducing the depth of the zone to below 6 m will allow single sided
ventilation to be more effective.");
                                            HideInterrogationGUI();
                                            TheReportWindow->qInfo.Show();
                                            TheReportWindow-
>qInfo.SetText("Please press the 'Guidelines' button for more detailed overview and
suggestions for this zone.");

                                    }else if(response == 2){
                                            TheReportWindow->qText.SetText("As
you can't reduce the zone's depth, how about placing a 'skylight' in this room?");

                                            TheReportWindow-
>qInfoTitle.SetText("Information about Skylights:");
                                            TheReportWindow-
>qInfo.SetText("Small well-insulated skylights (less than 3% of floor area in clear
climates, 5% in overcast) reduce daytime lighting energy and cooling loads.");
                                            ShowYesNoGUI();

                                            response = responsesHot[czID-
1][hCounter];
                                            hCounter++;

                                            if(response == 1){
                                                    TheReportWindow-
>qText.SetText("A skylight can be quite effective in zones like this, as it will
promote stack ventilation in hot periods, and allow solar access in winter.");
                                                    HideInterrogationGUI();
                                                    TheReportWindow->qInfo.Show();
                                                    TheReportWindow-
>qInfo.SetText("Please press the 'Guidelines' button for more detailed overview and
suggestions for this zone.");

                                            }else if(response == 2){

                                                    TheReportWindow-
>qText.SetText("Is it possible to increase the zone's height?");
                                                    TheReportWindow-
>qInfoTitle.SetText("Increasing Zone Height:");
                                                    TheReportWindow-
>qInfo.SetText("Increasing the height of the zone will allow the lighter hot air to
occupy the higher levels of the zone, leaving the much cooler air at the bottom
levels.");
                                                    ShowYesNoGUI();

                                                    response = responsesHot[czID-
1][hCounter];
                                                    hCounter++;

                                                    if(response == 1){
```

```cpp
                                                        TheReportWindow-
>qText.SetText("Increasing the zone's hight will allow the hot air to travel
upwards, leaving the cooler air down.");
                                                        HideInterrogationGUI();
                                                        TheReportWindow-
>qInfo.Show();

                                                        TheReportWindow-
>qInfo.SetText("Please press the 'Guidelines' button for more detailed overview and
suggestions for this zone.");

                                                }else if(response == 2){
                                                        // Tree branching
stops, show guidelines.
                                                        HideInterrogationGUI();
                                                        TheReportWindow-
>qText.SetText("Please press the 'Guidelines' button for more detailed overview and
suggestions for this zone.");
                                                }
                                        }
                                }
                        }else{
                                // Check if stack ventilation is possible

                                TheReportWindow->qText.SetText("I can see
this zone has single-sided Ventilation. Can you implement stack ventilation?");
                                TheReportWindow->qInfoTitle.SetText("Stack
Ventilation:");

                                TheReportWindow->qInfo.SetText("This ia a
passive cooling strategy, based on replacing the hot less dense air that rises by
the cooler air. A higher outlet opening is thus used to get rid of hot air.");

                                ShowYesNoGUI();

                                response = responsesHot[czID-1][hCounter];
                                hCounter++;

                                if(response == 1){
                                        TheReportWindow-
>qText.SetText("Stack ventilation is an effective passive cooling method. Create an
inlet in the northern (prevailing) wind, and a higher outlet to get rid of lighter
hot air.");
                                        HideInterrogationGUI();
                                        TheReportWindow->qInfo.Show();
                                        TheReportWindow-
>qInfo.SetText("Please press the 'Guidelines' button for more detailed overview and
suggestions for this zone.");

                                }else if(response == 2){

                                        TheReportWindow->qText.SetText("Can
you tell me the 'Effective Openning Area' of the window in this zone?");
                                        TheReportWindow-
>qInfoTitle.SetText("Effective Openning Area:");
                                        TheReportWindow->qInfo.SetText("This
term refers to the actual area of the window which is allowed to be opened for air
flow and ventilation.");
                                        ShowOKInputGUI();

                                        response = responsesHot[czID-
1][hCounter];
                                        hCounter++;

                                        TheDisplayInterface-
>myDebugger.SetText(TheDisplayInterface->ConvertFTS(response).c_str());

                                        effArea = response;
                                        float val =
```

```
ValidateWinEffectiveArea(cZone, effArea, 1.0, 0.55);

                                        if((response != 1) && (response !=
2) && (response != 99)){
                                            if(val != 999){
                                                string icc = "The
effective area you provided is not enough to maintain the required air change per
hour. The minimum required area is "+ConvertFTS(val)+" m Sq.";
                                                HideInterrogationGUI();
                                                TheReportWindow-
>qInfo.Show();
                                                TheReportWindow-
>qInfo.SetText("Please press the 'Guidelines' button for more detailed overview and
suggestions for this zone.");
                                            }else{

                                                //response =
responsesHot[czID-1][hCounter];
                                                //hCounter++;

                                                TheReportWindow-
>qText.SetText("The Effective Area seems to be acceptable to maintain the air
change per hour. Is it possible to increase the zone's height?");
                                                TheReportWindow-
>qInfoTitle.SetText("Increasing Zone Height:");
                                                TheReportWindow-
>qInfo.SetText("Increasing the height of the zone will allow the lighter hot air to
occupy the higher levels of the zone, leaving the much cooler air at the bottom
levels.");
                                                ShowYesNoGUI();

                                                response =
responsesHot[czID-1][hCounter];
                                                hCounter++;

                                                if(response == 1){
                                                    TheReportWindow-
>qText.SetText("Increasing the zone's hight will allow the hot air to travel
upwards, leaving the cooler air down.");
        HideInterrogationGUI();
                                                    TheReportWindow-
>qInfo.Show();
                                                    TheReportWindow-
>qInfo.SetText("Please press the 'Guidelines' button for more detailed overview and
suggestions for this zone.");

                                                }else if(response ==
2){

                                                    // Tree
branching stops, show guidelines.

        HideInterrogationGUI();
                                                    TheReportWindow-
>qText.SetText("Please press the 'Guidelines' button for more detailed overview and
suggestions for this zone.");

                                                }
                                            }
                                        }
                                    }
                                }
                            }
```

```
                }
        }
  return 0;
}
```

Generating Zone's Guidelines

```cpp
//*************************************************************
//*****************  POPULATING GUIDELINES ARRAY *************
//*************************************************************

void ReportingAgent::PopulateGuidelines(void){

        /*
        This function populates the guidelines array [gdArray] with the
        set of guidelines retrieved from multiple resources. The set
        (array) of guidelines will be later examined, and appropriate
        guidelines will be assigned to the specified zones, according to
        the association data minig technique, giverned by the rules
        derived from the users' preferences and the game's information model
        */

        if(GetCurrentZone().compare("OUTS") != 0){
                string cZone = GetCurrentZone();
                int czID;
                for(int i=1; i<MODELZONESNUM; i++){
                        if(wZones[i].zoneName.compare(cZone) == 0) czID = i;
                }

                //*************GUIDELINE 1: OVERHANGS ****************

                string tmpZone="";
                string cmpZN="";
                float whHolder, ovhDepth;
                tmpZone = GetCurrentZone();

                for(int i=1; i<7; i++){

                        cmpZN = wZones[i].zoneName;
                        if(tmpZone.compare(cmpZN) == 0){
                                // check for south-facing windows
                                if(wZones[i].isSouth){
                                        gdArray[1].gdMainTitle = "Use Horizontal Overhang
over windows in the southern façade";
                                        gdArray[1].gdText = "These can be structural
windows overhangs (fixed throughout the year), or mechanical, where it can be
expandable in summer and retractable in winter. The Depth and width of the required
overhang for this zone is ";
                                        for(int j=0; j<5; j++){

        if(wZones[i].wins[j].winOrientation.compare("south") == 0){
                                                        whHolder =
wZones[i].wins[j].winHeight;
                                                }
                                        }
                                        ovhDepth = CalculateOverhangDepth(whHolder);
                                        gdArray[1].gdText +=
ConvertFTS(CalculateOverhangDepth(whHolder));
                                        gdArray[1].gdText += " cm depth, as the periods of
overheat start from ";
                                        gdArray[1].gdText +=
CalcOverheatPeriod(GetCurrentZone());
                                        gdArray[1].gdText += ". The overhang should be
extended to both sides of the window by ";
```

```
                                     gdArray[1].gdText +=
ConvertFTS(CalculateOverhangDepth(whHolder)/2);
                                     gdArray[1].gdText += " cm.";
                        }
                  }
            }
            // assign images to accompany the text.
            gdArray[1].imageALink = "texture/gd_01_A";
            gdArray[1].imageBLink = "texture/blank";

            //*********** GUIDELINE 2: VERTICAL FINS ***********

            gdArray[2].gdMainTitle = "Use Vertical Fins in Eastern and western
façades.";
            gdArray[2].gdText = "I can see that this zone has Eastern/Western
facing windows. As the sun's altitude is relatively smaller, relying on horizontal
overhangs might not be efficient. It has to be understood that for these fins to be
effective, they can affect the window view. The number of vertical fins required in
the window can be reduced if the depth of each fin can be increased. ";
            // assign images for this guideline
            gdArray[2].imageALink = "texture/gd_02_A";
            gdArray[2].imageBLink = "texture/gd_02_B";

            //*********** GUIDELINE 3: N & S facing windows *******

            int czID;
            for(int l=1; l<MODELZONESNUM; l++){
                  if(wZones[l].zoneName.compare(tmpZone) == 0) czID = l;
            }
            bool hasSouthWin = false;
            bool hasNorthWin = false;
            bool hasEastWin = false;
            bool hasWestWin = false;
            bool whDeep = false;
            int wCounter = wZones[czID].winCounter;
            for(int m=0; m<wCounter; m++){
                  if(wZones[czID].wins[m].winOrientation.compare("south") == 0)
hasSouthWin = true;
                  if(wZones[czID].wins[m].winOrientation.compare("north") == 0)
hasNorthWin = true;
                  if(wZones[czID].wins[m].winOrientation.compare("east") == 0)
hasEastWin = true;
                  if(wZones[czID].wins[m].winOrientation.compare("west") == 0)
hasWestWin = true;
            }
            gdArray[3].gdMainTitle = "Design eastern & western facing windows to
face north or south.";
            double tThree;
            string direction;
            if(hasEastWin){
                  tThree = GetCurrentZoneWinArea(czID);
                  direction = "east";
            }
            if(hasWestWin){
                  tThree = GetCurrentZoneWinArea(czID);
                  direction = "west";
            }
            string tmpThree = ConvertFTS(tThree);
            gdArray[3].gdText = "You have a window area of ";
            gdArray[3].gdText += tmpThree.c_str();
            gdArray[3].gdText += "  square meters, facing ";
            gdArray[3].gdText += direction.c_str();
            gdArray[3].gdText += ".   It is recommended to shift the windows to
face north or even south to avoid direct overheat from periods of exposure in the
morning and the evening and reduce summer and fall afternoon heat gain. This can be
achieved by either tilting the window angle (Fig. 1) or sinking them deep in the
wall. This will not affect the heat gain in winter as then the sun angle is minimal
```

```
in the East and West facades.";
            gdArray[3].imageALink = "texture/gd_03_A";
            gdArray[3].imageBLink = "texture/blank";


            //********* GUIDELINE 4: Evapourative Cooling *********

            gdArray[4].gdMainTitle = "Use Evaporative Cooling.";
            gdArray[4].gdText = "When water evaporates, it draws a large amount of
sensible heat from its surroundings and converts this type of heat into latent heat
in the form of water vapour. As sensible heat is converted to latent heat, the
temperature drops. This phenomenon is used to cool buildings in two very different
ways. If the water evaporates in the building or in the fresh-air intake, the air
will be not only cooled, but also humidified. This method is called direct
evaporative cooling. If, however, the building or indoor air are cooled by
evaporation without humidifying the indoor air, the method is called indirect
evaporative cooling. ";
            gdArray[4].imageALink = "texture/gd_04_A";
            gdArray[4].imageBLink = "texture/blank";


            //******** GUIDELINE 5: Thermal Mass ******************

            gdArray[5].gdMainTitle = "Use Thermal Mass in direct gain zones";
            gdArray[5].gdText = "The thermal mass of a building determines its
aptitude to store and control the flow of internal heat. Using high thermal mass in
the building can shift its properties, allowing it to take longer periods to heat
up, and to cool down. As a result, the morning heat can be absorbed during the day
by thermal walls (for example), preventing the heat from the zone, and the walls
can release that heat at night when temperatures fall down. I can see you have big
area of this zone used for windows (";
            gdArray[5].gdText += ConvertFTS(CalcCZWinsArea(tmpZone));
            gdArray[5].gdText += " sq m) which can be a reason for heat gain/loss,
you should consider converting some of this area to thermal mass walls.";
            gdArray[5].imageALink = "texture/gd_05_A";
            gdArray[5].imageBLink = "texture/gd_05_B";


            //******** GUIDELINE 6: Sunny Spaces *******************

            gdArray[6].gdMainTitle = "Implement extended "Sunny spaces" to
maximise passive gain";
            gdArray[6].gdText = "A "sun space" is a space or room design to be
adjacent to the building's zones to collect heat and re-admit this heat to the
zones (directly or indirectly). Sun space is considered one of the most popular and
efficient passive heating system. It is also appealing for the occupants as it
serves as a semi-outdoors space, particularly in colder conditions. However, sun
spaces should be treated in summer using exterior reflective shades to block the
sun and ceiling vents to get rid of indoors heated air.";
            gdArray[6].imageALink = "texture/blank";
            gdArray[6].imageBLink = "texture/blank";


            //******** GUIDELINE 7: Building Orientation *************

            gdArray[7].gdMainTitle = "Optimize Building Orientation";
            gdArray[7].gdText = "To accommodate prevailing wind (";
            gdArray[7].gdText += CalcPrevWindDirection();
            gdArray[7].gdText += "in this case)optimise natural cross ventilation,
and to avoid overheating spaces via direct solar gain. Building orientation should
also be considered in designing passive heating in winter (like areas for sunny
spaces).";
            gdArray[7].imageALink = "texture/blank";
            gdArray[7].imageBLink = "texture/blank";


            //********* GUIDELINE 8: Materials and Colours *************

            gdArray[8].gdMainTitle = "Use suitable Flooring Materials and
colours";
            gdArray[8].gdText = "Use light coloured Low emitting materials in
summer, and high emitting materials in winter (like ceramics and marble flooring in
```

```
summer and cover with carpets in winter). Tiles or slate (even on low mass wood
floors) or a stone-faced fireplace can help store winter daytime solar gain and
summer nighttime 'coolth'";
            gdArray[8].imageALink = "texture/blank";
            gdArray[8].imageBLink = "texture/blank";


            //******** GUIDELINE 9: EFFECTIVE OPENNING AREA ************


            gdArray[9].gdMainTitle = "Accommodate "Effective Area of Opening"";
            gdArray[9].gdText = "Designing an effective window openning is
critical in achieving particular wind volume flow rate through a specific zone.";


            float Aw, Qt, nACH, Vz, Pw, DPw, Cpw=0.5, Cpl=-0.4, Ai=0, Ao=0;
            string effAreaRep;


            // Detect the zone's type of ventilation (single-sided, cross, ..)


            if((hasSouthWin == true)  && (hasNorthWin == true)){


                // Cross Ventilation Equations
                for(int g=0; g<wCounter; g++){
                        if(wZones[czID].wins[g].winOrientation.compare("north")
== 0){

                            Ai += wZones[czID].wins[g].getWinArea();
                }
                        if(wZones[czID].wins[g].winOrientation.compare("south")
== 0){

                            Ao += wZones[czID].wins[g].getWinArea();
                }
                }
                Aw = Sqrt(1/((1/(Ai*Ai))+(1/(Ao*Ao))));
                effAreaRep = "In this zone I can see that there is ventilation
from the north and south. According to the wind data, the prevailing wind is
North/North-West, so the northern window is the windward and the southern is the
leeward. This means that in this zone, the minimum effective openning area is "+
ConvertFTS(Aw)+" meters square.";
                gdArray[9].gdText += effAreaRep;
            }


            if(((hasSouthWin == true)  && (hasNorthWin != true)) || ((hasSouthWin
!= true)  && (hasNorthWin == true)) || ((hasEastWin == true)  && (hasWestWin !=
true))){
                // Single-Sided Ventilation Equations

                Vz = wZones[czID].zoneVolume; // Volume of current zone
                Pw = 0.612*(1.2*1.2);  // 1.2 is air vilocity at this area
                DPw = Pw*(Cpw-Cpl);

                Qt = 1*Vz/3600;
                Aw = Qt/(0.827*0.1*(Sqrt(DPw)));

                // Formulate guideline body
                effAreaRep = "In this zone I can see that there is ventilation
from only the ";

                if(hasSouthWin) effAreaRep += "South. ";
                if(hasNorthWin) effAreaRep += "North. ";
                if(hasEastWin) effAreaRep += "East. ";

                effAreaRep += "This means that in this zone, the minimum
effective openning area is "+ ConvertFTS(Aw)+" meters square.";
                if(hasNorthWin) effAreaRep += " However, as the depth of this
zone is big, relying only on natural single sided ventilation will not be
effective. You should also consider Stack ventilation and/or Skylights.";

                gdArray[9].gdText += effAreaRep;
```

```
            }

            // assign relevant images to accompany the text
            gdArray[9].imageALink = "texture/gd_09_A";
            gdArray[9].imageBLink = "texture/blank";

            //********* GUIDELINE 10: Promote Natural Cross ventilation *********


            gdArray[10].gdMainTitle = "Promote "Natural Cross ventilation"";
            gdArray[10].gdText = "This is the process of exhausting warm building
air and replacing it with cooler outside air. I can see that this zone is facing ";

            bool hasNSide=false, hasSSide=false, hasESide=false, hasWSide=false;

            if(wZones[czID].isNorth == true) hasNSide = true;
            if(wZones[czID].isEast == true) hasESide = true;
            if(wZones[czID].isSouth == true) hasSSide = true;
            if(wZones[czID].isWest == true) hasWSide = true;

            string pvWind = CalcPrevWindDirection();

            if((hasNSide == true) && (hasNorthWin == false)){
                  gdArray[10].gdText += pvWind;
                  gdArray[10].gdText += ", where the prevailing wind is coming
from. It would be effective if you place a window on this side (windward) ";
            }
            if(hasEastWin){
                  gdArray[10].gdText += "with the East facing window (leeward),
this can create a cross-ventilation zone that can reduce the temperature in
summer.";
            }
            if(hasSouthWin){
                  gdArray[10].gdText += "with the South facing window (leeward),
this can create a cross-ventilation zone that can reduce the temperature in
summer.";
            }

            gdArray[10].imageALink = "texture/gd_10_A";
            gdArray[10].imageBLink = "texture/blank";

            //********* GUIDELINE 11: STACK ventilation ************************

            gdArray[11].gdMainTitle = "Promote "Stack ventilation"";
            gdArray[11].gdText = "When air warms it expands, becomes less dense
than the surrounding air, and rises. This process is called convection and is the
main process by which heat moves around a room and the house. Provide vertical
distance between air inlet and outlet to produce stack ventilation (open
stairwells, two story spaces, roof monitors) when wind speeds are low. ";

            // STACK EQUATIONS HERE

            float Ti, To, Hs, As;

            Hs = 1.5;
            if(GetCurrentZone().compare("ZN01") == 0) Ti =
atof(zoneOneTemp[179][11].c_str());
            if(GetCurrentZone().compare("ZN02") == 0) Ti =
atof(zoneTwoTemp[179][11].c_str());
            if(GetCurrentZone().compare("ZN03") == 0) Ti =
atof(zoneThreeTemp[179][11].c_str());
            if(GetCurrentZone().compare("ZN04") == 0) Ti =
atof(zoneFourTemp[179][11].c_str());
            if(GetCurrentZone().compare("ZN05") == 0) Ti =
atof(zoneFiveTemp[179][11].c_str());
```

```cpp
            To = atof(outsTemp[179][11].c_str());

            //Ti = atof(TheDisplayInterface->GetCurrentTemp().c_str());
            //To = atof(TheDisplayInterface->GetCurrentOutTemp().c_str());

            Vz = wZones[czID].zoneVolume;
            Qt = 1*Vz/3600;

            Aw = Qt/(0.61*(Sqrt(((Ti-To)*Hs*9.81)/(((Ti+To)/2)+273))));

            for(int g=0; g<wCounter; g++){
                    Ai += wZones[czID].wins[g].getWinArea();
            }

            As = Sqrt(1/((1/(Aw*Aw))+(1/(Ai*Ai))));

            gdArray[11].gdText += " Implementing stack ventilation in this zone
can benefit air flow and reduce zone temperature in summer. In this zone the
effective area of the stack opening (located 1.5 meters above the windward opening)
is ";
            gdArray[11].gdText += ConvertFTS(As) +" meters square.";

            gdArray[11].imageALink = "texture/gd_11_A";
            gdArray[11].imageBLink = "texture/gd_11_B";

            //*********** GUIDELINE 12: Zone Height *****************

            gdArray[12].gdMainTitle = "Increase the "Zone Height"";
            gdArray[12].gdText = "Increasing the zone height is effective in
reducing the heat-gain effect in the zone. This is accomplished through
facilitating more efficient stack effect. The increase in zone height is also
effective in case of depending on ceiling fans, which affects the zone's occupants
by accelerating the evaporation of moisture on their skin. On hot days ceiling fans
or indoor air motion can make it seem cooler by at least 5 degrees F (2.8C).";
            gdArray[12].imageALink = "texture/gd_12_A";
            gdArray[12].imageBLink = "texture/blank";

            //********** GUIDELINE 13: Effective Insulation ***********

            gdArray[13].gdMainTitle = "Use Effective "Insulation"";
            gdArray[13].gdText = "A radiant barrier (shiny foil) will help reduce
radiated heat gain through the roof in hot climates. Extra insulation (super
insulation) might prove cost effective, and will increase occupant comfort by
keeping indoor temperatures more uniform. It is also worth investing in proper
insulation in walls, this will prevent heat gain in overheated zones in summer, and
will preserve heat indoors in cold weather.";
            gdArray[13].imageALink = "texture/blank";
            gdArray[13].imageBLink = "texture/blank";

            //********** GUIDELINE 14: Ceiling Fans ******************

            gdArray[14].gdMainTitle = "Use "Ceiling Fans" for cooling.";
            gdArray[14].gdText = "Though Ceiling fans have the potential to add to
the overall zone heat gains through its engine, Ceiling Fans have the ability to
create a wind-chill effect, which affects the zone's occupants by accelerating the
evaporation of moisture on their skin. On hot days ceiling fans or indoor air
motion can make it seem cooler by at least 5 degrees F (2.8C). This can be coupled
with Evaporative cooling to bring the indoors temperature down. Ceiling Fans can
also be used to pull the lighter warmer air out of a zone, after being heated by
different means.";
            gdArray[14].imageALink = "texture/blank";
            gdArray[14].imageBLink = "texture/blank";

            //********* GUIDELINE 15: Skylight **********************

            gdArray[15].gdMainTitle = "Use "Skylights" when possible";
            gdArray[15].gdText = "Skylights can be effective solution in many
```

```
zones, ";

                if(!hasNorthWin){
                        if(CalcPrevWindDirection().compare("north") == 0)
gdArray[15].gdText += "It can be used in this zone as a cold air inlet (example 2)
as this zone has no opennings on the north, where the predminant wind is. ";
                }else{
                        gdArray[15].gdText += "It can be used in this zone as a hot air
outlet (example 1) as this zone has an opennings on the north (where the predminant
wind is), thus help implementing stack ventilation.";
                }

                gdArray[15].gdText += "A skylight can be a good source of winter sun
to increase the zone heat gains and raise the indoors temperature towards comfort
range.";
                gdArray[15].imageALink = "texture/gd_15_A";
                gdArray[15].imageBLink = "texture/gd_15_B";

                //********* GUIDELINE 16: TREES ****************************

                gdArray[16].gdMainTitle = "Use Vegetation/planting near high direct
solar gain zones.";
                gdArray[16].gdText = "Trees can be considered a natural and effective
shading devices. The advantage of using such strategy is that trees are 'in phase
with the thermal year' – gain and lose leaves in response to temperature changes.
The solar transmission can be as low as 20% in summer, and as high as 70% in
winter. Use plant materials (ivy, bushes, trees) especially on the west to shade
the structure. Trees can also help promote natural ventilation and distort
reflected radiation (Indirect solar gain).";
                gdArray[16].imageALink = "texture/gd_16_A";
                gdArray[16].imageBLink = "texture/gd_16_B";
                gdArray[16].isForAll = false;
                gdArray[16].isForCold = false;
                gdArray[16].isForHot = true;

                //********* GUIDELINE 17: GLAZING ***************************

                gdArray[17].gdMainTitle = "Use proper effective "Windows Glazing".";
                gdArray[17].gdText = "High performance glazing on all orientations
should prove cost effective (Low-E, insulated frames) in hot clear summers or dark
overcast winters. Clear Glass reflects only 10% of the solar radiation and the most
is transmitted to the zone, while Reflective glass on the other hand can reflect up
to 50% of the solar radiation. As this zone contains a total glazing area of ";
                gdArray[17].gdText += ConvertFTS(CalcCZWinsArea(tmpZone));
                gdArray[17].gdText += " square meters -, effective glazing has the
potential to reduce the overall loads required to accommodate this area";
                gdArray[17].imageALink = "texture/gd_17_A";
                gdArray[17].imageBLink = "texture/blank";

                //********* GUIDELINE 18: LOUVERED OVERHANGS  *******************

                gdArray[18].gdMainTitle = "Promote "Shading" southern walls using
"Louvered Overhang"";
                gdArray[18].gdText = "Using Louvered Overhangs near windows in
overheated zones rather than Solid Overhang is more effective in preventing hot air
being trapped next to the building and windows, thus causing latent overheat. This
can be an effective method for resolving indirect gains.";
                gdArray[18].imageALink = "texture/gd_18_A";
                gdArray[18].imageBLink = "texture/blank";

                //********* GUIDELINE 19: MULTIPLE HORIZONTAL LOUVRES ***********

                gdArray[19].gdMainTitle = "Use multiple horizontal louvres in southern
facades";
                gdArray[19].gdText = "In some cases, using one fixed overhang for a
window could be very deep and unpractical (Fig.1). In this zone, the window(s)
require overhang of depth "+ ConvertFTS(ovhDepth)+" meters. You might wish to
```

```
consider using multiple horizontal louvers (Fig.2) to minimise the depth, but this
could affect the view. Alternatively you could use horizontal windows in southern
facades, which will reduce the window's height and the needed overhang.";
            gdArray[19].imageALink = "texture/gd_19_A";
            gdArray[19].imageBLink = "texture/gd_19_B";


            //********* GUIDELINE 20: EXTERIOR WING WALLS ***********


            gdArray[20].gdMainTitle = "Implement Exterior Wing-walls to promote
natural ventilation.";
            gdArray[20].gdText = "Wing-walls can be considered in the building
design to make best use of natural ventilation through the reflection of wind from
its prevailing direction into the interior of the building.  This is particularly
useful in overheated zones where natural cross ventilation is not possible. It can
also be useful in colder conditions, as it can act as a surface for reflected solar
radiations for the building zones. It can be coupled with using trees to prevent
the unwanted radiation in hot periods.";
            gdArray[20].imageALink = "texture/blank";
            gdArray[20].imageBLink = "texture/blank";


            //********* GUIDELINE 21: SMALL SOUTHERN WINDOWS ***********


            float cZoneArea = wZones[czID].zoneArea;
            float recWinArea = cZoneArea/2;


            gdArray[21].gdMainTitle = "Use small horizontal windows in southern
facades.";
            gdArray[21].gdText = "I can see this zone has south-facing windows.
Use horizontally rather than vertically directed windows in this zone to minimise
the direct solar gain and also minimise the required window's overhang. The
recommended total area of south-facing windows should not exceed 7% of the zone's
floor area to avoid overheating. In this particular zone, the recommended total
windows area is "+ ConvertFTS(recWinArea)+" square meters.";
            gdArray[21].imageALink = "texture/blank";
            gdArray[21].imageBLink = "texture/blank";
      }
}


//**********************************************************
// ALLOCATING APPROPRIATE GUIDELINES TO EACH ZONE
//**********************************************************

void ReportingAgent::UpdateGuidelinesSet(void){

      if(GetCurrentZone().compare("OUTS") == 0){
            activeGDSet[0] = 17;
            activeGDSet[1] = 1;
            activeGDSet[2] = 2;
            activeGDSet[3] = 5;
            activeGDSet[4] = 16;
            activeGDSet[5] = 3;
      }


      if(GetCurrentZone().compare("OUTS") != 0){

            // INITIAL CHECKS

            string cZone = GetCurrentZone();
            int czID;
            for(int i=1; i<MODELZONESNUM; i++){
                  if(wZones[i].zoneName.compare(cZone) == 0) czID = i;
            }
            float wArea = CalcCZWinsArea(cZone);

            bool hasSouthWin = false;
            bool hasNorthWin = false;
```

```
            bool hasEastWin = false;
            bool hasWestWin = false;
            bool whDeep = false;

            int wCounter = wZones[czID].winCounter;

            for(int j=0; j<wCounter; j++){
                if(wZones[czID].wins[j].winOrientation.compare("south") == 0){
                    hasSouthWin = true;
                    if(wZones[czID].wins[j].winHeight > 1.3) whDeep = true;
                }
                if(wZones[czID].wins[j].winOrientation.compare("north") == 0)
hasNorthWin = true;
                if(wZones[czID].wins[j].winOrientation.compare("east") == 0)
hasEastWin = true;
                if(wZones[czID].wins[j].winOrientation.compare("west") == 0)
hasWestWin = true;
            }

            // ******* NOW POPULATE THE GUIDELINES LIST ****

            /*
            The algorithms carry out a series of nested check, as part of
            the association data mining technique, and then assign the
            guidelines deemed relevant to the zones according to the
            gathered information and preferences.
            */

            int gdListCounter = 0;

            if(wArea > 15){
                activeGDSet[gdListCounter] = 17;
                gdListCounter++;
                activeGDSet[gdListCounter] = 5;
                gdListCounter++;
            }
            if(hasSouthWin){
                if(hasNorthWin){
                    activeGDSet[gdListCounter] = 9;
                    gdListCounter++;
                    activeGDSet[gdListCounter] = 8;
                    gdListCounter++;
                    activeGDSet[gdListCounter] = 1;
                    gdListCounter++;
                    if(whDeep){
                        activeGDSet[gdListCounter] = 19;
                        gdListCounter++;
                    }
                    activeGDSet[gdListCounter] = 18;
                    gdListCounter++;
                    activeGDSet[gdListCounter] = 4;
                    gdListCounter++;
                }else{
                    activeGDSet[gdListCounter] = 1;
                    gdListCounter++;
                    if(whDeep){
                        activeGDSet[gdListCounter] = 19;
                        gdListCounter++;
                    }
                    activeGDSet[gdListCounter] = 15;
                    gdListCounter++;
                    activeGDSet[gdListCounter] = 12;
                    gdListCounter++;
                    activeGDSet[gdListCounter] = 18;
                    gdListCounter++;
                }
                if(gdListCounter <6){
```

```
                                     activeGDSet[gdListCounter] = 16;
                                     gdListCounter++;
                             }
                     if(gdListCounter <6){
                             activeGDSet[gdListCounter] = 13;
                             gdListCounter++;
                     }
             }else{
                     if(hasNorthWin){
                             activeGDSet[gdListCounter] = 15;
                             gdListCounter++;
                             activeGDSet[gdListCounter] = 9;
                             gdListCounter++;
                             activeGDSet[gdListCounter] = 11;
                             gdListCounter++;
                     }else{
                             activeGDSet[gdListCounter] = 10;
                             gdListCounter++;
                             activeGDSet[gdListCounter] = 15;
                             gdListCounter++;
                             activeGDSet[gdListCounter] = 9;
                             gdListCounter++;
                     }
             }
             if((hasEastWin) || (hasWestWin)){
                     activeGDSet[gdListCounter] = 2;
                     gdListCounter++;
                     activeGDSet[gdListCounter] = 3;
                     gdListCounter++;
             }
             if(gdListCounter <6){
                     activeGDSet[gdListCounter] = 16;
                     gdListCounter++;
             }
             if(gdListCounter <6){
                     activeGDSet[gdListCounter] = 13;
                     gdListCounter++;
             }
     }

     // Display the relevant GUIDELINES in its window as a list
     // of six elements (buttons), and an area to display details.

     TheReportWindow-
>gdBtnA.SetText((gdArray[activeGDSet[0]].getTitle()).c_str());
     TheReportWindow-
>gdBtnB.SetText((gdArray[activeGDSet[1]].getTitle()).c_str());
     TheReportWindow-
>gdBtnC.SetText((gdArray[activeGDSet[2]].getTitle()).c_str());
     TheReportWindow-
>gdBtnD.SetText((gdArray[activeGDSet[3]].getTitle()).c_str());
     TheReportWindow-
>gdBtnE.SetText((gdArray[activeGDSet[4]].getTitle()).c_str());
     TheReportWindow-
>gdBtnF.SetText((gdArray[activeGDSet[5]].getTitle()).c_str());

     TheReportWindow-
>gdContents.SetText((gdArray[activeGDSet[0]].getText()).c_str());
     TheReportWindow-
>gdImage.SetTexture((gdArray[activeGDSet[0]].getImageALink()).c_str());
     TheReportWindow-
>gdImageB.SetTexture((gdArray[activeGDSet[0]].getImageBLink()).c_str());
}
```

Classes Definitions

```cpp
// *****************************************
// DEFINING CLASSES TO HOLD ZONE INFORMATION
// *****************************************

class WeatherZone
{
    public:

        string          zoneName;
        int                     zoneID;
        double          zoneWidth;
        double          zoneDepth;
        double          zoneHeight;
        double          zoneArea;
        double          zoneVolume;
        bool            isSouth;
        bool            isNorth;
        bool            isEast;
        bool            isWest;
        ZoneWindow      wins[20];
        int                     winCounter;
        int                     winNumber;

        void AddZoneWindow(double w, double h, string o){
            wins[winCounter].winWidth = w;
            wins[winCounter].winHeight = h;
            wins[winCounter].winOrientation = o;
            winCounter++;
        }
        int getZoneID(){
            return zoneID;
        }
};

class ZoneWindow
{
    public:

        double winWidth;
        double winHeight;
        string winOrientation;
        double getWinArea(){
            return winWidth*winHeight;
        }
};

// *****************************************
// DEFINING A CLASS TO HOLD THE GUIDELINES
// *****************************************

class Guidelines
{
    public:

        int                     gdID;
        string          gdMainTitle;
        bool            isForCold;
        bool            isForHot;
        bool            isForAll;
        string          imageALink;
        string          imageBLink;
        string          gdText;

        string getText(void){
```

```cpp
                        return gdText;
                }
                string getTitle(void){
                        return gdMainTitle;
                }
                string getImageALink(void){
                        return imageALink;
                }
                string getImageBLink(void){
                        return imageBLink;
                }
};

// *********************************************
// STRUCTURING THE DATA WAREHOUSE & ITS DATA SETS
// *********************************************

class DataMine
{
        private:

        public:

                float           zoneTemp;
                string          currentTemp;
                string          currentOutTemp;
                string          currentZone;
                int                     currentZoneID;
                string          currentDay;
                string          currentTime;
                string          currentMonth;
                float           comfortTU;
                float           comfortTL;
                string          outsTemp[365][26];
                string          zoneOneTemp[365][26];
                string          zoneTwoTemp[365][26];
                string          zoneThreeTemp[365][26];
                string          zoneFourTemp[365][26];
                string          zoneFiveTemp[365][26];
                float           averageTemps[12];
                string          DDayaZoneA[25][5];
                string          DDayaZoneB[25][5];
                string          DDayaZoneC[25][5];
                string          DDayaZoneD[25][5];
                string          DDayaZoneE[25][5];
                string          gainsConductionZoneA[365][25];
                string          gainsConductionZoneB[365][25];
                string          gainsConductionZoneC[365][25];
                string          gainsConductionZoneD[365][25];
                string          gainsConductionZoneE[365][25];
                string          gainsSAirZoneA[365][25];
                string          gainsSAirZoneB[365][25];
                string          gainsSAirZoneC[365][25];
                string          gainsSAirZoneD[365][25];
                string          gainsSAirZoneE[365][25];
                string          gainSolarZoneA[365][25];
                string          gainSolarZoneB[365][25];
                string          gainSolarZoneC[365][25];
                string          gainSolarZoneD[365][25];
                string          gainSolarZoneE[365][25];
                string          gainVentilationZoneA[365][25];
                string          gainVentilationZoneB[365][25];
                string          gainVentilationZoneC[365][25];
                string          gainVentilationZoneD[365][25];
                string          gainVentilationZoneE[365][25];
                string          gainInternalZoneA[365][25];
                string          gainInternalZoneB[365][25];
```

```
            string              gainInternalZoneC[365][25];
            string              gainInternalZoneD[365][25];
            string              gainInternalZoneE[365][25];
            string              gainIntZonalZoneA[365][25];
            string              gainIntZonalZoneB[365][25];
            string              gainIntZonalZoneC[365][25];
            string              gainIntZonalZoneD[365][25];
            string              gainIntZonalZoneE[365][25];
            string              gainTotalZoneA[365][25];
            string              gainTotalZoneB[365][25];
            string              gainTotalZoneC[365][25];
            string              gainTotalZoneD[365][25];
            string              gainTotalZoneE[365][25];
            string              relHumidity[366][25];
            string              windDirection[366][25];
            string              windSpeed[366][25];
            string              mLoadsHeating[60][115];
            string              mLoadsCooling[60][115];
            string              modelObjectsData[800][7];
            string              modelZonesData[100][4];

            string              causalitiesList[7][3];

            int                 MODELZONESNUM;
            float               tmpHi[400][50];
            float               tmpLo[400][50];
            bool                popHiCom;


            void SetCurrentZone(string zone){
                  currentZone = zone;
            }

            void SetCurrentTemp(float tmp){
                  zoneTemp = tmp;
            }
            void SetCurrentTemp(string temp){
                  currentTemp = temp;
            }
            void SetCurrentOutTemp(string temp){
                  currentOutTemp = temp;
            }
};

// *********************************************
// DEFINING THE RETRIEVING AGENTS AND ITS MEMBERS
// *********************************************

class RetrievingAgent : public DataMine
{
      private:

      public:

            string                        inputResponseZA_Cold;
            string                        inputResponseZB_Cold;
            string                        inputResponseZC_Cold;
            string                        inputResponseZD_Cold;
            string                        inputResponseZE_Cold;
            string                        inputResponseZA_Hot;
            string                        inputResponseZB_Hot;
            string                        inputResponseZC_Hot;
            string                        inputResponseZD_Hot;
            string                        inputResponseZE_Hot;

            int                           RLCounterA_Cold;
            int                           RLCounterB_Cold;
```

```cpp
            int                             RLCounterC_Cold;
            int                             RLCounterD_Cold;
            int                             RLCounterE_Cold;
            int                             RLCounterA_Hot;
            int                             RLCounterB_Hot;
            int                             RLCounterC_Hot;
            int                             RLCounterD_Hot;
            int                             RLCounterE_Hot;
            int                             moreInfoReqID;
            int                             modelObjectCounter;
            float                       responsesCold[5][6];
            float                       responsesHot[5][6];
            float                       ohdInputA;
            float                       ohdInputB;
            float                       ohdInputC;
            float                       ohdInputD;
            float                       ohdInputE;


            void ReadData(string type, int zoneNum);
            void ReadAllData(void){
                    for(int i=1; i<6; i++){
                            ReadData("DDays",i);
                    }
                    ReadData("RH",0);
                    ReadData("windDirection",0);
                    ReadData("windSpeed",0);
                    ReadZonesData(1);
                    ReadZonesData(2);
                    ReadMLoadsData();
                    for(int j=0; j<365; j++){
                            ReadGainsData(j);
                    }
                    displayTestData();
            }
            void ReadMLoadsData(void);
            void ReadTempData(string myZone);
            void ReadGainsData(int fileID);
            void ReadZonesData(int dataType);
            void MarkCZoneLevelACold(void);
            void MarkCZoneLevelBCold(void);
            void MarkCZoneLevelAHot(void);
            void MarkCZoneLevelBHot(void);
            float getZoneHeight(int zid);
            float getZoneArea(int zid);
            void displayTestData(void);
            int GetZoneWinNum(int zid);
            float getWinWidth(int zid, int wid);
            float getWinHeight(int zid, int wid);
            string getWinOrientation(int zid, int wid);
            int GetRLCounterA_Cold(void) {
                    return RLCounterA_Cold;
            }
            void IncremetnRLCounterA_Cold(void){
                    RLCounterA_Cold++;
            }
};

// **********************************************
// DEFINING THE ANALYSIS AGENTS AND ITS MEMBERS
// **********************************************

class AnalysisAgent : public RetrievingAgent
{
        private:
```

```cpp
    public:

            float                           effAreaA;
            float                           effAreaB;
            float                           effAreaC;
            float                           effAreaD;
            float                           effAreaE;
            WeatherZone                     wZones[60];

            bool                            currentlyCold;
            bool                            currentlyHot;
            bool                            currentPeriodCold;
            bool                            currentPeriodHot;

            string                          cDayComfortOutFrom;
            string                          cDayComfortOutTo;
            string                          cDayComfortOutFromB;
            string                          cDayComfortOutToB;

            void CalcComfortRange(void);
            int CalcOverheatIndex(string zone);
            string CalcOverheatPeriod(string zone);
            float CalcHiComfort(int day, int time, int month);
            float CalcLoComfort(int day, int time, int month);
            void PopulateHiComfort(void);
            void PopulateLoComfort(void);

            string ConvertFTS(float num){
                    stringstream out;
                    out << num;
                    return out.str();
            }

            string GetDayIndex(string day){
                    string
daysIndex[365]={"0101","0201","0301","0401","0501","0601","0701","0801","0901","100
1","1101","1201","1301","1401","1501","1601","1701","1801","1901","2001","2101","22
01","2301","2401","2501","2601","2701","2801","2901","3001","3101","0102","0202","0
302","0402","0502","0602","0702","0802","0902","1002","1102","1202","1302","1402","
1502","1602","1702","1802","1902","2002","2102","2202","2302","2402","2502","2602",
"2702","2802","0103","0203","0303","0403","0503","0603","0703","0803","0903","1003"
,"1103","1203","1303","1403","1503","1603","1703","1803","1903","2003","2103","2203
","2303","2403","2503","2603","2703","2803","2903","3003","3103","0104","0204","030
4","0404","0504","0604","0704","0804","0904","1004","1104","1204","1304","1404","15
04","1604","1704","1804","1904","2004","2104","2204","2304","2404","2504","2604","2
704","2804","2904","3004","0105","0205","0305","0405","0505","0605","0705","0805","
0905","1005","1105","1205","1305","1405","1505","1605","1705","1805","1905","2005",
"2105","2205","2305","2405","2505","2605","2705","2805","2905","3005","3105","0106"
,"0206","0306","0406","0506","0606","0706","0806","0906","1006","1106","1206","1306
","1406","1506","1606","1706","1806","1906","2006","2106","2206","2306","2406","250
6","2606","2706","2806","2906","3006","0107","0207","0307","0407","0507","0607","07
07","0807","0907","1007","1107","1207","1307","1407","1507","1607","1707","1807","1
907","2007","2107","2207","2307","2407","2507","2607","2707","2807","2907","3007","
3107","0108","0208","0308","0408","0508","0608","0708","0808","0908","1008","1108",
"1208","1308","1408","1508","1608","1708","1808","1908","2008","2108","2208","2308"
,"2408","2508","2608","2708","2808","2908","3008","3108","0109","0209","0309","0409
","0509","0609","0709","0809","0909","1009","1109","1209","1309","1409","1509","160
9","1709","1809","1909","2009","2109","2209","2309","2409","2509","2609","2709","28
09","2909","3009","0110","0210","0310","0410","0510","0610","0710","0810","0910","1
010","1110","1210","1310","1410","1510","1610","1710","1810","1910","2010","2110","
2210","2310","2410","2510","2610","2710","2810","2910","3010","3110","0111","0211",
"0311","0411","0511","0611","0711","0811","0911","1011","1111","1211","1311","1411"
,"1511","1611","1711","1811","1911","2011","2111","2211","2311","2411","2511","2611
","2711","2811","2911","3011","0112","0212","0312","0412","0512","0612","0712","081
2","0912","1012","1112","1212","1312","1412","1512","1612","1712","1812","1912","20
12","2112","2212","2312","2412","2512","2612","2712","2812","2912","3012","3112"};
```

```cpp
                        int index;
                        for(int i=0; i<365; i++){
                                if(daysIndex[i].compare(day) == 0) index = i;
                        }

                        stringstream out;
                        out << index;
                        return out.str();
                }
                string GetDayName(int day){
                        string
daysIndex[365]={"0101","0201","0301","0401","0501","0601","0701","0801","0901","100
1","1101","1201","1301","1401","1501","1601","1701","1801","1901","2001","2101","22
01","2301","2401","2501","2601","2701","2801","2901","3001","3101","0102","0202","0
302","0402","0502","0602","0702","0802","0902","1002","1102","1202","1302","1402","
1502","1602","1702","1802","1902","2002","2102","2202","2302","2402","2502","2602",
"2702","2802","0103","0203","0303","0403","0503","0603","0703","0803","0903","1003"
,"1103","1203","1303","1403","1503","1603","1703","1803","1903","2003","2103","2203
","2303","2403","2503","2603","2703","2803","2903","3003","3103","0104","0204","030
4","0404","0504","0604","0704","0804","0904","1004","1104","1204","1304","1404","15
04","1604","1704","1804","1904","2004","2104","2204","2304","2404","2504","2604","2
704","2804","2904","3004","0105","0205","0305","0405","0505","0605","0705","0805","
0905","1005","1105","1205","1305","1405","1505","1605","1705","1805","1905","2005",
"2105","2205","2305","2405","2505","2605","2705","2805","2905","3005","3105","0106"
,"0206","0306","0406","0506","0606","0706","0806","0906","1006","1106","1206","1306
","1406","1506","1606","1706","1806","1906","2006","2106","2206","2306","2406","250
6","2606","2706","2806","2906","3006","0107","0207","0307","0407","0507","0607","07
07","0807","0907","1007","1107","1207","1307","1407","1507","1607","1707","1807","1
907","2007","2107","2207","2307","2407","2507","2607","2707","2807","2907","3007","
3107","0108","0208","0308","0408","0508","0608","0708","0808","0908","1008","1108",
"1208","1308","1408","1508","1608","1708","1808","1908","2008","2108","2208","2308"
,"2408","2508","2608","2708","2808","2908","3008","3108","0109","0209","0309","0409
","0509","0609","0709","0809","0909","1009","1109","1209","1309","1409","1509","160
9","1709","1809","1909","2009","2109","2209","2309","2409","2509","2609","2709","28
09","2909","3009","0110","0210","0310","0410","0510","0610","0710","0810","0910","1
010","1110","1210","1310","1410","1510","1610","1710","1810","1910","2010","2110","
2210","2310","2410","2510","2610","2710","2810","2910","3010","3110","0111","0211",
"0311","0411","0511","0611","0711","0811","0911","1011","1111","1211","1311","1411"
,"1511","1611","1711","1811","1911","2011","2111","2211","2311","2411","2511","2611
","2711","2811","2911","3011","0112","0212","0312","0412","0512","0612","0712","081
2","0912","1012","1112","1212","1312","1412","1512","1612","1712","1812","1912","20
12","2112","2212","2312","2412","2512","2612","2712","2812","2912","3012","3112"};
                        return daysIndex[day];
                }
                string GetTimeIndex(string time){
                        string
timeIndex[24]={"00:00","01:00","02:00","03:00","04:00","05:00","06:00","07:00","08:
00","09:00","10:00","11:00","12:00","13:00","14:00","15:00","16:00","17:00","18:00"
,"19:00","20:00","21:00","22:00","23:00"};
                        int index;
                        for(int i=0; i<23; i++){
                                if(timeIndex[i].compare(time) == 0) index = i;
                        }

                        stringstream out;
                        out << index;
                        return out.str();
                }
                string GetTimeName(int index){
                        string
timeNames[24]={"00:00","01:00","02:00","03:00","04:00","05:00","06:00","07:00","08:
00","09:00","10:00","11:00","12:00","13:00","14:00","15:00","16:00","17:00","18:00"
,"19:00","20:00","21:00","22:00","23:00"};
                        return timeNames[index];
                }

                int GetMonthIndex(string month){
```

```
                    string
monthIndex[24]={"jan","feb","mar","apr","may","jun","jul","aug","sep","oct","nov","
dec"};
                    int index;
                    for(int i=0; i<12; i++){
                            if(monthIndex[i].compare(month) == 0) index = i;
                    }
                    return index;
            }

            float CalculateOverhangDepth(float winHeight);
            double GetAverageTemp(string month);
            double GetCurrentZoneWinArea(int zoneID);
            void SaveOverhangData(float ovh);
            float GetOverhangData(string zone);
            void SaveEffAreaData(float area);
            float GetEffAreaData(string zone);
            float ValidateWinEffectiveArea(string zone, float Ag, float Ce, float
DPw);
            float CalcCZWinsArea(string zone);
            bool CheckOrientation(int zid, string dir);
            void UpdatePossibleCausalitiesList(int zID, string dID);
            string CalcPrevWindDirection();
            string GetWindSpeed(int day, int hour);

            string GetCurrentZone(void){
                    return currentZone;
            }
            string GetCurrentTemp(void){
                    return currentTemp;
            }
            string GetCurrentOutTemp(void){
                    return currentOutTemp;
            }
};

// ***********************************************
// DEFINING THE REPORTING AGENTS AND ITS MEMBERS
// ***********************************************

class ReportingAgent : public AnalysisAgent
{
      private:
            TextElement                     temperatureText;
            int                                   ynResponse;

      public:

            Guidelines                   gdArray[30];
            int                              activeGDSet[25];

            bool                         overrideWA;
            bool                         overrideZEW;
            bool                         overrideOVH;
            bool                         overrideTM;
            bool                         niceAllDay;


            void GenerateDayReport(void);
            void GenerateMonthReport(void);
            void GenerateYearReport(void);

            string GenerateZoneBrief(string zone);

            void UpdateGuidelinesSet(void);
            int UpdateInterrogationData(void);
            void UpdateCausalitiesSet(void);
```

```cpp
            void PopulateGuidelines(void);

            int getGDSetIndex(int num){
                    return activeGDSet[num];
            }

            float CalcCZWinsArea(string zone);
            float TestCZWinsArea(string zone);

            void GDReduceNSWinArea(float area);
            void GDIncreaseSWinArea(float area);

            void ShowYesNoGUI(void);
            void ShowOKInputGUI(void);
            void HideInterrogationGUI(void);
            void HidePossibleProblems(void);
            void ShowPossibleProblems(void);
};

// **********************************************
// DEFINING THE REPORTS WINDOW AND ITS MEMBERS
// **********************************************

class ReportWindow : public GameWindow, public Singleton<ReportWindow>
{
      private:

            ReportWindow();

      public:

            ~ReportWindow();

            TextElement                     textElement;
            //
            TextElement                     gdContents;
            TextElement                     gdTitle;
            TextElement                     reasonA;
            TextElement                     reasonB;
            TextElement                     reasonC;
            TextElement                     reasonTitle;
            TextElement                     qText;
            TextElement                     qInfo;
            TextElement                     qInfoTitle;
            TextElement                     dayReportText;
            TextElement                     monthReportText;
            TextElement                     yearReportText;
            //
            EditableTextElement       editBox;
            EditableTextElement       userDataInput;
            QuadElement                     divider;
            QuadElement                     bannerLightA[4];
            QuadElement                     bannerLightB[4];
            QuadElement                     bannerLightC[4];
            QuadElement                     bannerLightD[4];
            QuadElement                     bannerSide[4];
            QuadElement                     darkDiv[4];
            QuadElement                     darkDivB[4];
            QuadElement                     vertDiv[4];
            //
            QuadElement                     gdTop[4];
            QuadElement                     gdBottom[4];
            QuadElement                     gdBigA[4];
            QuadElement                     gdBigB[4];
            QuadElement                     gdTabA[4];
            QuadElement                     gdTabB[4];
            QuadElement                     gdTabC[4];
```

```
            QuadElement                         gdTabD[4];
            QuadElement                         gdTabE[4];
            QuadElement                         gdTabF[4];
            //
            QuadElement                         moreInfoTop[4];
            QuadElement                         moreInfoBottom[4];
            QuadElement                         moreInfoBG[4];
            TextButtonElement          moreInfoClose;
            TextButtonElement          moreInfoResolve;
            TextElement                         moreInfoTitle;
            TextElement                         moreInfoWinTitle;
            TextElement                         moreInfoText;
            //
            TextButtonElement          overviewBTN;
            TextButtonElement          dailyReportBTN;
            TextButtonElement          monthlyReportBTN;
            TextButtonElement          yearlyReportBTN;
            TextButtonElement          yesBTN;
            TextButtonElement          noBTN;
            TextButtonElement          okBTN;
            TextButtonElement          whatBTN;
            TextButtonElement          moreOneBTN;
            TextButtonElement          moreTwoBTN;
            TextButtonElement          moreThreeBTN;
            TextButtonElement          moreFourBTN;
            //
            TextButtonElement          gdBtnOpen;
            //
            TextButtonElement          gdBtnA;
            TextButtonElement          gdBtnB;
            TextButtonElement          gdBtnC;
            TextButtonElement          gdBtnD;
            TextButtonElement          gdBtnE;
            TextButtonElement          gdBtnF;
            TextButtonElement          gdBtnClose;
            //
            ImageElement               gdImage;
            ImageElement               gdImageB;

        static void New(void);
        static void Open(void);

        void AddText(const char *text);

        void Activate(void);
        void Close(void);

        bool HandleKeyboardEvent(EventType eventType, long key, unsigned long
modifiers);
        void HandleElementTrigger(Element *element);

        void ShowTabOne(void);
        void ShowTabTwo(void);
        void ShowTabThree(void);
        void ShowTabFour(void);
        void ShowGDTabA(void);
        void ShowGDTabB(void);
        void ShowGDTabC(void);
        void ShowGDTabD(void);
        void ShowGDTabE(void);
        void ShowGDTabF(void);
        void ShowGuidesWindow(void);
        void HideGuidesWindow(void);
        void ShowMoreInfoWindow(void);
        void HideMoreInfoWindow(void);

        void ShowGDBTN(){gdBtnOpen.Show();}
```

```
                void HideGDBTN(){gdBtnOpen.Hide();}
                void ShowQInfo(){
                    qInfoTitle.Show();
                    qInfo.Show();
                }
                void HideQInfo(){
                    qInfoTitle.Hide();
                    qInfo.Hide();
                }
};

// **********************************************
// DEFINING THE SETTINGS WINDOW AND ITS MEMBERS
// **********************************************

class SettingWindow : public GameWindow, public Singleton<SettingWindow>
{
        private:

                TextElement                      textElement;
                EditableTextElement      editDate;
                EditableTextElement      editTime;
                EditableTextElement      editOccFrom;
                EditableTextElement      editOccTo;
                EditableTextElement      editOccNum;

                QuadElement                      divider;
                QuadElement                      bannerLightA[4];
                QuadElement                      bannerLightB[4];
                QuadElement                      bannerLightC[4];
                QuadElement                      bannerLightD[4];
                QuadElement                      bannerSide[4];
                QuadElement                      darkDiv[4];
                QuadElement                      vertDiv[4];
                TextElement                      windowTitle;
                TextElement                      occTitle;
                TextElement                      ocnumTitle;
                TextElement                      dayLabel;
                TextElement                      timeLabel;
                TextElement                      occfLabel;
                TextElement                      occtLabel;
                TextElement                      occnLabel;
                TextButtonElement        dailyReportBTN;
                TextButtonElement        monthlyReportBTN;
                TextButtonElement        yearlyReportBTN;
                TextButtonElement        saveBTN;
                TextButtonElement        noBTN;
                SettingWindow();

        public:

                ~SettingWindow();
                static void New(void);
                static void Open(void);
                void AddText(const char *text);
                void Activate(void);
                void Close(void);

                bool HandleKeyboardEvent(EventType eventType, long key, unsigned long
modifiers);
                void HandleElementTrigger(Element *element);
                void SaveSettings(void);
};
```

Appendix [I] – The Game's DVD

This section provides information about the DVD that accompanies this thesis, with information about its contents, running and controlling the environmental design game, and the minimum system requirements.

Disc Contents

The associating disc contains these folders:

- [C4_ED_Game]: The folder containing all the files related to the games, including the game's source code (packed in a .pak file), the required EXE and DLL files, the game world file, and the simulation data exported from Ecotect.

- [Ecotect-Files]: Contains the Ecotect model (model.eco), and the used LUA script.

- [Thesis_Documents]: Contains electronic copies of this research thesis (in PDF and DOCX format).

System Requirements

- This version of the game runs only under a windows operating system, particularly Windows XP, Windows Vista, and Windows 7.

- The Engine requires 1 GB of hard disk capacity

- The Engine supports graphics hardware processors for Nvidia (GeForce 6600 or higher) and AMD (Radeon X1300 or higher)[37].

- The game is designed to run under a screen resolution of [1024x764] or higher.

---

[37] Further hardware compatibility issues are explained on the C4 game engine's website: http://www.terathon.com/wiki/index.php/Graphics_Hardware_Compatibility

Running the Game

As the game reads data from external resources, it is thus recommended to copy the entire game folder [C4_ED_Game] with all its contents to a local hard drive, where it would be possible (and have sufficient credentials) to read external data.

To run the game, double click the 'C4.exe' file inside the 'C4_ED_Game' folder. The game's main menu contains options to adjust the player, graphics, audio and control settings. To load the game, select 'New Game', and then make sure 'ED_Game' file is selected in the games list.

Game Controls

Controlling the game is via the mouse and keyboard in a six-degree-of-freedom manner; where rotation on the horizontal and the vertical axes is carried out by the mouse, and the linear movement is carried out by the keyboard controls as expressed in Figure A.
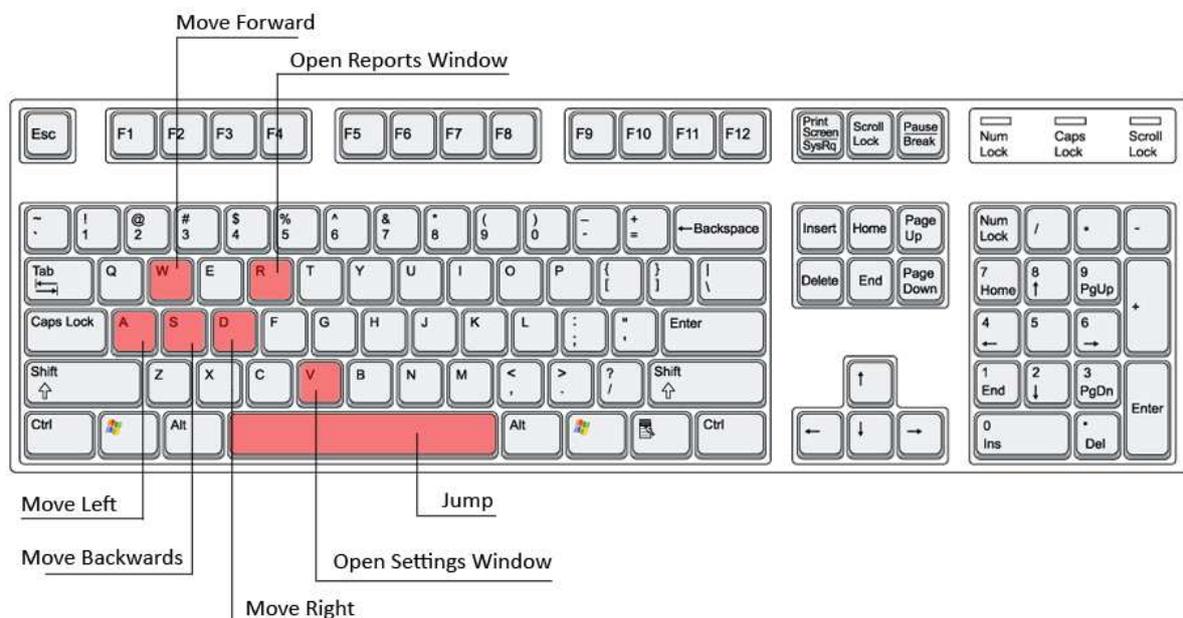

Figure A. 17: The Keyboard controls of the game.