A STUDY OF STAKEHOLDERS' EXPERIENCE OF THE ARCHITECTURAL DESIGN PROCESS TO STIMULATE AN INTERACTIVE FORM OF COMMUNICATION

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Abstract

The architectural design process involves the input of many stakeholders. Communication between them is crucial as it ensures an effective design process. The practice of architecture has been transformed by advances in hardware and software technologies, to the point where both the workflow and the design process are changing. These technologies have also impacted on the methods of representing and communicating design work. At present, traditional communication uses 2D and 3D drawings, as well as digital media such as animation, computer gaming or graphic design, which have impacted on architectural representations. While these tools are very useful, problems in communication between stakeholders are revealed. For instance, differences in architectural background knowledge and requirements lead to misunderstanding the design, confusion caused by working on inconsistent information, and use of incompatible software which causes difficulties in accessing work.

This research project attempts to identify and analyse issues relating to communication within the design process in order to improve it. The study is undertaken using a number of key questions to guide the development and progress of the research. The extent of communication via digital media in the design process, in contemporary architectural practice, is examined, along with the perceived value of digital technology by stakeholders. Architectural design work would benefit from exploiting digital media and the Internet to provide an effective form of communication for enabling a user/stakeholder-oriented involvement in the design process.

The work presented revisits the conventional methods of communication in design work, between various interested parties in any given project (stakeholders: architects, engineers, planners and clients), with a view to formulating an outline for a potential system that facilitates communication as part of a participatory design process. This study puts forward suggestions to improve communication in the design process, through a storyboard represents users' experiences in using an interactive communication system. The suggestions are being tested through a mock-up of the web application, which is then presented to participants to receive feedback. Three guiding principles inform the development of the final system: interaction (to allow fast input and feedback); accessibility (to ensure any particular design software is able to interact with the system); and inclusivity (to allow both specialists and lay people to use the system).

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Acronyms

AEC – architecture, engineering, construction

AR – augmented reality

BIM – building information modelling

CAAD – computer-aided architectural design

CAD – computer-aided design

CAVE – Cave Automatic Virtual Environment

CG – computer-generated

CGI – computer-generated imagery

CPU – central processing unit

EVPS – experience-based virtual prototyping system

HCI – human–computer interaction

HMD – head-mounted display

IA – information architecture

ID – interaction design

IDCM – interactive design and communication management

NPR – non-photorealistic

PWM – project workflow manager

SA – social architecture

UI – user interface

UX – user experience

VR – virtual reality

Preface

This research stems from my years of experience and interest in digital media in architecture. Developing from being a user to a producer of digital media has allowed me to acknowledge both improvements and problems. Having worked as new media teacher, I came to have close encounters with professionals from related areas such as graphic design, web design and computer game design. This experience has taught me that architecture is slow in keeping up with the changes of the digital revolution and not making full use of what those disciplines can offer architectural representation and communication.

Architects are key to 'pushing' the design process but so too are other important stakeholders. This research aims to increase the contribution of other key stakeholders in a design project: engineers, planners and clients all have an important contribution to making decisions. It is therefore a central aim of this research to facilitate the design communication process so that all stakeholders are enabled to 'push' and 'pull' relevant design information.

The present research has enabled me to study stakeholders who have experience in the architectural design process, as well as to identify problems and introduce suggestions for improvement. The investigation into existing technologies has allowed me to create an interactive communication system and present this in the form of a story, showing use in the design process by professionals and laypeople.

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Declaration

I declare that the research contained in this thesis, unless otherwise formally indicated within the text, is the original work of the author. The thesis has not been previously submitted to this or any other university for a degree, and does not incorporate any material already submitted for a degree.

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Introduction

Introduction

Context

Advanced technologies in hardware, software and social networking have transformed architecture, its workflow, design processes and architectural outcome. Changing technologies have also impacted the methods of presentation and communication of architecture. The ways in which architectural design is represented include using computer-aided design (CAD) and computer-generated imagery (CGI). Recent architectural representations have been revolutionised under the influence of digital media disciplines such as film, animation, computer games and graphic design. The purpose of representation in architecture is to enable those involved or interested in the process to understand and appreciate the design and its significance; it provides a certain experience of the building as an end product, even before it is built.

In recent years, besides the advancement of techniques used for design and representation, tools that facilitate communication and management in architecture and enable collaboration between the architect and stakeholders in architectural projects have been developed, such as Building Information Modelling (BIM)[1]. The BIM system has received widespread attention in the architectural, engineering and construction (AEC) industries. A combination of 2D drawing and 3D modelling, BIM enables fast and efficient communication during the design process, and provides control of costs and environmental data. While such innovative tools are useful, the different levels of architectural background and technical knowledge of the various stakeholders involved in the decision-making process, still pose a challenge. For example, stakeholders might lack technical skills or cannot afford the purchase of specific software packages and/or training, which causes architects not to employ available tools to their full potential.

[1] Building Information Modelling (BIM) is a 3D model-based process used by architecture, engineering and construction professionals, giving insight to better plan, design, construct and manage buildings and infrastructure.

On the other hand, advanced Internet technology such as cloud storage, for example Dropbox[2], Google Drive[3] and Microsoft OneDrive[4], enables the highly effective use of digital media for communication, including the sharing and storing of design information. However, architects do not always make the most of these technologies, presenting information from their point of view to clients, engineers and other stakeholders involved in the design process, rather than working closely and efficiently with all parties. Interactive media such as web applications allow working in real time, so design information can be accessed and exchanged more quickly. This can therefore be a potential tool to assist the workflow of an architectural design project.

Digital visualisation and the demonstration of design in architecture is currently developed through various software packages such as the computer-aided architectural design (CAAD) tools, AutoCAD, Revit, 3ds Max and Rhino, allowing for a generation of digital models that are more complex than previously known. This research finds that digital tools for design collaboration, which are not yet available in the same way as tools for visualisation, should not only permit architectural representations but, more importantly, should facilitate communication and collaboration, enabling users to view the design and ‘pull’ the necessary information they need for making decisions. Therefore, exploring the needs and the potential contribution of all stakeholders in the design process, such as architects, engineers, planners and clients, is crucial for developing a design communication.

In this context, the current PhD research is based on the following identified problems:

1) The large choice of software design packages and tools available, employed on the basis of affordability and convenience, leads to incompatible file formats making collaborative working more difficult.

[2] Dropbox is used to share and store digital files. It is an online data hosting service operated by Dropbox Inc.
[3] Google Drive is an online storage service from Google.
[4] Microsoft OneDrive is used to keep and share files, operated by Microsoft.

2) Some non-specialist stakeholders who are important for making design decisions, experience difficulties in learning and using software that is designed for specialists in the built environment industry.

3) Misunderstanding in communication including misinterpretation of architectural representation and conveying wrong information to stakeholders that lead to conflicts between architects and other parties.

4) Architects do not seem to engage enough with new media, such as web applications, which would enable the inclusion of larger, non-specialist communities in decision making during the design process.

Research questions and aims

Consequently, this PhD research addresses the issue of providing viable alternative or improved methods of communicating architectural design that can significantly improve the workflow in architectural design projects. The thesis responds to three main research questions:

1) To what extent do digital media affect communication in the design process in contemporary architectural practice?

2) How and to what extent do stakeholders perceive the use and value of digital technology?

3) How can architectural design work exploit digital interactive media and the Internet to provide effective communication that enables inclusiveness in a user-/stakeholder-oriented design process?

The aim of this research is to critically investigate communication in contemporary architectural practices with a view to identifying problems and finding ways forward to improve communication and collaboration in the design process.

The objectives of this investigation are to:

1) Critically review existing digital technologies used for architectural design communication in order to identify gaps in design communication and the potential for improving the design process.

2) Explore stakeholders' points of view regarding the use of digital technologies in architectural design projects including digital modelling, design communication and information sharing to identify potential contributions.

3) Identify attributes and develop strategies for a communication system for architectural design, applying interactive digital media to enable different stakeholders to collaborate more effectively and in real time.

In terms of the first objective, this study examines software and hardware to identify the potential for improvements of communicating design work between stakeholders. In particular, it explores existing digital media and applications in respect to opportunities for input from various stakeholders, regardless of their ability to use the design software of the architect or specialist.

The second objective investigates stakeholders' points of view to learn about issues and problems that occur during the design process. Advantages and disadvantages of tools currently being used in design and communication are identified in relation to improved workflow. This investigation also enables the research to acknowledge how stakeholders perceive and value digital technologies used in the built environment industry. This also includes feedback from the stakeholders on their professional backgrounds and knowledge of digital media in architectural projects.

The third objective is to support communication and collaboration in the design realm, including various forms of digital media. This investigation explores the attributes of digital media use in architecture and, in particular, media capabilities that enable users to communicate interactively. Finding qualities and strategies of digital media is important to develop the design of a communication system that encompasses: a) demonstration of design information; b) capacity to receive feedback; and c) communication between stakeholders in the same project, in one place.

In summary, this research aims to propose solutions for a communication tool that is affordable and accessible for various stakeholders, by exploring existing tools, investigating stakeholders' experiences including working cultures, problems and benefits of current uses of digital media in design communication, and developing a communication system in practice.

Methodology and outcomes

This PhD research produces conclusions through:

- literature review;
- qualitative study (survey with 20 participants including architects, engineers, planners and clients, employing semi-structured interviews and questionnaires);
- practice (designing the communication system, mock-up and storyboard); and
- end users' feedback sessions.

The outcomes of the PhD research include:

- A survey of software used in the built environment. CAAD tools are explored in respect to functions, file extensions and capabilities of connecting to BIM. This survey presents beneficial characteristics of design tools that are useful to communication and collaboration development.

- A survey with stakeholders. The work presented in this research revisits the conventional methods of communicating architectural design work between various interested parties in any given design project. Stakeholders include architects, engineers, planners and clients. The results are structured as: 1) categories such as 'benefits' and 'problems' of using digital media, and 'suggestions' for attributes; and 2) three guiding principles which inform the development of the final system. The guiding principles are 'interaction', 'accessibility' and 'inclusivity'.

Interaction allows fast input and the exchange of comments and feedback. Users can achieve real-time communication and be able to interact with architectural design information. Accessibility enables all participants to access data on the system, with no barrier of using incompatible software. Inclusivity allows both specialists and non-specialists to use the system.

- An interactive design and communication management (IDCM) system that enables effective and efficient communication between stakeholders within the design process. The IDCM system is presented through: a) visual diagrams to show relationships between all data categories and functionalities; b) a mock-up to follow up users' feedback; and c) storyboard to present the use of the system. This system aims to enable stakeholders to 'pull' information based on their requirements and access the input of various other stakeholders.

The contribution of this PhD research to the knowledge in this field is the development of a new strategy of communicating design solutions using omni-directional dimensions, without the barriers caused by using different software packages. Traditionally, architects provide and convey messages from their own perspectives. However, an effective design process should be more open to collaborative working, rather than being one where other stakeholders are passive. This thesis explores the attributes and capabilities of interactive media, specifically web applications, which architects can exploit in a creative way to contribute to communication in the design process. Therefore, this work is a valuable tool for investigating efficient communication using interactive media.

Chapter contents

The first three chapters focus on the context within which this research has been developed.

<u>Chapter 1</u> explores the human experience of architecture through architectural presentations. It studies how we perceive the built environment based on digital

representation as well as identifying issues relate to design communication and collaboration.

Chapter 2 provides a review of current digital technologies used in architecture, including software, hardware and architectural representation techniques. Characteristics of digital tools that are required for improving design communication are summarised.

Chapter 3 explores theories and models in order to identify the significant elements and relevant issues of communication in architecture. It also reviews digital media and technologies used for communication and management systems.

Chapters 4–8 focus on the process of establishing design requirements and proposes solutions to improving the workflow in the design process.

Chapter 4 presents the results of the survey conducted with stakeholders. A qualitative approach is employed, including semi-structured interviews to elicit insights and information from the stakeholders. The collected data inform the establishment of three guiding principles for the design of a new communication system.

Chapter 5 explains the process of creating the IDCM system, developing the mock-up, and how it is to be used by demonstrating through the storyboard.

Chapter 6 details the user feedback on the IDCM system and the design of the mock-up, after tests with end users. The results are discussed showing a positive outcome with minor concerns about data management.

Chapter 7 includes a discussion and reflections of the overall findings of the research, and of the IDCM system and the mock-up, including possible enhancements to the mock-up for future applications.

Chapter 8 summarises the study, regarding both theory and practice. Contributions to knowledge and limitations are underlined, together with applications of the research being identified.

Documents attached in the appendices provide supplementary information and are referred to appropriately in each chapter. The DVD included in Appendix E presents a video demonstration of the IDCM system. The mock-up is also attached in Appendix E for trial.

Key terms

To answer the research questions, a number of key terms that are relevant to the discussion of the spatial experience need to be defined, particularly in the context of digital media. These include: digital media, design communication, architectural presentation, perception and interactive media. The focus of these terms relates to the context of digital media in design communication and collaboration. This research delves into the use of such technology to assess the extent to which digital media can affect workflows in architectural practices. Perception and design communication are theoretical subjects that are used to address the research questions. Szalapaj (2004:6) states that architectural practices are concerned with the presentation and communication of information about the design, with partners and clients throughout the various stages of the process. The design is usually conceived as a response to a set of functional requirements in the form of a brief generated by the client, and further shaped by the standards, attitudes and design philosophies of the practices. Digital architecture is used to explain the design, integrated with the relevant information. CAD supports the design process and architectural presentation.

Digital media is created in a digital form used to convey the content of the design to the recipients (viewers, clients and other designers) viewing on digital electronic devices. Brinkmann (2008) gives an overview of the technical and artistic nature of the field, covering a wide range of topics from basic images to the visual cues that generate a believable experience. Theoretical investigation in the area of digital presentation is explored in the context of 3D visual illustration. This PhD proposal investigates technology, which generates the relationship between digital media and the stakeholders in parts of the visual aspects of the design and communicating information; it also evaluates how digital media has been used, as architectural presentations affect the perception of design.

Design communication is a theoretical and technical aspect of the relationship between representation and perception. Consequently, it affects human understanding. Biocca (1993:59) states that: “Communication research is about how humans create techniques and technologies to turn each other’s thoughts into each other’s experiences.” Designers are using large amounts of knowledge to communicate, and this is transforming the environment into information, which enhances our lives with emotion, motion, direction, depth and freedom (Antonelli, 2011:16). Individuals or social groups undertake the communication of design while being surrounded by a communication-rich environment.

Architectural representation is a crucial aspect of the interaction with computers, as it has been increasingly used in representation techniques. Static and dynamic representations are introduced as the principal emerging modes of architectural representation, with techniques such as 2D drawing, 3D modelling, montage, animations and digital media playing key roles. Aksamija and Iordanova (2010) state that the currently available computational tools are starting to change the design process, communication and fabrication. Tools that are especially difficult to use are ones that have the ability to represent what was formerly obtained through education and practice; these tools contain the implicit value of architectural knowledge. Information-centric methodologies for design depend on the computational representation of design processes, elements and knowledge.

Perception has been significantly influenced by technology, which has in turn influenced architectural practices concerning its contribution to the design process from the early stages to the end of a project. Visual perceptions are required to investigate the new forms of digital media. These digital tools also shape the practice of design because they eliminate design constraints by providing influential visualisation capabilities. The relationship between digital representation and perception is investigated to explain the impact of these two fields of digital architecture. Problems always happen when representational channels do not match the viewer's perceptual channels. For example, sending 2D drawings to someone who is expecting 3D images will cause difficulties in understanding. Furthermore, the theory of communication is the background for encoding and decoding information. This research tries to solve these problems with the usage of digital media to assist workflow in architectural practices, by exploring these key areas in order to answer research questions and contribute new knowledge.

Interactive digital media refers to products and services on computer-based systems, which respond to users' actions. This is presented in several forms such as electronic text, graphics, moving images, video, animation, sound and computer gaming. People are enabled to interact with media content for various purposes. The digital world has affected daily life; current technology has the power to change the methodology of representation in architecture. This research addresses the challenges of digital representation in architecture, using the notion of creating across disciplines. Interactive digital media bring ordinary architectural presentations to life and improve workflows, so users can navigate information from a web application and communicate effectively. Such media can improve the efficiency of the design process by enhancing theories of design communication. Sending messages requires decoding and encoding, and these are essential to people from different architectural backgrounds.

This work uses the above-mentioned theories and notions to improve communication and collaboration in the design process in architectural projects. Interactive digital media theory is applied to architectural representation to realise its contributions. This research examines stakeholders' experience of the design process to inspire professionals in architecture to find ways that enable stakeholders to enhance communication and collaborative design.

Chapter 1 Communication and collaboration in architectural design

Chapter 1 Communication and collaboration in architectural design

This chapter describes the background of the research and outlines communication problems between the stakeholders involved in the design process and in contemporary architectural practices. This first section explains perceptions in architecture related to design communication that are shaped by digital technologies and innovations. It focuses on imagining physical space through architectural representations, as well as discussing ‘push’ and ‘pull’ media. The second section explores how stakeholders influence the design process, including architectural representations relating to stakeholders’ perception, the architectural background knowledge of each party, and their impact on design collaboration. Consequently, the complexities of the architectural design process are ascertained to identify issues relevant to communication and collaboration that can improve workflow. This final section concludes findings of this chapter to inform this research to emphasise improving the design process.

In the design process, effective communication and collaboration can help to ensure efficiency in the workflow and use of time and resources in the architectural project. Typically, architects communicate with their clients and other stakeholders through architectural representations to demonstrate design concepts and practices. This chapter argues that advanced technologies enable an architect to draw upon stakeholders’ imaginations. For example, digital media can produce and present a realistic image that can be understood with little effort. Virtual reality (VR) allows people to become immersed in physical space together with digital space. However, discussions related to issues of poor communication – such as inaccuracy, inconsistency and misunderstanding of ideas in the design process – are still relevant. Hence, exploring communication between stakeholders through digital media is necessary. The chapter highlights factors that cause ineffective communication and collaboration, and focuses on the development of digital media in architecture.

1.1 Perception relating to communication in architecture

Architectural representation as a design communication method and its development are influenced by changes in the use of computing in architecture and it is important to explore whether the change affects people's abilities to perceive architecture. This section reviews theories relevant to human perception. The design project is demonstrated based on many theories relating to perception, such as psychophysics and the sensory.

The perceptions of architects and other people involved in the design of a building have a significant interrelationship, as architecture is principally designed for human living. Architecture is experienced via both the perception of physical space and representations. The experience thus involves perception; the perception of a project is based on the physical reality of the building and on the illustrations used in the design and planning of the architecture.

Kronhagel (2010:325) describes classic early–mid nineteenth century psychophysics. His evidence substantiates the idea that sensation can be quantitatively defined; he also states that the connection between the stimulus intensity and sensation is an area of natural science. Murray (1993:115–186) discusses classic views in psychophysics by Weber, Fechner, Brentano and many others who explain the separation between people's sensory responses and the physical intensity of what stimulates those responses. How loud something sounds, how heavy a load is, or how bright lighting appears, is the result of triggering stimuli, which can be measured. Triggers include noises, such as acoustic pressure, the load as mass or weight and (for the light source) the luminance density. These aspects of the environment can be measured. In addition, Murray (1993) discusses how sensation or sensory responses to stimuli can be measured. Kronhagel (2010) indicates that in science, human perception is measured through all the senses. However, in architecture, there is no physical measure for the design process, as the concepts are understood through individual perceptions. Therefore, the perception of architecture is based on human experience and an understanding of the surroundings of the built environment. Architectural design develops through the experimentation by an architect and other stakeholders in the design project. Understanding architecture through architectural representation such as drawings, three-dimensional (3D) models and images, depends on an individual's thoughts and experience of objects, events and situations.

According to Guildford (cited in Agostinho, 2005), humans are visual and analogical, using visual reasoning to predict outcomes in ways comparable to mathematical modelling. Objects have surfaces, contours, dimensions and distance. These become variables in the individual's vision and correlate to reality. Understanding and interpreting the images necessarily involves a perception of the surrounding visual context. The interpretation is important for the viewer to perceive size, form and other dimensions. Arnheim (1969) associates perception, that is, the images of thought, with the establishment of cognition. Thus, there is a link between thought and perception. Good perception means that individuals can read the exact quality of the object perceived (Agostinho, 2005:83–90), which is important for a viewer when looking at the visual representation of a building. A high-quality rendering represents realistic images, resulting in the viewer's enhanced understanding. In the 1990s, computer-aided design (CAD) was introduced and became the basis for the technical representation of architecture. According to Agostinho (2005), if the architect wants to draw a client's vision of their project using CAD, this effects communication because of the link between perception and experience. Stakeholders' understanding is likely to differ as they have different levels of architectural background knowledge. Therefore, both 2D and 3D modelling need to be used. Employing 2D drawing enables the architect to show areas, functions and circulations. In addition, employing 3D modelling enables viewers to understand further, because 3D modelling is more immersive. From the third international conference on *Digital Human Modelling*, Duffy (2009) notes that the focus of human–computer interaction (HCI) is perceptual and has motor aspects. Advanced equipment and displays such as computers, mobile phones, interactive toys and touch screens, draw a rich picture of real-world perceptual motor experiences (Duffy, 2009:247–256). Such digital technologies have been developed to assist an almost effortless understanding of architecture.

Architectural representations are understood differently depending on stakeholders' experiences and existing digital media, enabling the stakeholders to be both passive and active audiences. An individual's thoughts and reactions are unique and affect perception (Kaptelinin and Nardi, 2006). Agostinho (2005) notes that visual concepts need constancy for people to easily manipulate them in their minds. Bertol (1997:20) explains that people experience both natural and manufactured worlds in terms of 3D space because their perception is filtered. In addition, he states that people do not only create images, which generate the identity of the perception of a specific architectural space, but that they also bring subjective backgrounds with cultural and psychological impressions, to create objective images of the world. This means that people interpret architecture based on their real experiences, even though they have no previous experience of that particular design space. Architectural representations, such as images and animations, are created from an architect's experience; thus, they envision the building in context before it is built. While computer graphics can generate realistic experiences, 3D rendering in architecture works like a photograph to provide a hint at reality. As a result, people can perceive and understand the image or rendering, even when they do not have architectural knowledge, which reduces the chance of misperception. In addition, the technology of interaction with 3D models allows access to various aspects of the digital model and provides an alternative architectural representation. This allows viewers to visualise the model in a VR context. It is particularly useful on projects where various stakeholders can access and view the model to explore the design. They can simulate themselves walking or flying through the design space, which helps with their cognition of the space. VR is beneficial to stakeholders as it allows users to walk through, select views and find information by themselves. It also helps an architect to avoid presenting unnecessary information to stakeholders. Although VR is useful, the architect is not able to control which specific views the stakeholders look at when exploring a virtual model, thus important information that the architect wants to convey can be missed.

CAD is used to draw both 2D drawings and 3D models. 2D drawings use symbols to represent materials, doors, windows, walls, staircases and other aspects of the building, so the viewer needs sufficient architectural knowledge to understand the drawing. This knowledge can be gained and enhanced by experience or training. In addition, a development of CAD entails a Building Information Modelling (BIM) system that includes design, representation and collaboration tools (see more details in Chapter 2). Although these tools provide revolutions in architecture, they often require the learning of a new technological skill, which is not time-or cost-effective.

Technology has transformed architectural representation in recent times. Design concepts and architectural information can be demonstrated through various techniques. Although these representations have benefited from new technologies, their production is time-consuming, expensive and requires high technical skill. Hence, many aspects of the methods of representation should be considered, in order to incorporate them as part of an efficient design communication for a wide range of stakeholders. This PhD research values the individual's perspective and is essential to understanding stakeholders' views and experiences of the design process.

1.1.1 Experiencing digital media in architecture

As a designer, the architect has to produce information through various analogue and digital media before the design is transformed into a building. This research explores the principal factors in that transformation, which allow the conception of the original image to be maintained. Often, stakeholders are disappointed when they compare the actual project to a digital presentation; these can sometimes distort reality and generate a perspective that leads to higher expectations than can be realised. The accuracy and appropriateness of digital effects are significant. Hence, this section explores theories that are essential to the accuracy of peoples' perceptions. Rasmussen (1959) describes the ancient Greeks' understanding of human perception. They found there is a relationship between simple mathematical proportions and the physical world. Scale and proportion play very important roles in architecture (Rasmussen, 1959:105). In addition, Bertol (1997:20) states that the relativism of the physical world is not a new interpretation. To illustrate perception, one needs only to consider aspects of the landscape. For example, a mountain appears completely different depending on the viewpoint: whether an individual flies over it, drives around it, or climbs up it, will greatly affect how they perceive the mountain. Similar observations can be made about the manufactured world and architecture in particular. For example, a series of different perceptions arise when people drive and walk around a building or if they are inside it. Pfautz (2002) investigates 'depth cues theory' by examining linear perspective and stereo image presentation. His work shows that inconsistent objects prevent accurate perception. The relative size of an object is presented inconsistently at different depths through parameters such as size, shape, and distance; the issue of human perception being essential to architecture causes an impact on communication, which is a consideration of this research. The aim of this work is to suggest that all those involved in the consultation and/or design of a building should be able to interact with the design model and experience the effects of any alterations that are likely to be introduced at the design stage. Spiller (1998:47) states the following:

> "The overriding architectural concerns will not be water tightness, gravity or human scale, but what it means to be 'human' or 'real'. Will virtual reality be of use in designing 'real' buildings? In human terms, the travellers in cyberspace can choose to adapt any desired representation."

Consistent presentation of matter is important; Pfautz (2002) and Bertol (1997) agree that inconsistency in architectural representation impacts stakeholders' perceptions, especially those with non-architectural backgrounds. Spiller (1998) points out that VR would facilitate building design by helping viewers to immerse the space as it provides consistent images. This PhD research agrees that VR can aid consistent perception, as people can simulate themselves in the real world. In contrast, the perspective views provided through 3D images, may give stakeholders an inaccurate perception of what the real building will look like, if the images are distorted or inconsistently presented. At this point, one is entitled to ask the validity and usefulness of using CAD-based drawings to explain design schemes to stakeholders, especially those who have no specialist technical knowledge.

At present, CAD tools allow architects to design and redesign, achieving the best results for real buildings fit for a location. They need to have a vision of the building in mind, including how it will look, what the atmosphere of each room will be and how the space affects users' perceptions. The discrepancy between objective dimensionality and perceptual dimensionality is achieved by representing 2D images with 3D rendering. These 2D representations are mixed with 3D renderings so that viewers can perceive a solid building. Working with images in the imagination requires theories of scale and proportion to avoid false perspectives. Without physical measurement, sensory experiences help people to perceive the space by comparing the proportion of one object to another in the same context. In some cases, architects produce misleading 3D models because they want to impress clients. Such modelling can reveal a whole city to present buildings within their environment. The accurate shape, size and height of the buildings need to be compared to the surrounding environment. Previously, physical models have been a useful tool used to create mock-ups of physical space in order to visualise the design of a building. Today, these are often replaced by digital 3D modelling, which allow architects to conveniently change the designs, share and move models, and archive works. In addition, software and applications allow stakeholders to explore 3D models by rotating as well as zooming in and out. These features play an important role in design communication. There are valid reasons for the need to enhance experience in architecture through digital media and by transforming physical space into a digital environment.

1.1.2 Digital representation: 'push' and 'pull' media

This section discusses matters relating to architectural presentation that has been transformed by the introduction of various digital technologies. 'Push' and 'pull' media are discussed to explore the concept of using interactive media in communication and collaboration in the design process.

This research explores types of digital representations that have been employed and the reasons for their use in transforming representation methods. Liu (2005) states that architects focus on designing new concepts of space; this has been developed through computer and the advent of the Internet. Technology enables architects to understand how people view the digital world and virtual space, to find the implications of new concepts of space and to bring those findings to the physical world. Therefore, elements of design have been transformed because of technology. For example, the materials used in the structure and façade of buildings have been changed from stone to concrete and from wood to brick. Moreover, cladding systems have been designed for covering buildings. The architect needs to represent these ideas effectively. Traditionally, hand drawings were used to demonstrate material types, but now CAD can represent all the design elements in 2D and 3D. Architectural representations have been transformed from pen drawings and colour paintings into CAD outputs. This research agrees that digital technologies enable design and demonstration, whereas the architectural representations themselves remain unchanged in contemporary architectural practices.

Digital modelling is a design tool that is already well established in contemporary design practice, including architecture. The research in this area explores the importance of digital modelling on the practice of design and its impact on the design process. According to Khaminwa (2011), modelling tools are no longer peripheral add-ons to architectural practice; they have become integral to it. However, problems are still encountered in the use of such modelling techniques. These problems include the accuracy of the digital model, the time needed to produce it, and its effectiveness as a communication tool. The part of this research that addresses these issues would help redefine the practice of design and enable its communication to be more effective, especially for those individuals with non-architectural backgrounds.

Architecture has experienced a cultural change in the communication of design in recent years. The development of computer technology, the increase in computer memory and processing power, and the improvements in display resolution, software and mobile applications allow for the helpful communication of information about architectural projects. The most notable forms of architectural illustration employ computer-generated image (CGI) representations. The rapid innovation of the Internet continuously transforms styles of presentation. Although digital media are widely used in architecture, there seems to be a significant gap in knowledge about digital presentation and alternative methods of communication. Architectural practice now faces a challenge in shifting communication methods to encompass the development of new technologies.

Architectural representations are currently portrayed from architects' points of view. The architects 'push' information that they want to show to certain stakeholders. This is normal practice, as a designer knows the best design project strategies to present. However, this method might mean that objectives are missed if other stakeholders are looking for different information.

'Push' media, such as television, are used to deliver messages to potential customers, whether they want to receive them or not. Bosma (2006:31) explains that push media is a term that describes the audience's position in a new media environment. The audience is not involved in adding content, navigation, reaction or acceptance of an invitation to participate. Wong (2013) explains that advertisements are produced to push the message to customers. According to Luppa (1998), web design incorporates push media. Advertisers want to put forward the latest information by making adverts 'jump out' of the computer screen. Another characteristic of traditional push media for advertising is that they represent *'one-way systemic communication'.* The advertiser talks and people listen but cannot talk back (Luppa, 1998:25–27). Likewise, push media in the present research context refers to information which is presented by the architect. In this case, viewers are not involved in navigating, adding content or taking any actions.

In contrast to this, *'pull'* media offer a different way of communicating, as stated by Wong (2013):

> "Instead of pushing, you need to learn to pull. It takes more effort, time, and creativity, but in social media, this is the only way to genuinely build your community of online supporters and retain them."

Wong is of the opinion that pull media require effort from users, with the result that they are able to engage more fully with the media. There are opportunities in the use of this kind of media for it influences users, especially in social communication. Pull media can build active distance communities, meaning people will get responses from each other more quickly than before. This research investigates the capability of employing pull media, such as interactive digital media, to contribute to design communication. Furthermore, the research explores users' working practices being grounded in the design of communication systems and interactive digital media. The design process is concerned with communication between the stakeholders and their active participation. Architects, engineers, clients and other stakeholders have varied background knowledge and different levels of technical skills, and therefore perceive media in different ways. According to Corby (2006), pull media entirely depend on the engagement of participants. Bosma (2006) states that the media designer must know the user's activities. The best way to capture the user's attention is to show hospitality, 'creating a playful and interesting space of engagement' (Bosma, 2006:32). To design interactive media, a friendly user interface is beneficial for various users.

Wong (2013) suggests the first strategy of pull media is that the designer must know the products and users. Second, the designer must determine users' requirements. Thirdly, the product should become the main source of information for users in the industry. She suggests that people should stop pushing and start pulling. Designers need to think about what users care about, put forward the work and make sure that the message is received. Manivich (1995) (cited in Lopes, 2009:32–35) talks about interactive media in which people are asked to participate. The user clicks on an image on the computer screen to link to another, thus following the designer's plan. Hagel and Brown (2008) find that pull models seek the opportunity for creativity, allowing participants to deal with immediate needs. To exploit the opportunities created by uncertainty, pull media help people to respond to unanticipated events and attempt to increase available resources, while simultaneously supporting people to find the information that is most relevant to them. For example, YouTube lets people search for and choose their favourite programmes. This evidence shows a trend in creating platforms that assist people to choose appropriate resources when they require them (Hagel and Brown, 2008:93–110).

Therefore, a step forward for communication during the design process would be to encourage stakeholders to 'push' and 'pull' information, while new media can enable people to interactively communicate and the information can be distributed quickly, widely and efficiently. Hence, exploring stakeholders' experiences of the design process and architectural representation is important in identifying their problems and the required improvements. The lessons learnt from reviewing some of the literature on pull media can be applied to this research by determining the design information that stakeholders want to see. It is important for architects to acknowledge stakeholders' backgrounds, in order to push appropriate information to them. In accordance with Wong (2013), this is an opportunity to integrate the idea of pull media into architectural representation. The architect should consider using digital media for the presentation of designs to stakeholders, updating information based on interactive media concepts to create a collaborative product.

The use of social media promotes interactive collaboration, as Internet technologies enable users to connect to each other, creating communities and activities. It is a fascinating idea to identify significant attributes of social media that can be applied to communication practices in the design process. Push and pull actions in the design process are operated through digital media by exploiting certain activities on social media such as real-time communication, viewing and sharing information. Therefore, attributes of social media applications will be explored, together with software use in the built environment, in order to bridge their characteristics to facilitating the design process and solving problems in communication.

This research emphasises the analysis of communication problems within the design process. One issue raised from architects pushing information, is that this method creates misunderstanding between stakeholders, as they look for different design information based on their individual project role. Architects try to demonstrate the best design to convince clients and gain uniqueness in their plans. They attempt to escape from the use of grids or a metric system, although they do need advice from engineers at the beginning of design. If it is too late to seek advice, this will affect the design process as the work will need to be redesigned; it takes more time to deal with problems that have already happened rather than to prevent problems. An insufficient design process affects the life cycle of an architectural project, as any problems encountered during the construction process always increase time and cost. A construction is a customised procedure. To enable an effective project, avoiding errors in the construction process is aided by efficient communication and collaboration in the design process.

To improve communication and collaboration in the design process, the attributes of pull media influences this research to investigate how current digital media are used by stakeholders in architectural project. Advanced digital technologies aid design and expression, for professionals and laypersons alike, to better understand architecture. However, certain issues are revealed such as misunderstandings in communication and using incompatible software between stakeholders. Moreover, cost and technological skill can be barriers to using advanced technologies. Therefore, by considering stakeholders' experience, the architect can understand problems and find solutions in the complex design process. The circumstances of communication in the design process need to be reviewed so the relevant issues are elucidated and possible contributions uncovered.

Digital media in architecture are used to communicate the design, however, stakeholders are the audiences and the efficient communication would not be achieved if the receivers without understanding their desire, requirements, and experiences in the design process. The next section investigates stakeholders in the design process in order to find the critical issues in communication and collaboration.

1.2 Collaborative design and stakeholders' impact

In the design process, the collaboration between stakeholders is established at the beginning of the project or when architects seek advice from other parties. The architect is briefed by the client(s) or their representative, and then begins the project in collaboration with other stakeholders. Architects employ architectural representations to demonstrate design concepts and information. The operation of the project requires communication between people. There are messages to convey such as the ideas and information between architects, clients and other professionals, depending on the type of project. The medium for communication is based on many factors such as the kind of project, stakeholders' experience and the technological skills of those involved. Unsuccessful projects can be the result of poor collaboration between stakeholders. Consequently, understanding other stakeholders' points of view to prevent miscommunication and facilitates workflow.

> "Creativity, it has been said, consists largely of re-arranging what we know in order to find out what we do not know." (Kneller,1965)

According to Kneller, the design process is a loop of decision making which generates efficient design and collaboration; it is a heuristic process. Each stakeholder should focus on the common goals of the project. Problems inevitably occur during the design. Stakeholders have to share their information and participate as much as possible in order to effectively overcome any issues that occur.

1.2.1 Architectural representation and the audiences

This section explores the audience's background, which relates to their appreciation of the architectural representation. The audiences in this research are the stakeholders, who directly receive a message from the architect. The design process is a collaboration that includes an architectural representation using 2D or 3D modelling. However, the design would be more effective if all stakeholders' ideas were considered at the beginning of the project. The modern architect should respect and value the stakeholders' relevant preferences and leave the design process open ended while encouraging stakeholders to provide their input (Binnekamp *et al*., 2006).

Factors that affect perception of the design and impact on collaboration are explored. Different levels of background knowledge cause misunderstandings in the interpretation of design. Therefore, it is important to ascertain the impact of key stakeholders.

> "While we inhabit an overwhelmingly built-up world, most work of architecture receives only a passing glance. Few people understand buildings as architects do, as complex spatial and structural creations, described in technical drawing, and explained in dense theoretical and historical language." (Schwarzer, 2004:13)

Schwarzer indicates that not everyone understands architecture like the architect does; understanding depends on the background of the individual. Tan and Rahaman (2009) also state that end users' backgrounds, senses of perception, technical knowledge, learning ability, interests and ideologies, largely influence how they will react to and interpret the content communicated in design media. In addition, Bertol (1997) explains that the visual perception of architecture, as with any other visual perception, is a 2D image mapped on the surface of the retina. The medium of architecture (which is in 3D space) is often emphasised. Zevi (1975) (cited in Bertol,1997) describes architecture as the 'art of space'. Architectural creations are 3D solid artefacts generated by the moulding of space. Nevertheless, the final perception is a sequence of 2D images, which generates the identity of a certain architectural space. In the act of seeing, the viewer not only creates an objective image of the external world, but also brings their own subjective background with its associated cultural and psychological impressions (Bertol,1997:20). This research is informed by visual perception and allows for the investigation of the stakeholders' experiences and how architectural representations affect communication and collaboration in the design process.

Nowadays, architects choose communication methods depending on their availability and affordability. Part of this research revisits existing communication tools, to identify gaps in communication and collaboration in the design process. The traditional communication system commonly employed with stakeholders consists of using digital tools. The architect sets up a design package produced by CAD and then sends the work by email or post. The architect and stakeholders then set up a meeting, either face-to-face, by telephone or video conference. Face-to-face meetings seem more efficient than isolated communications, as all parties have physical access to the same documents. These meetings also allow for better communication and updating of information. Internet-based technologies are necessary for isolated communication. Working globally saves money and time. Thus, emerging communication tools that use the Internet are important. There are many communication systems in this context, such as blogs, which can be used to post and update information. Normally, an architect creates a blog for stakeholders so they can view the work and provide feedback. In addition, mobile applications enable users to interactively view and mark the work where it needs clarification. Most applications enable the client to view the work, but the design process also involves the input of other significant stakeholders. Therefore, this research considers other key stakeholders including planners, engineers as well as the client, who contribute to the collaborative design process so that the workflow is more efficient.

Generally, the architect and engineer work together to communicate with the client and finish the project with the permission of local authorities. Each stakeholder has a different experience in architecture, which leads them to interpret the representation provided by the architect. The engineer has an experience similar to that of the architect, as they both use CAD as a tool in their workflow. Therefore, they can read the symbols on the drawings as well as understand the 3D rendering in various views. However, the artistic sense of the building may differ; engineers are more concerned with effective building based on technical structures.

Some planners come from architectural backgrounds, but some do not. The planners with no architectural experience may have been trained to read architectural representations. This difference in training and experience will mean the planners have a diverse perception of an architectural representation, depending on their backgrounds. Planners are more concerned with the consistency of an architectural representation because of the project's relationship to the context. Planners respond to environmental issues that affect people in the area, including neighbours. There are three types of planning: design, highway and land use. Councils may employ specialists for each of these three types of planning while others employ one planner to carry out all three.

The client has the most effect on the architectural representation because the architect wants to impress the client and sell their work to them. This means the architect needs to investigate what is most likely to persuade the client. Clients may not have architectural background knowledge so the representation needs to be clear and honest to avoid misunderstandings. The architect's representation affects the trust between himself and the client.

Stakeholder involvement in the design process varies; their individual roles and perception of architecture significantly affects design communication. This section highlights important stakeholders involved in the design process. Although many researchers focus only on clients, this research underlines the important contributions of each stakeholder in the design decision making.

1.2.2 Analysis of the impact of key stakeholders on design collaboration

Although different stakeholders deal with different aspects of the architectural project, some of their interests are interrelated. The architect is the person who leads the design process and essentially deals with each of the stakeholders. A number of other people are involved in the design process, depending on the complexity of the project:

The **architect** is key to interpreting the client's vision, developing the ideas and transforming them into reality. Architects should have the skills to creatively design, coordinate, manage and articulate the internal decision-making mechanisms for the overall building project. The architect also advises the stakeholders and needs to manage the design process throughout the lifecycle of the project. At the beginning of the design process, the architect will send the design package to the stakeholders. Since the architect chooses the type of digital media and the method to deliver the design, the other stakeholders simply accept what the architect provides. It is the responsibility of the architect to know what the stakeholders want and to understand their capability of viewing and understanding the work.

The **engineer** is concerned with structure. Engineers support the architect to develop the design proposal. They are responsible for the structural, mechanical and electrical aspects of the project. They will plan for all these parts to fit into the design from the architect. However, it is not always possible to do what the architect wants; collaboration is needed to ensure that there is agreement. It is important that the engineer is involved early in the design process to prevent design mistakes. The engineer works in a similar way to the architect because they both use CAD, although each specialist uses specific types of software to deliver their part of the project. Incompatible software causes issues in file accessibility. These issues are critical barriers to effective collaboration.

The **planner** needs to approve the proposal of the project, which also includes building control and listed building issues. Planners are concerned with the building within its environment. Planning permission is the responsibility of the local authority's planning department, which is concerned with the visual appearance of the proposed work, its height, and size, and whether it is sympathetic to its location. For example, the planning department takes into account whether the building will overlook neighbouring properties, its distance from the road and whether it conforms to the local plan (RIBA, 2008). The planner usually adopts commonly-used commercial software programs, such as Microsoft Office, Adobe, ACDsee and Internet web browsers. The architect needs to send files in a format that is accessible to the planner. Sometimes, the architect will have to reduce the quality of the work in order to compress the files to be sent via the Internet, as sending via email has file size limitations.

The **client** is a person or group of people who generate a project. Client expectations include effective design, functionalities, time and cost. The architect has to pursue the client and help them to understand and accept the design decisions. Although there are many decisions that are made by the client, these are still subject to a number of regulations (managed by the planner) and the construction approach and materials to be used (managed by the engineer). The client has the power to place the project on hold, to stop it entirely, or to operate according to economic, personal or political situations. Although much of the power is on the client's side, other stakeholders can have more influence at different stages of the design process; effective design should involve an exchange of knowledge.

Other stakeholders who are not mentioned here, such as suppliers and legal professionals, are also involved in the design process. Nevertheless, this research considers the above-mentioned individuals as being key stakeholders and those most concerned with using digital media for efficient collaboration.

1.2.3 Identifying complex communication in the design process

This section explores factors that obstruct communication when it involves several parties. Each has their responsibility for different aspects in the process, which can lead to misunderstandings. The problems identified in this section lead to research into guidelines for resolutions to these communication issues.

The design process is a combination of recognition, analysis, expression of problems and presentation of solutions. Research has shown that communication between clients and architects can be a major cause of project failure (Brown, 2001). Clients are pivotal to the design process, as they own the project. The architect–client relationship has been investigated to identify potential problems and understand the management of complex communication (Norouzi *et al*., 2015:635–642). Shen (2011) and Yu *et al*. (2005) propose the following reasons for communication difficulties between designers and their clients: namely, when the client's viewpoint is not considered fully and there is not enough communication between stakeholders. As a result, design requirements are not sufficiently managed because the needs of the clients often change. When an architect makes changes, there is a lack of feedback from clients. In addition, Bogers *et al*. (2008) finds communications between architects and clients unclear, inconsistent or incomplete. Chen (2009) points out that clients work with many parties and nobody insists design knowledge transfer is accurate and on time. The RIBA roundtable report entitled *Relationships of architects and client*s (RIBA, 2013), found that architects sometimes lack the people skills needed for working collaboratively. If architects can gain these skills, it would reboot their reputation and achieve a more favourable result. Better listening and understanding greatly improves collaboration and project outcomes. There is often a conflicting interrelationship between architects and clients, as they stick to their own perspectives. However, Lawson (2014) believes this issue can be creatively solved through correct interaction and enhanced communication. Scholars clearly agree that the engagement of stakeholders and open communication will help all parties to understand each other. In conclusion, a good relationship between architect and client can improve the design project.

The collaborations between architects and engineers are also important. Pressman (2014) identifies barriers and complexities in this relationship. It is argued that engineers should be involved in the early stage of the design process, as they highlight structural issues to the architects, who may otherwise shun symmetric forms of buildings and function (Charleson and Wood, 2014). Capra (2009) researches collaboration between AEC, revealing inconsistency in design information, such as missing column positions when comparing architectural and engineer drawings. Problems in collaboration may occur due to a misunderstanding in verbal communication. Each party interprets words according to their different experiences. Technologies enable professionals to conduct video conference meetings, which facilitate isolated engineers and architects in working together, influencing the speed of decision making. This mitigates gaps in collaboration and helps build relationships to clarify misunderstandings (Deutsch, 2014).

A further level of complexity in communication arises from the planner's point of view, as they may have a different architectural and technical background knowledge to those of the architect and engineer. Bartholomew and Locher (2008) present in *Erasing Boundaries*[5] that there a lack of literacy exists: "Few people in our culture are attentive to the impacts architecture and planning have on the built environment." Campbell (2014) points out that people are unlikely take an interest in the work of town planners, but we should pay attention to this to achieve a better society. Kasprisin (2016) reported that planners are asked to give comments, whereas a lack of comments from stakeholders shows a gap in collaboration. This research finds that efficient design also requires interaction from planners, however, it is rare to find a study of a complex communication and collaboration between an architect and a planner. Hence, an understanding of the issues of communication between architects and planners should be also investigated in this research.

In the literature, communication in the design process between AEC and clients is investigated extensively (Dodds,2014; Leon, 2015; Norouzi *et al*., 2014;

[5] Erasing Boundaries represents the work of a consortium of educators, students and community partners from the disciplines of architecture, landscape architecture and urban planning interested in furthering the pedagogy of service-learning, and community engaged teaching/research. The project is a sub-grantee of a federal grant to the Pennsylvania and New York Campus Compact Consortium project.

Øyen, 2007). However, the complexity of collaboration within the planner domain is not frequently discussed in the literature. The current research argues that planners are as important as clients and engineers. Without planner approval, buildings will not be constructed, so planners play a very important role in the design process.

Each stakeholder contributes to different stages of the design process to come up with efficient design decisions and results. Stakeholders must take the time to communicate their implicit knowledge in a factual and clear manner, rather than leaving their knowledge locked in the perceptual domain (Smulders *et al*., 2008). Therefore, an investigation of wider-ranging stakeholders would provide an understanding of communication in the design process, with the aim to avoid unnecessary distractions, delays and regulatory barriers. In addition, evidence shows that the complexity of communication is a result of stakeholders' hierarchy in the design process. This can be addressed by using BIM, which enables each professional to take control in their area of competency while achieving common project goals. Therefore, skills, communication and competencies should be made transparent to improve teamwork culture (RIBA, 2013).

The design activity itself consists of the recognition, analysis and expression of possible connections between identified problems, as well as potential tangible solutions, while simultaneously taking into account the external dynamics of organisational, political or economic origins. Design is a complex cognitive activity that begins with an abstract idea that is translated into a plan, which then becomes a concrete spatial construction: the building (Dursun, 2007). This process is not a linear problem-solving procedure (Perugia, 2015). The design process should be operated by stakeholders who are able to consider multi-dimensions, as technologies nowadays allow omni-dimensional communication.

There are many causes of complex communication and collaboration in the design process, such as culture of working, architectural representation, politics and budget. This research mainly considers architectural representations and relevant issues, for example, styles, methods, uses and impacts. Investigation of how these affect architectural design enables the research to examine how to reduce the risk of confused perception and poor communication, which can lead to delays and excessive costs.

Various advanced software programs enable architects to produce, communicate and collaborate their designs, making them more powerful. Work can be edited and multiple copies produced through 2D and 3D software, which is convenient and creates realistic perspectives with actual environments. This enables people to achieve a realistic perception and understanding of the design. In addition, BIM systems support the lifecycle of an architectural project, including design, cost-effectiveness, energy saving and facility management. Although advanced software offers various options for communication, it leads to a variety of architectural representations that use non-standard presentation forms; as a result, incompatible file formats may be used. As Beetz and colleagues (2004) point out, no standard formats exist to facilitate and exchange information seamlessly and completely. Stakeholders in the design process have different background experiences. Moreover, technological challenges increase as a result of different types of software, cost, responsibility and levels of teamwork (Randy, 2011, cited in Leon, 2015:32). As such, professionals in the built environment are required to use different software packages; it takes time to learn new software, an updated version or a plug-in, as some of these are incompatible.

Stakeholders in the design process are central to study, their background and experience directly affect communication and collaboration. Issues are addressed in this section stimulate this research to find the ways to improve.

1.3 Conclusion

This chapter has explored people’s experiences of architecture, including understanding through digital representation and involving stakeholders who can shape the vision. These two main subjects influence communication and collaboration in the design process. Visual perception is important since people usually have the benefit of an imagination. Additionally, interactive media engage communication, perception and collaboration. Architectural representation is important because it is used to demonstrate the design and elicit people's perceptions. Although digital technologies facilitate design methods, presentations and communications, this research interrogates professionals in the built environment industry about using all available capabilities that technology can offer. This background motivates the research objective of finding problems in design communication, in order to propose solutions and avoid faulty perceptions in architecture. Therefore, an investigation of stakeholders' experiences is needed to understand their architectural background knowledge and respond to their requirements, identifying ways to improve communication in the design process.

'Push' and 'pull' media inspires the development of communication in the design process, which typically involves stakeholders such as architects, engineers, planners and clients. Currently in architectural practices, design information is presented from an architect's point of view. Issues may occur during the design process as stakeholders come from a range of different architectural backgrounds so that miscommunications and conflicts in collaboration may occur. This research finds potential for digital interactive media that enables stakeholders to engage, find, input and 'pull' information that they require.

Effective collaboration is important to improving the design process. Stakeholders are involved in different stages of the process with different perspectives on the architectural design. Some conflicts can be seen when people attempt to 'push' their information from their own views. Key stakeholders (architects, engineers, planners and clients) who have the most effect on the design process are identified. They have different impacts on different design stages; collaborative design allows each role to express their expertise and influence the process. Hence, knowing each party's requirements will promote effective communication; to convey the right information to the right perceivers. Investigation of this research ascertains issues that are obstacles to the flow of collaboration.

Based on the literature review, the following issues can be identified as challenges to both communication and collaboration in the design process, that the present research is interested in exploring:

- misunderstandings in design communication;
- slow involvement in the design process;
- lack of feedback;
- using incompatible software;
- lack of technological skill; and
- inconsistent information in design.

Some obscure information may be elicited from actual stakeholders involved in the design process. This needs to be recovered and highlighted to improve communication and collaboration in the design process, in order to establish an effective design project.

This chapter has explored stakeholders' perceptions of architectural representation. Section one explores the experience of architecture through architectural representations and finds that push and pull media can influence digital media in design and communication. Section two considers collaboration between stakeholders and their impacts on the design process. Finally, the chapter has revealed issues in design and communication which motivates this research to find ways to make improvements.

The next chapter explores digital technologies including, software, hardware and digital media in architecture in terms of the uses and effects on the design process and stakeholders.

Chapter 2 Review of digital design tools

Chapter 2 Review of digital design tools

This chapter reviews the digital tools currently in use in the architectural design process and analyses their attributes and effects on workflow. The first section reviews current digital technologies used in the built environment. This review enables the researcher to identify the gaps in the workflow, given the multitude of tools, and that opens up the opportunity for providing efficient communication regardless of the software being used. File extensions and architectural presentations are identified in order to eliminate incompatible software and misunderstandings that might occur through the design process, making it easier to find the appropriate architectural presentation to suit each stakeholder. The second section explores types of digital media as presentation and communication tools in the design process. The effects of digital media on stakeholders' perception and workflow are described. The third section presents and discusses the use of digital media in design communication as a working tool. The last section summaries the findings of this chapter.

Digital media is used for producing architectural presentations. It has developed with various computer technologies, including software and hardware. Software develops links between 2D drawing and 3D modelling within a program, which enables architects to edit work in real-time. Hardware is developed to support a system such as render farm[6] used for real-time rendering. Continuous improvements contribute to communication in the design process. For example, there are advances in presentation software and the increasing improvements in hardware (such as more memory[7] and better graphics support[8]). Although software has been developed to assist the architects in improving their architectural representations, there still seems to be problems in design communication. Two main issues were found from the literature review, as well as the researcher's experience. The first was related to misunderstandings of the design, including the architectural presentation, and the architectural information, such as presentations with a large number of drawings, which

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[6] A group of networked computer support rendering images, used widely in animation film production.

[7] Computer memory is any physical device used for storing information such as Random Access Memory (RAM)

[8] Computer cardboard support graphic display on computer screen.

could be inconsistent. The second was the accessibility of the design packages, typically due to the use of incompatible software.

This research argues that, due to misunderstandings in the design process and stakeholders’ difficulties in accessing the technology, digital media has not achieved its full potential. Using digital media for the architectural presentation to stakeholders equally incorporates technical, theoretical, and artistic approaches. The architecture industry sustains investigations into new methodologies for virtual presentations, including design information such as concepts, materials, forms, and costs. The advent of Building Information Modelling (BIM) has generated a need to understand the means of fabrication, as well as the methods of assembly and collaboration between AEC professionals. Many architectural practices are interested in this new development and they hope BIM can improve their workflow and efficiency. However, only a limited number of practices are able to use BIM due to high costs in purchasing the software and advanced level of computer skills required.

2.1 Review of current digital technology used in the built environment

This section explores the uses and the attributes of the existing software available and often used in the design process in organisations. This research reviews the relevant software for architects, engineers, and planners based on literature reviews and the researcher’s field work experience. Ultimately, this section recommends types of a digital representation for design communication. Although this research does not create software, studying the attributes of software enables the identification of important attributes to help improve workflows in the built environment.

The report entitled *State-of-the-art Digital Tools Used by Architects for Solar Design* (Dubois *et al*., 2010) presents a review of currently used tools, including 56 software programs. The programs are classified into three types: CAAD, visualisation, and simulation tools. The report analyses software for building projects with a focus on the early design phase (EDP). The report reviews many

CAAD tools, such as ArchiCAD, AutoCAD, Maya, Google SketchUp, and 3ds Max. Visualisation tools, such as Artlantis, LightWave, Mental Ray, and Vray, are also reviewed (more details in Section 2.2.1). In addition, the report examines simulation tools, such as Ecotect, bSol, Green Building Studio, and DesignBuilder. The programs most commonly used in architectural practices are the CAAD tools. Visualisation and simulation tools are typically used exclusively by technical specialists. A comprehensive study within the EU project InPro (Pfitzner *et al*., 2007) investigated software review use in the early design phase process. The survey reveals the most important missing functionality in architecture software packages is collaboration (followed by visualisation). The research also reveals other important features that are missing, such as import and export functionalities, .dwg and .dxf[9] are the most common data formats used to transfer 2D to 3D drawing files. The PhD research's investigation concerns general workflows in the design process in architectural projects. Therefore, this research focuses on exploring CAAD tools in order to establish their contribution to design communication.

2.1.1 Computer-aided architectural design (CAAD) tools

This section explores CAAD software programs that have been widely employed by architectural practices. In addition, they have potentials use in architectural design. Exploring software enables this thesis to analyse its effect on workflow in the design process. In addition, it helps to identify capabilities of software that can create digital media to improve communication design. This selection of software is described as follows:

ArchiCAD is software which can be used in 2D and 3D projects. It is user-friendly, and first-time designers and architects can easily maximise the software's potential. ArchiCAD is mostly used by architect. However, it easy exchanges BIM model with engineer. Although it has almost all the features the other applications have, it is not the most popular software package. The lack of popularity may be due to the results of its poorer rendering quality in comparison to other software and its inability to be used with other programs,

[9] AutoCAD by Autodesk can work and save as many file formats, e.g., .dfx, .dwg, can be used across other software.

such as 3ds Max (from Autodesk). Moreover, ArchiCAD requires specific technical knowledge to be able to get the most out of the final 3D rendering.

AutoCAD is the most popular software, and architectural practitioners around the world have used this software for many years. It offers both 2D and 3D representation. However, people are likely to use the 2D feature to draw 2D plans, sections and elevations then export the files to 3D software in order to build a 3D model. This is achieved through 3ds Max, Google SketchUp, or Maya. Although AutoCAD is mostly used widely across the built environment, it does not directly support BIM because this software is not compatible with .ifc[10]. Therefore, it is not used as a BIM application.

Blender is used in some architectural practices. Besides its modelling features, it also has an integrated game engine. Blender has similar features to Maya and 3ds Max. Blender may not be popular because it is difficult for users who have little experience using 3D modelling. It is a free, open source 3D software product.

CINEMA 4D is a 3D modelling, animation, and rendering application developed by MAXON Computer GmbH in Germany. It has the most common features found in most 3D modelling applications. This software is good for rendering. It is used for primary 3D modelling, and architects and designers use this software to achieve a realistic result.

Maya is software for 3D animation, modelling, simulations, and rendering; it also offers a creative toolset for artists. These tools provide a starting point to create vision in modelling, animation, and lighting. Maya has modelling features like other software. The benefit of using Maya is in creating particles and freeform. It allows the user to manage the form of an object efficiently. It is widely used among architects and designers to create 3D animations and effects.

MicroStation has been popularised as software because of its stability. MicroStation is used in a complex design project for architects and engineers.

[10] IFC files based on the following International Alliance for Interoperability (IAI) data exchange standards. For example Revit provides .ifc import.

The software can be used to design, visualise, analysis and document buildings. The 3D modelling feature can perform real-world solar opening and shading analysis. This is an advantage of this software.

Navisworks is software used in engineering practices. The engineer can get a model from the architect and import it to this software in order to work on the structure. This software enables architects, engineers, and construction professionals to review integrated models and data with stakeholders to provide efficient control over project outcomes (Autodesk, 2014). It also offers links between 2D drawings and 3Dmodels which reflect changes as they are made. If a plan is changed, other plans, sections, elevations, and models will be automatically changed. This feature is good for collaborative design.

Revit Architecture is software built for BIM, which is the key for sustainable design. The changes that users make are automatically coordinated throughout the project. This software has significant potential in the built environment because it offers BIM attributes.

Rhinoceros 3D (Rhino) is a NURBS-based modelling tool, and it includes annotation tools. Rhino also supports dimensions in the perspective view. In addition, analysis tools that evaluate the area, volume, and calculation are available. Rhino is commonly used by industrial designers, architects, automotive designers, and graphic designers (Dubois *et al*., 2010). There are a number of Rhino add-ons and plug-ins. The new version, Grasshopper, is a graphical algorithm editor integrated with Rhino's 3D modelling tools. Grasshopper does not require programming or scripting knowledge, but still allows designers to build form generators (Grasshopper, 2015). Unlike other programs, it does not require programming or scripting knowledge. Therefore it is easy to use to explore a project's design.

SketchUp is very user-friendly software. SketchUp has obvious icons to represent commands and functions. This software is of value for students to generate 3D designs in a short time and for users who are just beginning their architectural careers. SketchUp is open source software for basic modelling, but the user will need to buy a premium version to gain advance features, such as Vray, a rendering plug-in for 3D software to make a photo-realistic 3D model.

The benefit of Google's SketchUp is that it can be used with other 2D and 3D software packages. Users can export or import files to SketchUp to modify models.

Unity is used widely in the video game industry. It offers flexibility and powerful development platforms for creating multi-platform 3D and 2D games and interactive experiences (Unity.com, 2015). Some architectural practices use it for visualisation and creating virtual worlds. Unity can import models from Autodesk Revit, ArchiCAD, 3dsMax, and SketchUp Pro; it can create an engaging interactive walkthrough. Although not widely used by architects, this software has the potential for producing specific working platforms because it enables users to create content for multiple platforms, such as websites or applications, which architects can employ in a specific project.

Vectorworks is a line of industry-specific CAD and BIM solutions that allows designers to advance their ideas from concept through completion, from preliminary design to photo-realistic renderings and construction drawings. It is able to import objects that have file extensions from 3D Warehouse and TurboSquid.com, such as .3ds and .skp. This means it works with other open source programs.

3ds Max is a program for making 3D animation, models, games, and images. It offers modelling capabilities and plug-ins for architectural designs. It is also widely used by video game developers, TV commercial studios, and architectural practices. This software has been used in most architectural practices for many years. This may be due to the fact that it is from Autodesk, so it is compatible with AutoCAD. It can also conveniently share 3D objects with other open source programs.

The reviews of these tools are used to identify the aspects that influence the research's focus. Features such as functions, import/export, and BIM contribute to the creation of the web application. The researcher acknowledges actual users who use each of the software packages mentioned above. The functions of each software program enable the researcher to know what jobs the users perform and how they use the software. Import/ export categories are useful for this project as they help indicate the type of extension and how the files work co-ordinately. This allows for the proposal of a system that can sufficiently support sharing and accessing information using these files. BIM is significant as it affects the workflow. Therefore, it is useful to identify the software programs that work directly with BIM (or have no connection with BIM).

Table 2.1: **The attributes of different software packages**

Software	**Functions**	**Actual Users**	**Import/Export**	**BIM**
ArchiCAD	2D/3D drawing	Architect/ Engineer	.dxf, .dwg	Capable
AutoCAD	2D/3D drawing, 3D rendering	Architect/ Engineer/ Planner/ Technician Drawer	.pdf, .jpg, .wmf, .dgn, .sat, .eps	Approaching BIM's definition but not used as BIM
Blender	3D drawing and rendering, 3D animation, 3D video game	Architect/ Designer/ Game Designer	.tga, .jpg, .png, .OpenEXR, .dpx, .Cineon, .Radiance, .3ds, .dxf, .obj, .LightWave	Incapable
CINEMA 4D	Animation tools	Architect/ Designer	.psd, .tif, Targa, .jpg, QuickTime, .avi	Incapable

Table 2.1: **The attributes of different software packages (Continued)**

Software	Functions	Actual Users	Import/ Export	BIM
Maya	3D modelling/ 3D rendering Animation	TV/video game industries/ Architect/ Designer	.igs, .dxf, .obj, .wrl2, .mov, .rtg	Incapable
MicroStation	2D/3D design and drafting, 3D rendering	Architect/ Engineer/ Town Planner/ Contractor/ GIS professional	.dgn, .dwg, .dxf, .skp, .kml, .3dm, .pdf, .ifc, .rvt, .rft, .rfa, .jpg, .bmp, .avi, .vrml	Capable
Navisworks	2D/3D drawing, 3D rendering	Engineer	.nwd, .nwf, .nwc, .dwg, dxf, .3ds, .prj, .fbx, .dgn	Capable
Revit	2D/3D drawing, 3D rendering	Architect/ Drafter/ Engineer	.dwg, .dxf, .dng, .sat, .skp, .adsk, .jpg, .png, .tif, .bmp,.xls, .avi	Capable

Table 2.1: **The attributes of different software packages (Continued)**

Software	Functions	Actual Users	Import/ Export	BIM
Rhinoceros 3D	3D modelling 3D rendering	Architect/ Designer/	.dwg,.dxf,.dgn, .fbx,.3ds,.obj, .RIM,. wrl, .skp, .bmp, .tga, .ai, .sat	Incapable
SketchUp	2D/3D drawing, Plug-in rendering	Architect	.jpg, .png, .tif, .tga, .pdf, .eps, .kmz, .fbx, .obj, .mov, .3ds, .dwg, .dxf	Incapable
Unity	3D drawing and rendering, 3D animation 3D video game	Architect/ Designer/ Game Designer	.fbx, .obj, .Max, .Blend, .3ds, .dxf	Incapable
Vectorwork	2D/3D drawing, 3D rendering	Architect/ Designer/ Landscape Architect/ Engineer	.dxf, .dwg, .3ds, .skp, .kml, .jpg, .tif, .psd, .eps, .sat	Capable

Table 2.1: **The attributes of different software packages (Continued)**

Software	Functions	Actual Users	Import/ Export	BIM
3ds Max	3D modelling 3D rendering, animation	Architect/ Designer/ Game Designer/ Engineer	.dwg, .dxf, .obj, .fbx, .wrl	Incapable

Table 2.1 shows the different attributes of various CAAD tools. These tools were reviewed in order to identify their functions, users, file formats and BIM coordination. In addition, Table 2.2 demonstrates significant attributes are identified which help to find the best characteristic for the envisaged design communication tool. Although all these attributes are significant, this research focuses on the advantages that are relevant to the experience of the stakeholders who will be using the software.

Table 2.2: **Advantages and disadvantages of software used in CAAD**

Software	Advantages	Disadvantage
ArchiCAD	*- 2D drawing and 3D model can be coordinated.*	*- Limited in free form creation.* *- High cost.*
AutoCAD	*- Document can be printed in various forms for multiple users.* *- Quick produce and copy.*	*- Training* *- Expensive start up cost.*
Blender	*- Realistic outcome.* *- Free software.*	*- Running on large amount of hardware.*
CINEMA4D	*- Rendering realistic 3D images and animation.*	*- Running on large amount of hardware.*
MAYA	*- 3D modelling.*	*- Training required.* *- Running on huge amount of hardware.*
MicroStation	*- Real-time result of changing parametric design.*	*- Training.* *- High cost.*
Navisworks	*- Transferring 3D to 2D.* *- 3D coordination.* *- Clash detective*	*- Training.* *- Inaccurate rendering image.*
Revit	*- BIM feature- cost, data management.* *-Widely use in the market.*	*- High Cost.* *- Running on huge amount of hardware.*
Rhinoceros 3D	*- 3D rendering.* *- VR feature.*	*- Training.* *- Running on huge amount of hardware.*
SketchUp	*- Easy to use,* *- Friendly user interface.*	*- Limited in design.*
Unity	*- Easy and quick import process* *- Providing user experience and web-based application.*	*- Training* *- High spec of computer required.*
Vectorwork	*- Open-source.*	*- Not suit for large project.*
3dsMax	*- Realistic visualisation.* *- Comprehensive use for 3D modelling.*	*- Running on huge amount of hardware.* *-Training.*

Table 2.3: **List of common files types**

File Extensions	Architectural Presentation Types
.dwg / .dxf	*Drawing*
.3ds / .obj / .fbx / .skp	*3D Modelling*
.jpg/ .tif / .png	*Image*
.mov / .avi / .QuickTime	*Animation/ video*

Table 2.3 shows the file types that can be imported/ exported from each software program listed in Table 2.1. This result informs the design of the communication tool, which should consider all of these types in order to design architectural presentations using compatible file extension. Table 2.4 shows the architectural presentation tools users can utilise for communication. The data in Table 2.5 leads to identifying tools that different users require to perform their jobs. The researcher has identified which architectural presentation tools fit each stakeholder.

Table 2.4: **Functions required for producing architectural presentations**

Functions required	*2D drawing*
	3D rendering
	3D animation
	Video

Table 2.5: **Architectural presentation types required by various stakeholders**

2D/3D Drawing *3D Modelling/ rendering* *3D Animation* Architect	Engineer *2D/3D Drawing* *3D Rendering* *3D Animation*
Users	Planner *2D/3D Drawing* *3D Rendering*

Table 2.5 shows the architectural presentations categorised by the stakeholders' requirements. These results enable the researcher to consider types of architectural presentation in terms of the users' requirements and show which software is able to produce these tools for each user.

This research is concerned with developing the communication in the design process and addresses architectural representation and presentation with CAAD tools. This section reviews software used in the built environment for design, presentation and collaboration. However, reviewing CAAD tools is limited because they are not compatible with a number of features (like web browsers). Only Unity offers a web-based feature. Therefore, game and graphic design software was considered since it can create a virtual environment as well as an interface design. This finding would be beneficial features for alternative architectural communication methods.

The software reviews above give examples of the tools architects and engineers use. This PhD research acknowledges the attributes of the main tools used by architects and presents them in table 2.1. This software review empowered the researcher to analyse issues related to communication such as technological skill required, appropriate types of architectural presentation and nature of each stakeholder in the design process that may affect communication. In addition, studying the software features and interfaces enable the researcher to find a tool for digital media creation. The application design encompasses the use of icons; the interface should be familiar to most stakeholders and allow them to efficiently navigate the work. However, sharing information is still a problem, as there are different types of software programs used across practices. Stakeholders using different types of software may not be able to open files with the programs they have. Therefore, this research investigates using digital media to share files and design information

2.1.2 Hardware tools

This section explores the hardware used in design communication and focuses on visually-augmented reality rather than basic tools such as CPU memory, smartphones, tablets, interactive displays or drafting tools, interactive pens, and microphone. A review of hardware technology allows for the design of a communication system that supports the latest technologies. Mobile devices, such as smartphones and tablets, have changed people's lives. Information or entertainment is readily available. People can conveniently access data. Touch screens have improved along with Human-Computer Interaction (HCI).

Users' abilities are normally determined by their generation, which affects how they use devices; technological skill and the design of application also influence device usage. In architecture, users' technological skill and knowledge are required, too. Therefore, the notion of a user-centred design is central to this PhD research. Exploration of the existing tools in order to design an application for users is required. In addition, preparing the design of the communication system to support new technology as it develops in the future is significant. This enables the system to make best use of technologies as they occur.

Various devices have emerged to encourage people to experience virtual reality in architecture. The head-mounted display (HMD) is a device worn on the head that allows a user to see a computer-generated image (CGI). In architecture, it is used for augmented reality (AR) and is used for showing a virtual place. For example, the HoloLens offers an AR experience similar to that of the Oculus for

VR. The HoloLens is made for special components that together enable holographic computing. These components allow the user to move freely and interact with the hologram (Microsoft.com, 2015). Google Cardboard, which is made from card board supports the VR experience and it a smartphone for the experience. Although Google Cardboard is not as powerful as Oculus or HoloLens, it is cheaper. The development of these devices helps users to experience immersive architecture. Hardware has a developing relationship with software.

These hardware technologies have not been used widely in architectural practices. Nevertheless, they might be ubiquitously employed in the future when they become affordable and convenient. Hardware technologies are crucial for this research because identifying trends in technology helps to develop the communication design and features which can work with suitable devices and plan for future peripheral devices.

2.2 The effect of digital media on workflow

This section provides a brief history of the use of digital media in architectural practices. Presentations convey the original idea from the start to the end of the project. Ways of presentation have been transformed, from hand sketching to CAAD. Today, technology affects the architectural framework and showing ideas in three dimensions has become the norm. Porter (1997:119) states: "without doubt the representation method which has superseded all previous forms of visualisation in the last decade or so is that which involves the computer and its equipment". It has been also proposed that future architecture would be at its best once it was influenced by digital media developments and that the new phase of architecture would be related to using digital media as a tool (Lang and Waal, 2009). Technology in architecture has a long history and continues as computers evolve (Kalay, 2015).

The current time is an exciting period for digital modelling in design. New digital tools are used for design and physical building making. Carpo (2013:9-16) states that the future digital tools will also rapidly change digital fabrication which is not only media development as young architect thought they would be involved in web design. Architecture has defined reality in terms of media and simulation. Media introduce the appearance of what and how we see. The computer technology used to produce visual imagery has reached a stage at which refined virtual reality can be created using CGI. There are many tools to demonstrate project designs. Among these is the use of static 3D images as a generic form of presentation; these images can become part of a dynamic 3D animation or film that helps viewers understand the design better. Each medium communicates the production and technique of the proposed architectural project, as well as the impact on the perception of the viewer. According to Kalay (2004), communication is also sharing information between humans and computers.

> "It is relatively easy to communicate information from computers to humans, who process the intelligence needed to understand textual, numerical, graphical, and auditory messages. But it is frustratingly difficult to communicate information from humans to computer, who lack the intelligence and the ability to interpret messages, unless they are coded in a completely unambiguous manner."

Kalay states that humans' perception of the world around them is almost entirely dependent on sight, with at least one third of our brain relying on vision (Kalay, 2004:161). At present, 3D visualisation is more than a mere device to communicate complex projects. 3D modelling is not only a tool for presentation, but it is also created for designers to study and represent their complex designs. Whyte (2002:33) shows a similar approach using VR when she states,

> "I thought to myself if I can construct this in Virtual Reality (VR), I can then convey what it is about truth. There were all kinds of misconception and nobody really understood the project in its entirety, it was far too complex to be simply modelled and drawn in a conventional manner. It didn't really lend itself to just typical model making, typical representation, so I started making VR as a representation device."

The above reference was written to support digital media as a medium to present an important framework. The framework was for a collaborative 3D model for architectural design practices. The model was not only used for design presentation, but was also used to communicate often complex conceptual and technical designs to a wide audience, including designers and stakeholders. Although digital media has developed to offer a nearly realistic environment, making a realistic digital model needs expertise and advanced equipment. To represent design thinking through digital media from a commercial point of view, most architects rely on realistic digital modelling and an impressive presentation. However, the renowned architect and specialist in the field of architectural visualisation, Stikeman (2007) (cited in Carlson, 2007) argues even without a photo-realistic image people can understand ideas and designs. Visual memory does not depend on perfect representation. The numbers of question are raised in this PhD research such as how practices use digital media, how they communicate with stakeholders, and whether they work effectively with basic architectural communication.

The advent of BIM has resulted in an interest in the workflow. Nassar (2010) describes that this essential change involves using digital modelling software to more effectively design, build, and manage projects. BIM includes project cost and time estimates. These functions become more accurate by supporting the sharing of project information and collaborating with the contractor and the design team. This is an innovative tool widely use at present in architecture and recently, the UK government aims architectural practices fully used BIM for the government's projects (HMGovernment, 2011)[11]. The research agrees that BIM will be used more widely in the future. However, the barriers would still prevent its usage in a small architectural practice in terms of the high cost and technical training required.

The presentation tools used in architecture for 3D rendering which show images, photomontages, and animations push the information from the designer to the viewers. Producing a 3D model for communication creates a sketch of the designer's idea, and the designer always establishes the level of complexity. Different levels of complexity can be attained depending on the needs of the designer. The architect as a designer constructs and navigates the architectural presentation for other stakeholders. The architect at this stage focuses on

[11] A report for the Government Construction Client Group Building Information Modelling (BIM) Working Party Strategy Paper. At:http://www.bimtaskgroup.org/wpcontent/uploads/2012/03/BIS-BIM-strategy-Report.pdf

pushing design information to stakeholders who are the viewers. This push approach has limitations, which is why this research explores the design information required from the other stakeholders' points of view and not only the architect's point of view.

People communicate throughout the design process. Digital media is used for designers, clients, and other professionals to convey ideas and share information, depending on the project. The digital tool for communication needs to be chosen according to many factors, including the kind of project and the stakeholders' experiences and technological skill. Designers will benefit from choosing the right type of digital media to appeal to their audiences, such as when an architect uses a model for negotiation between stakeholders in design development (Rua *et al*., 2011). Computer-aided design (CAD) allows for 3D modelling and it is broadly used among architects as a medium to convey architectural concepts (Chen, 2004; Ambrose, 2012). There is a need for design firms to use digital communication with stakeholders. Knowing the nature of the audience is significant in designing the appropriate type of media for enhanced communication.

To express the design concept, architects might include digital specialists who use their skills across digital media disciplines. Demonstrating the idea requires the right tools to communicate. Computer-based tools help architects find a creative medium for new presentation concepts. Examples of these new types of presentations are 3D modelling and virtual world simulations on web pages. Lang and Waal (2009) state that the development of new media affects architectural presentation. The use of interactive media in architecture first began in early 2000. Interactive design was seen as increasingly important to design. The traditional ontological difference between architecture and interaction design where the prospect of frames for our lives that central to the concern for both disciplines is being challenged. Computing embraces an interactive system and the Internet, both are examples of interactive technology integral to peoples' physical life (Wiberg, 2015). Further evidence that supports the growing importance of interactive media in architectural design comes from the Media Art and Architecture Group's publication on the 17th International Symposium on Electronic Art entitled *Art Electronic Future Lab Media Art and*

Architecture Group, which says that media and technology are major tools architectural practices can use to develop global cities. The architecture group consists of artists and researchers who focus on emerging interfaces and communication methods and take into consideration the environment of the context. The architecture group includes in its research that interactive media is important for communication in fields such as computer science, design, communication, media sciences, and sociology. The research group concentrates on the situation and the function of media in architecture and examines the employment of interactive media (International Symposium Electronic Art, 2011). The uses of interactive media have been investigated by other researchers. Although there are documents showing that interactive media significantly improve design communication, the research investigates a particular user in community and does not include the varieties of stakeholders in general design project communication. Considering other key stakeholders is therefore a defining feature of this PhD research.

In architecture, employing digital media as a tool to convey conceptual design is the norm. This research investigates efficient tools that impact communication. The previous section explores tools to produce work in the design process and the kind of media generated by these software packages for design communication. This section explains the effects of digital media on workflow by describing the architectural presentation tools currently used in the workflow, such as 3D image rendering, photomontage, and animation.

Figure 2.1: **3D image rendering of a Holiday Inn project, Manchester (Meechao, 2009)**

3D image rendering (see Figure 2.1) illustrates the designer's idea and design concept. The content is provided from the designer's perspective, which tries to demonstrate the project before it has been built to impress the viewer. Therefore, the visualiser works to make the image as realistic as possible because the image is very important in motivating clients. In this case, the visualiser as an artist produces a work of art. CGI conveys ideas about a design from the architect to the stakeholders, particularly the client (and sometimes the designer), to better understand the design (Gueorguiev and Georgieva, 2008:340-345). Therefore, the digital tools used in design communication need to be used for both external and internal communication.

Although 3D image rendering is an efficient tool for communication (Chen, 2004), misunderstandings among stakeholders happen. For example, architects want to show a good overview of the completed building structure as well as provide an exciting camera angle. However, Cuff (1992:74) states that clients do not prefer the 'bird's eye view' because it shows solar cells or the roof. Clients prefer a normal, street-level view. The preferences of stakeholders should be considered in order to employ digital media to suit with stakeholders' backgrounds and experiences as this medium affects stakeholders' perception and understanding.

Figure 2.2: **Photomontage: Project CRD, London (Ghobrial, 2009)**

Figure 2.2 shows an example of a photomontage. It is a useful tool that illustrates the real environment by composing a photograph of the environmental context with the 3D rendering using the same perspective. This method creates a realistic photograph and the image is livelier than a pure 3D image rendering because the trees, cars, and people in the frame are real. Bates-Brkljac (2012:185-204) states photorealism is a comprehensive representation as close as possible to how something will be seen in reality. This research finds that the photorealistic image is important in enabling stakeholders to understand the design and envision overall image.

The above representation methods are good for planners and clients. However, other stakeholders, such as engineers, may not want to see realistic images because they focus on the structure of the building. Non-photorealistic (NPR) images are used to represent design even quicker than providing realistic presentation style and at the same time NPR images are used to convey design purposes at many levels and meanings (Gueorguiev and Georgieva, 2008:340-345). Therefore, this research argues that using the methods like the photorealistic image and 3D image rendering are not necessarily the most suitable for all stakeholders.

Animation is an attractive tool for advertising an architectural project. It can capture viewer attention because it is produced from a special technique which selects the views that the designer wants to show (Brito, 2008:270). An example of animation is shown in Figure 2.3.

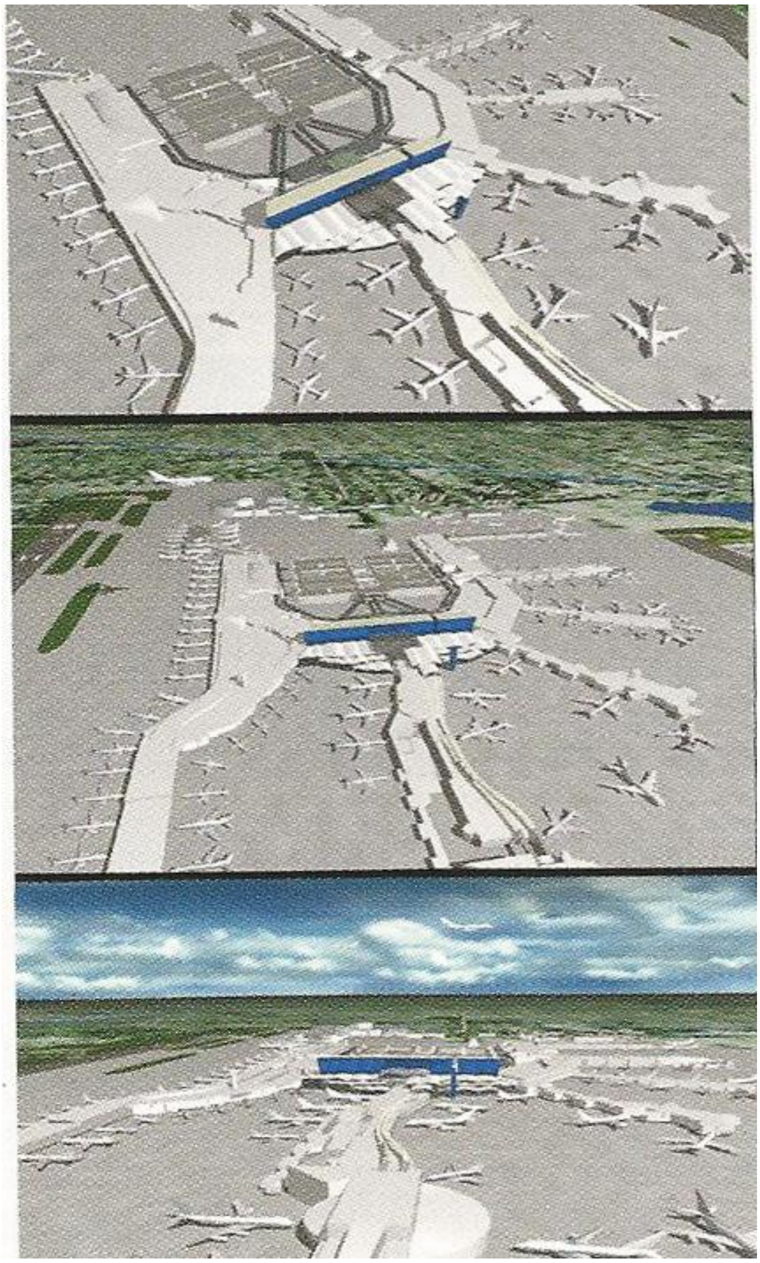


Figure 2.3: **Animation: 'fly-over' sequence. Exterior Miami International Airport Terminal (Uddin,1999)**

In addition, Ng *et al*. (2006) explains that animation establishes communication between ideas and reveals the layering of architectural thought. The approach to a narrative used by architects is similar to that used by filmmakers. Manaugh (2009) states that producing animation relates to film theory because producers must have a storyboard in their heads. They move from shot to shot to lead the viewer to interesting perspectives. Some of the most interesting work today is from complete with elaborate plots and storylines, explained why a building should exist or require designing (Manaugh, 2009:14). However, it is also notable that within this framework, the architect usually thinks of how to present their work and typically uses a storey board to identify the point they are trying to make, whether by perspective drawing or another form of presentation. The work that architects present to their audiences would normally show only the part that the designer would like their stakeholders to see, such as the perspective view of particular parts of a building from the entrance to the main lobby or from the hallway to the courtyard. However, in reality, the audiences may want to see or experience the space not in such sequences, but in a random way. For this reason, it can be argued that the spaces perceived in everyday life in architecture need to be manipulated by a range of stakeholders. This coincides with the concept of 'pull' media where the experience of the audience is specified by the audience who can contribute rather than being controlled by an architect or designer.

The effect of using digital media from stakeholders is investigated. This enables the researcher to ascertain existing digital media and their potentials. This research's purpose is to see opportunities for applying digital media to introduce a new form of architectural presentation and collaborative work. Such media that responds to people's action, interactive media have that strategy- it is a presentation tool that the user can interact with. Hence, it still needs to be investigated in terms of capability and creativity. Most of the interactive media used in architectural practices are for advertising work. At present, architects employ websites for their customers' information and this information can be pulled from the site but not exchanged by stakeholders. Thus, this research endeavours to exploit of an interactive media in a creative and collaborative ways and would not emphasise on marketing aspect.

2.3 The use of digital media in design communication as a working tool

This section introduces digital media as a working tool. Currently, 3D digital modelling is a standard tool for displaying the creative output of designers and architects. Architectural designs are becoming more complex and complicated, and architects are turning to technologies like CGI. This is far more advanced than traditional methods and provides almost realistic visions for handling the complexities of the design. In such complex designs, form, materials, technology, and structure must be communicated through simulated projects. These are important for communicating conceptual ideas and delivering near-real designs before the building is completed.

Digital representation of architectural entities and digital manipulation of those entities provide alternative means to produce architecture. Digital media is a tool used for different purposes. For example, photographic 3D image rendering used for communicating with planners should be as close to reality as possible. However, engineers require simple models that can be manipulated because they need to see the model from different views. Therefore, an investigation into the means of current presentations will help improve communication.

Digital media uses in the design process for an accurate representation. One issue concerning architectural presentation is reliability. The architect wants to attract stakeholders' attention and motivate them to take action. The architect is responsible for providing reliable architectural information. This paper focuses on finding digital media which avoid faulty perceptions in the design process. The aim is for reliable representation. In the proceedings of the Information Visualisation Conference in 2006, concerns were raised about the credibility and veracity of visual representations of architectural design ideas. There is a conflicting perspectives about visual representations including accuracy and reliability of computer generated visual representation. For example, a planning application for the Heron Tower development in Bishopsgate in London caused conflicts and question of how reliable of computer visualisation presented design in order to resolve the matter public enquiry. Most people in the debate agree that the design information supplied through visual representation has to be accurate and reliable, but there is a broad disagreement on how different kinds of representation affect the understanding of design and what criteria require to be achieved so that such representations are authoritative in the representation of the proposed urban development (Bates-Brkljac, 2006:337-342). Reliable and accurate 3D visualisation is necessary for presentations in architectural practices. 3D visualisation is often distorted and leads to misunderstandings (Gueorguiev and Georgieva, 2008:340-45). For example, a beautiful sky or an attractive landscape created for a 3D rendered image can lend sophistication to project images. However, images in reality do not have the same atmosphere, which results in disappointment for the viewers. This inaccuracy also happens with selecting views from the camera and the speed of footage of 3D animations; Brinkmann (2008) notes that perspective becomes more important as an object moves away from the lens. Scale is determined by the speed at which the object moves and its perspective (Brinkmann, 2008: 394). Such distortions and unreliability of the image in a presentation can have negative effects on the stakeholders, including the architect. This is why this research revisits architectural presentations as the issues are discussed.

In addition to essential communication, 3D modelling can be used to sell ideas. Hillier states that using virtual reality enables designers access to new markets for their concepts. Evolution of a new understanding of space in the virtual world is taking place in architecture (Whyte, 2002:73). According to Bates-Brkljac and Counsell (2007),

> “It is technically possible to create highly realistic and accurate computer representations of proposed architectural designs. For the final stage of design people agree that computer generated representations of design ‘sell better’ design concept and are likely to have more persuasive power than traditional means of representation.”

Even though it may be used for marketing purposes, the visualisation is often a result of the planning conditions. It can be advantageous to use an image derived through the planning process to create a public impression of the proposal and promote it. Porter says that when he works with a client, a computer-generated visualisation can sell a building concept quickly (Porter, 2000:106). This additional function might be relevant to this research. It could be beneficial when the client has input into a planning project, and when they see the result in a visualised form, they are more likely to want to buy the design.

Architectural projects are expected to become global in nature and entails remote working. The benefit of today's technology allows people to work remotely. For example, taking advantage of cloud computing solutions provides the same computing potential to all workers, regardless of where they conduct their work. Workers can sit in a coffee shop or stay at home to review the work or send drawing files. As a result, in the future, architectural practices may not be based in one large building with several floors- they may be collectives of people who work remotely to reduce the time and cost required for the overall design. Yeung and Harkins (2011) show the challenge of working remotely. They apply using architectural computing for the context and proposal in humanitarian design in remote areas of developing countries (Yeung and Harkins, 2011:17-31). Mobile and changing work locations are relevant to this research because they improve the design communication of architectural practices now and in the future. Digital media make it easier for isolated workers to do their jobs, leading to an opportunity for increased connectivity and more effective communication with stakeholders who have different levels of architectural knowledge. A part of this study is on the experience of people from different professional backgrounds and how this knowledge can assist the use of design media to communicate as an increase isolated working.

The literature review shows that researchers have examined the uses of digital technologies in architectural practices that help architects define ideas, get people to perceive the immersive environment, use for marketing tools and provide for remote work. Architects have to define a complex design project by organising, structuring, and categorising their information. Most media used in the architectural practices are provided to present the design, such as images, animations, and videos. However, information from stakeholders is also important to decision making in the design process. Hence, this PhD research examines digital media in design communication and explores the potential for using it as a communication system where stakeholders can also input their requirements to improve communication. To create this system, current digital media need to be explored in order to elucidate their attributes. Findings can then inform the development of the concept of the communication system.

2.3.1 Computer-generated (CG) static images

This section introduces the most common tool most practices employ, CG static images.CG static images are realistic and closer to reality, so more people can understand them. Most software packages can produce a static image and typically offer a range of convenient tools. The rendering of CG static images is one of an architect's many skills. However, producing CG static images requires the use of a computer for rendering. Traditionally, the architect invests in the technological resource that enables the production of the CG static images. This investment means that only the architect can create the CG static images. Thus, the resource gives the architect power. However, architects need to be aware what they present and the result that clients perceive. Accroding to Stikeman (2007) (cited in Charlson 2007), there is a concept in visualisation to be remembered. People imagine beyond rendering images as realistic. As Stikeman says "We remember what a brick looks like with a mere suggestion in a more complete way than if it were photographically rendered." There is a difference between the way things exist and they way they appear. Thus producing CG should consider this fact.

Representation through imaging helps people understand the design and the potential building. It is a standard form which has a long history. A representation has developed from hand drawings and paintings to CGI. Various computer techniques are now used for architectural design in order to produce a realistic image. Visual representations are commonly used in architecture to draw an image of how the building will look and be built. This becomes a significant tool that necessitates communication, so architects try to improve their creative visualisation. Bates-Brkljac defines two main diverging forms of representations as a technique and the final representation. Technique is a process and the final representation, also referred to an artist's impression, is the outcome. He concludes that the output from CG photomontage is preferred by people because these images are typically the most realistic (Bates-Brkljac, 2012:185-204). Gueorguiev and Georgieva state that by working in the area of architectural and design visualisation, visualisers move into a development process that is often chaotic and conflict-laden. The goals of CGI are to communicate ideas about a design from the designer to the client and for the designer to better understand the design (Gueorguiev and Georgieva, 2008:340-345). 3D rendering helps the client visualise the project and serves as a tool for the architect to consider the design or communicate within their practices.

Currently, there is common use of CG static images as various software packages offer these types of presentations and architects typically have the technological skill so they can widely use this technique. Clients can easily understand the design from these images and the files are convenient to store. In addition, the 3D rendered images are a good marketing tool. Interior designers, architects, and real estate companies use 3D rendering to market the properties they are selling. A set of images can capture a buyer's attention at an early stage as the images can turn an idea in their mind into a more tangible concept (Doherty, 2015). Using 3D rendering as a marketing tool can provide benefits to both the sellers and buyers (Power Rendering, 2013). Bertol (1997:177) states that for several years, the use of digital presentation media mainly focused on the visualisation of architectural concepts using 3D computer graphics. These tools proved to be a powerful presentation tool. This type of media is widely accepted in the building industry. At present, a static image is necessary for communication, it is a common tool which architects can afford and stakeholders can understand. Architects may select perspective views to render views that other stakeholders may not want to see, leading to wasted time since rendering requires effort and resources. This research argues that the views presented must not be only what architects want to show, but also what the stakeholders want to see. For this reason, the research investigates the form of presentation that involves people in the early stages of design so that stakeholders can actively participate in the design process and avoid miscommunication.

2.3.2 Animation in architecture

This section describes the principles of animation. Animation is a speedy sequence of images that displays the movements of objects according to the animator's plan. This research explores animation recorded with digital media. 'Classic Animation' refers to the animated cartoons pioneered by Walt Disney. Feireiss (2004:194-195) notes that the 'Disney principle' of animation, where the animator animates inanimate objects, can be applied to architecture. An animated architectural image can incorporate playful effects, such as unusual colours and ornamentation. For architecture, showing buildings in context in the design realm can incorporate static images and the planning and preliminary stages can be negotiated through digital animation. The role of the architect includes the permission to become an animator and to employ 3D animation in a project (Lostritto and Ambrose, 2008). The states of visualisations, computer modelling, and animation are important to show viewers a design concept in form of storytelling.

Ednie-Brown (2001:72) states the following:

> "Architecture becomes an animated diagrammatic in a sign language of qualitative effect. The animation is not a matter of rushing out to make things move, but a question of the terms through which architecture becomes animate as a technology in itself."

In addition, Brito states that animation is concerned with the techniques of creating and managing the keyframes and timelines that affect the output. A 3D animation can be faster or slower than movements in real life, so the architect as an animator needs to find the right speed for the audience (Brito, 2008). Animation is produced for the purpose of immersive perception and can be impressive when the building image is combined with images of its surroundings. Although the building cannot move, the surroundings (such as birds, pedestrians, or clouds) which are moving objects can appear in animation and influence people's perception.

The basic goal of all animation is to reach the audience. The following rule applies: "always look at a project through the eyes of the audience" (Feireiss, 2004:133). Animation represents design to provide for a better visualisation of a project. It is an elaboration of views, angles, and the shape of the building. Architects use animation for showing the building and its surroundings. Animation attracts the viewers' eyes though the moving images. It is also more attractive when the animation has sound, so using animation to represent architectural design employs the same disciplines as film. The sequences of shots need to be set and the architect has to anticipate what the viewers want to see in the design. This research considers 3D animation similar to static image presentation in terms of the information that the architect provides. The architect shows certain views in order to sell the project and the audience perceives only what the architect presents. To make communication more equal, this research considers a presentation form that can offer informed responses from the stakeholders.

2.3.3 Building Information Modelling (BIM)

This section reviews the use of Building Information Modelling (BIM) for architectural practice. Since the mid-2000s, the BIM system was widely introduced to the architecture, engineering and construction (AEC)/facility management (FM) industry. With the high level of collaboration among software developers, researchers and industry practitioners, BIM is currently acknowledged as a technical advance and has had a profound impact on the professions of AEC; it is an approach that assists the industry in developing new methods of design and practice. There are several types of BIM such as architectural BIM for architects, BIM for mechanical, electrical, and plumping (MEP) engineers and structural BIM used by civil engineers. BIM technology has developed beyond design operation into the maintenance segment of building assets, as well as in the decommissioning of information (Kivits and Furneaux, 2013). This section particularly focuses on the impact the BIM system in architectural practices, which is a purpose of this research.

The advent of the BIM system has integrated the architectural design and construction domains; using CAD for architecture facilitates the building design process before the actual construction stage, including the plan, energy performance analysis, cost estimation and construction management. Zhang *et* *al*. (2015) state that BIM is designed to host the information of the building throughout its lifecycle. Krygiel *et al*. (2008) explain that it provides a methodology that allows data exchange and communication between all stakeholders, including the design team (designers and consultants), the builders (contractors and subcontractors) and the client (developers and facility managers), where they can share a greater quantity of information more effectively than using traditional methods.

In comparison, Eastman *et al*. (2008) argue that BIM is just a form of software or a tool. In their opinion, BIM is defined as a type of modelling technology with an associated set of processes to produce, communicate and analyse building models. Hardin (2009) agrees with Eastman *et al*., that BIM is a process and software program that make a significant difference to a project workflow and delivery process by using a 3D intelligent model.

BIM supports integrations between people, systems, business structures and practices in a collaborative way, providing efficiency though all process of the project (Glick and Guggemos, 2009). Leon (2015:14) finds that it enables AEC and FM professionals to foresee the possible occurrences of issues and problems during the design and construction process.

Patrick MacLeamy, ChiefExecutive Officer of HOK from 2000 to 2003, states (2012):

> "BIM is the first truly global digital construction technology and will soon be deployed in every country in the world. It is a 'game changer' and we need to recognise that it is here to stay – but in common with all innovation this presents both risk and opportunity."

BIM enables AEC professionals to gain several benefits, as follows:

3D simulation. In a BIM-based system, 3D models can be created through BIM software, and plans, elevations and sections can be generated; designers can access all angles of the building to explore the design and its content. Editing one view in the model will influence other views. Architects can input design information into each element of the drawings and any changes made will simultaneously affect all elements of the information such as size, cost estimates and material requirements. The BIM system provides an interoperable 2D and 3D tool in a single place, which helps in saving time and increasing accuracy, even with multiple changes made to the design. According to Azhar *et al*. (2008), any editing of plans, sections or elevations in conventional 3D CAD can cause error, such as an inconsistency of letters to describe the views; an architect is required to check and update this information when using traditional 3D modelling while BIM can be automatically updated consistently when one view is changed. In Azhar's paper, he also explains the use of a BIM model to simulate construction in a virtual environment. The model contains relevant information that supports design, procurement and construction. After the building is built, the model can be used for maintenance purposes. For BIM, a single model of a building is the origin for multiple representations suited to the briefing, design, evaluation, construction and operation-in-use stages. Yeung and Harkins (2011:17–31) present a case study of the ongoing disaster renovation in the Solomon Islands, which is part of their research on the application of advanced technologies for humanitarian design in low-tech contexts. A particular digital tool using parametric modelling and BIM was created to simulate the design for the site and project-specific requirements, to help reduce the time and cost required in the general project.

Advances in computing architecture have enabled architects to develop parametric design, using algorithms to design complex forms of buildings. The computer is used to generate and visualise new forms and structures. BIM software allows architects to understand a complex form, spatial composition and tectonic joints and to quickly build 3D models and drawings. Park (2011) uses the parametric software program of Gehry Technologies' Digital Project and Autodesk Revit with the minor practice of Hanok, an environmentally-friendly Korean traditional form of architecture that is popularly known. The study creates structural standards for a small group of professionals in Korea. In his work, the benefit of using BIM is economic efficiency. Additionally, it contributes to the popularisation of Hanok culture in order to provide structure to modern Hanok practices. His research shows that the technology of BIM is not only beneficial for creating large projects, but also small practices. BIM characteristics enable design as well as multiple layers of property information linked to geometry. Azhar and Brown (2009) use parametric modelling to enable the creative exploration of a design space through varying parameters, looking at their relationships to optimise sustainable building design. Despite the ability of parametric software to respond to forms desired by an architect, there is always a problem when a 3D model is transferred to a 2D drawing where unwanted lines are shown. It is time consuming for a draftsman to clean up the mess. This issue can be the catalyst to users' selection of BIM software.

Energy performance analysis. This is one of the significant features of BIM, which drives architectural design toward sustainable building. Energy saving performed through BIM software addresses concerns such as heat, cold, light and CO_2. To create an effective design, a building information model is used to store and input information, to visualise the simulation of building performance in the early design stage. This would help architects to make a holistic view of the building possible. In their 2009 paper, Schlueter and Thesseling focus on balancing CO_2 emissions in a building. Rahmani Asl *et al*. (2013) use BIM-based applications to optimise building design through HCI at an early stage of design; their project employs the technologies of parametric modelling and BIM (Autodesk Revit), energy simulation technologies (Autodesk Green Building Studio) and visual programming (Dynamo), to analyse a number of light-saving measures by changing window size. This way of working challenges architects' responsibilities. To simulate design information, energy saving can be generated through BIM software, which enables designers to foresee how to overcome electricity wastage. It helps to work on the density of sunlight and the volume of air flow (Shoubi *et al*., 2015). Stundon *et al.* (2015) introduced BIM for energy performance assessment as an alternative method, compared to the manual calculations of energy use, in order to provide accuracy and faster speed of operation even in complex buildings. Krygile *et al*. (2008) present best practices for working on sustainable buildings through the use of BIM software. BIM helps architects to optimise the design of a building and enable alternative options to achieve the best scheme. Moreover, this software allows the creation of sustainable buildings that are environmentally friendly.

Cost estimate. The BIM system offers an effective cost estimation by reducing human error caused in calculating cost. In general, architects design buildings; assessing the cost of building is the responsibility of the estimators. However, architects should fully consider this matter, as they have a close relationship with the clients and know what their requirements are in saving costs. In order to provide a cost estimate, the estimators require the architect's paper drawings, to be imported into cost-estimating software. There is potential for errors of calculations and measurements to be input from the original drawings. However, this issue can be overcome by using BIM, as users can count and measure concurrently from the underlying model.

The BIM-based approach enables architects to assess the building budget. If the model is changed in the design, the information automatically cascades to all relevant documents as well as all calculations and measurements, which are important to a cost estimate (AIA and Rundell, 2006). At this point, a materials database is generated from which data is used for calculations. For example, if the walls are initially made from mortar in a specific area, this may later be changed to a smaller or larger area, or the materials may even be changed. These changes are shown on the database and are coordinated to relevant information sheets. Franco *et al*. (2015) investigate subcontractors adopting BIM, compared to traditional forms of estimation; the result is that automated estimation with BIM is more efficient than traditional conventions. However, they find barriers remain, including cost, time spent in developing the model, cooperation among departments and the need for staff training. Wu *et al*., (2014) review BIM-based cost estimation, finding that BIM can be used to speed up traditional estimation methods as it can link quantity and cost information to representative models and simultaneously update information when the design is changed. However, in summary, they state that the substandard quality of models, inconsistent design information and format used for estimation, and data exchange issues in BIM tools, are struggles that prevent the use of this software to its full advantage.

It is clear that cost estimation is another key benefit for the AEC industry. Architects can use it to provide reliable cost advice at the beginning of the design stage, in order to offer the best value and confidence to clients.

Facilitation of building management. This feature allows the built asset management sector to operate and maintain a building post-construction. The BIM system is used to store information to support the facilities management of the building throughout the lifecycle of the project (Ding *et al*., 2009). Of all the features of BIM, this specifically provides a link between the specifications information and the suppliers who supply each element of the building. It was designed for clients, who directly gain the most of the benefit. The majority of investigative research in this field is in engineering, specifically in the FM discipline, which operates for engineers and building owners (Su *et al*., 2011; Yalcinkaya and Singh, 2014). This discipline is beyond the scope of this PhD research, which investigates the design process stage, not post-construction. However, the literature shows that this beneficial feature of BIM can be adopted for architects to use for their project design. BIM can be used to consolidate information regarding all aspects of building operational performance. For example, the storage of specifications helps users to quickly search for materials, such as doors or windows, when they need to use the same specifications as those used in a good design previously. Moreover, architects can store blocks of drawings and 3D model templates in one place, in order to use them for future projects.

Collaboration. Architects exploit BIM to coordinate the design and construction process, using it to reduce the gap in communication and avoid the fragmentation of stakeholders. Rizal (2011) states that “for BIM to be successful, collaboration from all different stakeholders is needed.” The BIM model is used for the evolving progress of the project. Virtual representation can be controlled by the design team then delivered to the contractor or sub-contractors. Clients can also suggest changes and evaluate the works during the whole project. Using BIM supports cross-disciplinary and cross-phase collaboration, opening new dimensions in the roles and relationships between project stakeholders. According to the *Autodesk White Paper* (Autodesk Building Information Modelling, 2011), project information needs to be integrated, shared and managed between team members. BIM proposals are rich in information through the models, that help the project team gain insight. Lam (2011:79–88) states that BIM is more than a source of building representation. A key attribute of BIM lies in its ability to enable collaboration between applications and databases. Sunil *et al*. (2015) note that BIM has emerged as a feature that helps the construction industry in several ways. For example, BIM facilitates the isolated actions of stakeholders, supporting tighter integration by allowing communication and providing a platform for users to work collaboratively, maintaining ideas, drawings and information in one place. BIM is used to make collaborations more efficient by enabling the sharing of information (Wu and Jeng, 2012:49–54). Kelly (2011) uses case study to present new teaching models for professional collaboration, developed through BIM efficiency. Although he generates a new efficient collaborative design in his work, the investigation is limited to the education domain. In fact, professional lives are affected by many other factors such as time, finance, politics, culture and hierarchy in the industry.

BIM is clearly beneficial for modes of collaboration, though only small number of projects have realised its full advantage because the collaborative approach is not supported by traditional delivery methods. For instance, the architectural project requires varying level of collaboration, BIM lacks of obliged aspect that support collaboration between parties to ensure that achieve goals of the project is achieved (Stirton *et al*., 2015). In addition, Azhar (2011) finds the risk of BIM is that the collaboration concept blurs the level of responsibilities, as a design project involves stakeholders; if they are not clear about actions and responsibilities, this leads to ignorance and pushing liability. This PhD research acknowledges that the communication system should encourage participation; storing a history of the work process would help in clarifying communication according to the roles of stakeholders. The storage of a time line of communication would also work across other digital media.

As Krygiel *et al*. (2008:220) describe:

> “One tool cannot be all things – the primary and most obvious need to achieve better sustainable solutions with BIM is better interoperability between software packages. Analysis packages already exist for things like costs, labour, energy, comfort, daylight, and life cycle analysis, with more likely to come.”

Although BIM is useful for design, energy analysis performance, cost estimation and construction management, limitations remain such as incompatible files, technological skill required and cost. These affect the use of BIM between architects and other stakeholders. There is evidence to show that the adoption of BIM is still slow in the industry, even though the potential benefits are well documented, in terms of improved productivity, together with many other potential benefits (Gu and London, 2010; Azhar *et al*., 2008; Bernstein and Pittman, 2004). In addition, Boeykens (2012) states that many practitioners and researchers are not convinced about BIM benefits, as the use of this software often overlooks a lack of user experience or a different point of view in the design process. Therefore, the BIM system still harbours several barriers to use as follows:

Incompatible software. Global professionals work on various forms of BIM software and levels of information; as such, the design process brings many parties together and fails to standardise software. There are many types of software such as Revit, ArchiCAD, NavisWork, some of which are not able to interchange information. According to a document detailing the current state-of-the-industry on information (InfoComm, 2015), inter-product compatibility is one of the biggest issues for BIM. Software manufacturers provide significant features for their product making it different from other software. It is difficult for the project to function well if team members operate in different software packages. Various stakeholders may use different software and encounter issues of being unable to open incompatible files. Aside from the software type, different versions of software used can also cause problems. BIM is tied to specific software such as Revit, ArchiCAD, Reviswork, etc., which can result in issues in sharing files between parties.

As BIM is promoted to be used as a global system, however, a current debate exists on what software would be most suitable for BIM. A selective system enables practitioners to choose different software. For instance, in the UK and USA, people work on Revit; in New Zealand, Australia and Europe, ArchiCAD is used. This does not only cause file incompatibility, but also results in the need to learn many different programs. Hence, it makes sense for the design process to be made more efficient by allowing any professional to use any software they like, while enabling them to share files or information in a compatible format.

Another issue of using BIM is that it distributes different levels of information; detail that is input into drawings and models, such as doors, windows or material specifications, can then be expanded from the drawings. In the UK, regulations determine operation at Level 2, which involves developing building information in a collaborative 3D environment with data attached, but created in separate discipline models (Government Construction Strategy, 2016). Hence, global design projects require a standard level of information as the design and construction teams may be located in geographically separate places.

Technological skill required. As a traditional working style, architects begin with 2D drawings and then build 3D models or vice versa. Moving to BIM systems has changed this traditional system and requires not only learning BIM software, but also understanding interoperation when architects need to input numbers in the 3D geometric while they represent 2D drawings. This challenges the technical skills of the architects in terms of thinking and technique. In his book, Deutsch (2014) clearly explains that one problem of BIM is not technologies or business, but people. One person cannot response to every task. The integration of teams in the design process is significant, involving different cultures, mutual respect and trust, authorship, comfort with the work process, the impact of technologies, personality, identity, collaboration and communication. All of these affect effective BIM. This research agrees that people are necessary to all factors and can be difficult to deal with. Underpinning this research is the need to investigate stakeholders to get an insight into their thoughts, mindsets, attitudes, cultures of work and workflow, all of which affect communication and collaboration. Despite advances in tools that have been developed with powerful features to facilitate workflow, in fact it is up to adoption by users. Hence, uncovering problems and finding keys to improve communication in the design process are goals to be achieved.

Cost. To change the working system toward BIM, budget is a big issue for architects, especially for small practices. It is suggested by Tse *et al*. (2005) that a lack of demand from clients is a major reason why architects do not employ BIM. Their survey shows that “existing entity-based CAD systems could fulfil their drafting and design needs.” The architects will not spend on BIM if they cannot see better productivity than with the CAD system. Yan and Damian (2008) survey the use of BIM in the AEC industry, with the results showing both advantages and disadvantages; cost is the greatest barrier to implementation of BIM because of copyright requirements, training and resources. Hence, there are benefits to finding opportunities and challenges to assist the AEC industry with achieving ease of use of systems and at less cost than the existing technologies available.

In summary, researchers have investigated this area as they can see BIM’s potentials. Technological advancement that allows the free flow of effective working processes in the building design industry may find great promise in BIM. However, such intelligent apparatus requires much effort and expertise to meet an accepted execution; for this reason, many people have been put off from fully engaging with such systems. Therefore, it is time for necessary consideration in support of a more user-friendly system, both in terms of interoperation as well as interaction. The proposed communication system should assist the BIM system rather than being opposed to it; certain features of BIM are highlighted in this research and the study is expanded to examine what would facilitate communication between stakeholders and provide an improvement to workflow described as follows: 1) interactive interoperation – information is cultivated and updated to all stakeholders at the same time, helping fragmentation in the industry; 2) data management – storing and linking data together in one place; and 3) 3D modelling, which can be used to simultaneously connect to other design information when the design is changed. Hence, this research focuses on these points to continue to ascertain further attributes that would be useful for alternative working system use in the design process.

In addition, this research highlights that the BIM system lacks consideration of the planning process, which is essential to an effective design process; planners should be involved at an early stage of the project. The BIM system assists AEC professionals with technical knowledge in sharing their information silo. Some planners have a lack of architectural background; ideas on architectural drawings might be misunderstood. The design collaboration should encourage specialists and non-specialists to work efficiently together.

2.3.4 Innovative tools for design communication: new media

The roles of the audience and the designer are changing as a result of digital environments. Digital media exploit technology to create channels to improve communication. In the book entitled *The Language of New Media*, Manovich (2001) describes show 'new media' is analog media that converts to digital representation, which can then be copied multiple times with the same quality. It can be interactive: the user can choose and follow content depending on their interests or become a co-author in generating unique work (Manovich, 2001:49). While new media (at the moment) enable many people to use different platforms to engage with issues and interests that affect the design-making decisions, architects seem to have a solitary approach to design (Ampatzidou and Molenda, 2014). This is a significant view that needs to be revisited, exploring how digital new media would be exploited in the architectural design process.

New media has changed many areas of life, including design and communication. Architects have employed digital media in their professional practices. CAD has been used to create new visualisations. More recently, the processing power of computers has been used to simulate architectural design spaces. This leads to a new stage in the relationship between spatial design and new media where the creation of forms is reflected in the technology. New media, in particular virtual reality can be shaped by virtual architecture (Lang and Waal, 2009). New media enable architects to develop innovative design methods and concepts. Virtual reality can be used both in the design and the building process. Another tool for design communication is augmented reality (AR). AR is a process of imposing digitally-rendered images onto real-world surroundings to give a sense of illusion or virtual reality. Krakhofer and Kaftan (2015) investigate an AR tool for collaborative design during decision meetings. The AR tool is applied to an urban analysis project. They work with a small neighbourhood called SauWah Fong in Hong Kong. This project has developed AR tools for comparative and collective decision-making as part of the architect's workflow (Krakhofer and Kaftan, 2015:231–240), since AR can help develop human perception by letting users to perceive to real world through digital devices, along with engaging information. This PhD research explores the development of AR affects on communication design.

Technologies in digital media have been studied to evaluate their use in communication. A report by the University of Cambridge on the dissertation titled *Depth of Perception in Computer Graphics* presents the relationship between human perception of depth and 3D CGI in order to improve the design process. The study shows that inconsistent objects in motion prevent people from making accurate relative depth judgements; this issue can be overcome by algorithm manipulation of size, distance and location from the edge of an object to enforce consistence. In this report also suggests linear perspective is a common depth cue, and interactive systems utilising binocular disparity cues are of increasing interest (Pfautz, 2002:5). In addition, Fukuda *et al*. (2003:46-469) examined the establishment of a citizen's participatory design method using Virtual Reality (VR) and Consumer Generated Media (CGM) as design or communication media in the design process. These studies contributed to this research investigating the attributes of new media used in collaborative design.

A number of researchers have investigated how new media assists design in architecture. Fraser (2004), who works on real-time modelling, discusses the first thorough application of the digital realm to architecture and urban design. His work shows the advances in partial applications which combine expertise in architecture and computer games. He adapts the principles and techniques of real-time environments from computer games to designing buildings (Fraser, 2004:187). In the computer game industry, 3D modelling is used to simulate virtual worlds. Sturken and Cartwright (2009) show that the look of a video game is crucial to the worlds that these games help us to imagine (Sturken and Cartwright, 2009:175). Game software offers a virtual world with functions that allow the user to interact with it and make a community. For this reason, this research considers game development software to propose a communication system so users can experience greater social interaction.

There has been research on the potential for the Internet to support CAD development and transform architectural practices. Jabi (2003:171) shows that networking can support a social dimension with regard to design. Sidawi and Hamza (2012:308-318) highlight that architectural design is a social phenomenon, which support by analysis of design and social interaction between designer and business partner. Currently, most CAAD systems have web communication tools that enable designers to communicate their ideas. From this evidence, it can be seen that researchers have considered new media's ability to assist communication in architecture. This research agrees that the invention of the Internet impacts on digital media design as sharing information feature are increasingly demanded. In addition, storing and archiving information online are needed as a result of a remote working. Therefore, the researcher takes the above-mentioned evidence as a starting point.

As stated earlier, studies have shown positive results for using new media in the design process. However, mistakes can be made by completely losing the sense of humanity in the design process. Inconsistency prevents subjects from making accurate relative depth judgments; for moving images, these distortions are most visible when the object is moving slowly, the pixel size is large, the object is located close to the line of sight, and/or the object is located at a large virtual distance from the viewer. All these aspects affect perception and can make it inaccurate. However, accurate communication is necessary (Pfautz, 2002:5). Many factors affect accuracy of viewers' perception and it is difficult for the architect to handle the right medium for all stakeholders. New media is capable to incorporate multiple architectural presentations together interactive feedback for stakeholders. There makes the design process more participatory.

The use of digital media in communication is reviewed. In order to enable this research to draw on the material from the relevant digital media disciplines, it is necessary to pay attention to visualisation and collaboration as used in the different disciplines. Viewers' perspectives, which contribute to the communication among the stakeholders, are central. By addressing the proposal of an interactive communication system by using interactive media in architectural practices, the research suggests that working in architecture with interactive media (such as web design) is possible. It also suggests that there could be future developments within computing which would enable digital media to meet the needs of the architectural industry.

Communication in the design process needs digital transmission to convey design information to stakeholders. These stakeholders have different areas of interest and expertise, as well as different points of view, and it takes time to communicate this information to all of the concerned parties. Rather than only using digital media produced from a designer's point of view, this research proposes a type of digital media that can contain information from all the stakeholders' views.

2.4 Conclusion

This chapter reviews a range of digital technologies used by professionals to design and communicate as part of a collaborative process in architectural practice. The design tools were explored in terms of functions, interface designs, features and file extensions. Stakeholders need to exchange work and it is problematic opening files if they are incompatible. Therefore, identifying the significant attributes of the tools is required to promote design communication and collaboration.

This chapter revisits and discusses digital media used in the built environment to identify the efficient methods for architectural presentation. The literature review shows that rendered images and 3D animations are comprehensively employed by architects, but they do not always allow stakeholders to engage with them. In addition, BIM systems have a huge impact on the architectural industry in many aspects, including design, energy analysis, cost management and collaboration. It also has been adopted by government projects in order to gain effective design and building quality. Many researchers have investigated the use of BIM, while software developers have improved compatible BIM software (Revit, ArchiCAD, MicroStation, and so on). Nevertheless, barriers emerge on having to learn the use of the software required, cost issues and using incompatible software between each party. In particular, small architectural practices still struggle to employ BIM as they think it is not worth their financial and technical skills. Although BIM has efficient analysis and performance data, collaboration aspects could be extended. This research argues that to enable effective collaboration, facilitating access to information is crucial; compatible formats should be standardised and effortless use of systems would promote the workflow. This research finds gaps of communication and collaboration in the design process by exploring existing issues in this area and introduces ways to improve. Innovative new interactive digital media enable users to engage with media content by navigating or inputting design information. Hence, this research finds potentials for an interactive tool to better facilitate communication and collaboration in the design process. This will lead to a new contribution to contemporary architectural practices.

In conclusion, this chapter has concentrated on current digital technologies used in design communication in order to find obstacles in using tools. Section one reviews software and hardware to identify the attributes and effects of tools used in design and communication. Section two describes the effects of digital media currently used in the design process. Section three discusses digital media as a working tool in terms of the use and its effect on stakeholders, such as static rendering image, animation, BIM system and innovative digital media.

The next chapter explores theory in communication and the use of digital media in architectural practices, reviewing design projects that employ innovative tools for communication and collaboration to identify contributions to the design process.

Chapter 3 Digital media for design communication

Chapter 3 Digital media for design communication

3.1 Introduction

This chapter focuses on emerging digital media in design communication in contemporary architectural practice. Theories and models of communication are reviewed to acknowledge the current issues in design communication. This review is underpinned by the study of a number of projects where digital media was used. Understanding the use of such media will help identify strategies for communication design, which would contribute to an efficient design workflow in the built environment. The chapter explores the advances in digital media that have been used in design communication, introducing the current interactive tools that are employed and the opportunities for developing interactive digital media to contribute to the architectural design process are explored. Therefore, interactive media such as websites, applications and relevant platforms are investigated. In addition, people experiencing architecture through interactive media and its impact on communication are discussed. The review of this chapter points out the need for an interactive design and communication management (IDCM) system with a view of improving communication within context of problems in the design process, which is the objective of this research.

A design team always includes architects, clients, engineers, planners and other specialists. It is hard to explain the basic design to those who find it difficult to read architectural drawings. Architects use digital media as tools to convey the design to stakeholders. Therefore, the architect needs to know stakeholders' backgrounds for efficient communication. In this research, models of communication are reviewed to identify issues of design communication in systems currently in use. Technology offers varied possibilities and means for communication: images, animation films, or multimedia that can be included in a presentation in order to help stakeholders to understand the design. Hence, knowing the end users of the media is supported by studying models of communication, from which a new concept and communication system are proposed.

3.2 Exploring theories and models for design communication

This section explores theories of and models for communication in order to contextualise the primary objective of this thesis, which is the proposal of an IDCM system for collaboration in the design process. The section presents how digital developments are currently transforming communication. The review of these models of communication sets the framework and structure of the proposed IDCM system.

Effective communication is the successful transmission of information from sender to receiver in which the receiver is able to understand the message in the precise way that the sender intends to convey it. In the architectural design process, both internal and external communication processes are used. Internal communication within the practice is crucial as it enables development of the design. External communication is the important communication among the people outside the architectural practice who represent stakeholders in the design process. The present research investigates communication, which concerns people occupying different roles in the design process. Hence, studying communication theories and models is required to establish knowledge and understanding of factors that affect the quality of communication. The advantages and disadvantages of each communication model are evaluated, and relevant parts are applied to improve communication. For a summary of all the communication models considered, reference is made to Appendix A.

One of the most widely known models is that of Shannon and Weaver (1949). Initially, this model was designed to develop effective technical communication between sender and receiver. It was later applied in the various fields of communication theories. The model simply concerns sender, encoder, decoder and receiver. The main criticism levelled at this model is that it shows communication as a linear process and it is effective in person-to-person rather than group or mass audience communication. By 1960, this model was expanded by Berlo, but remained linear with no feedback from receiver included. Therefore, in order to understand it, people require the same level of knowledge. The main criticism of this model is that it limits communication to the five senses as channels: hearing, seeing, touching, smelling and tasting, and does not highlight aspects of thinking, understanding and analysing, which should be added and considered for collaborative communication (Communication Theory, 2010).

In the electronic age, humans convey information and technology enables greater forms of expression. McLuhan and Gordon (2013:85–86) describe the new media, people sought to store and translate everything into art, which is applied knowledge. “Applied means translated or carried across from one kind of material form into another.” In recent years, technology such as the Internet has influenced the way people communicate. The technology of the Internet and new media enable people to express themselves and send and receive information more easily than before. More sources of information are readily available online, which possibly affects the way people think, understand and analyse. It seems to be a discursive direction in communication. According to McLuhan (2008:25–43), the media have been influenced by technology. The author does not focus on theory, but he starts with observation, which evokes a question, for which an answer is needed. His procedure is to start with problems and to find ways to solve them. The process suggested by McLuhan (2008) is applied in this research, as current situations in design communication are observed, issues are considered and solutions are put forward.

Lasswell (1948) formulates a model of communication use in which he adds questions for analysis of particular elements, such as communicator, message, medium receiver and effect (McQuail and Windahl, 1993:12). The message is sent via a channel, to suit the content of the communication, and an analysis of intended audiences shows the likely effect of that communication. Although Lasswell’s model analyses four features as stated above, it is a linear communication in which feedback and noise are not mentioned; the messages flow in a multicultural society among multiple audiences. Thus, the present research takes into account communication in the design process, which concerns the full range of stakeholders. However, linear communication does not allow for feedback from stakeholders. Colombo (2004) reports a reworking of Lasswell’s (1948) model, which incorporates media influences on public opinion. Colombo explains the effects of mass communication as being dependent on the interaction of content, channel, audience and effect. Lasswell's ideas on the direct effects of the means of mass information on the attitudes and behaviour of the public, were discarded as a result of an increasing interest in the variables that occur in the relationship between the message and the response of the users (Colombo, 2004). Stakeholder feedback influences decision making in the design process. Hence, non-linear model for communication is important, which includes feedback from stakeholders.

Schramm's (1954) model of communication is circular and dynamic, in which the situation can change according to roles and effects in response to communication. This model offers the idea that the sender and receiver can be the same person, and feedback is a central feature. In a design process situation, stakeholders can represent both sender and receiver. For instance, engineers can send their works and receive feedback from architects. Moreover, feedback is information that affects design development in which Schramm's model applies. Therefore, a medium for communication between stakeholders in the design process should provide potential for users who want to instantly exchange messages.

Barnlund (1970) put forward a transaction model of communication, which works by both sender and receiver simultaneously receiving and sending messages. According to this model, the meaning of messages is interpreted differently depending on the receiver's background (International Association of Communication Activists, 2013). Therefore, this research considers the backgrounds of stakeholders as parts of significant data to analyse and identify issues that contribute to communication in the era of the digital revolution.

The Internet allows information to be shared conveniently via digital interactive media as a transmitter. Communication models are no longer linear or analogical but rather discursive in approach. An interactive communication is formed by two attached linear models, and is quickly flipped upon the return message with feedback which is added to the process with instant messaging (see Appendix A). The message is encoded and sent to the decoding receiver, and then the roles are reversed. The receiver encodes and sends a response to the original sender, who has now become a receiver. For a number of years, design process communication has involved electronic messages such as email to contact stakeholders. These stakeholders used instant messages from many available applications, such as Skype. An architect could attach architectural presentation files to demonstrate the design or information. However, the advent of digital media and the Internet have enabled more channels to become available, and users can access and share messages more conveniently than before. The present research intends to include an instant message system with architectural presentations to assist communication in the design process. Including different channels in one platform will save time typically spent locating and sharing information via different sources. It will also conveniently organise messages and design information. A design system is necessary for complex communication and is empowered by a discursive approach.

Rafaeli (1988) defines interactivity as being located in the relatedness of information exchange among participants. He defines interactivity as going beyond simple one-way ‘action’ or two-way ‘reaction’ to being, ‘an expression of the extent that in a given series of communication exchanges, any third or later message is related to previous exchanges referred to even earlier messages’ (Rafaeli, 1988, cited in McMillan, 2006:205–230). Such thinking inspired the present research to enable the archiving of architectural information, as part of a design communication system, in a way that allows stakeholders to refer to earlier iterations. Each architectural project involves several design revisions, and these revisions are saved manually. It would be beneficial for interactive media to automatically archive the revised versions of a project. By using Rafaeli’s interactivity model, the present study can consider the full range of activities and issues within the design process. Currently, an architect sets the design package, which includes 2D and 3D drawing and modelling, then presents the work to stakeholders. Feedback is then returned to the architect indicating if the stakeholders like the work or wish to add some ideas. The feedback usually requests that the designs be revised and reworked; the architect typically needs to prepare yet another design package. The architect is required to produce an archive, and work is saved on his/her computer and cannot be accessed by stakeholders. Many stakeholders are involved in the design process, and they sometimes need access to the previous work, which may be confusing given the number of revisions often involved. The present research proposes that this process can be done inclusively if the work can be uploaded and other stakeholders can view the same working archive. Stakeholders could then make informed queries about the previous design information or easily compare the current draft to the past drafts. Therefore, the idea is to use digital technology, which helps archive the work online, so people can track the previous information or messages.

In ineffective communication, noise can create misunderstanding. According to Shannon and Weaver (1949), noise is a determining factor, which affects communication. Muthuchamy and Thiyagu (2011:87) describe noise as an interference to decoding a message that has been sent to an encoder over a channel. Communication noise can be any of the following:

- Physiological impairment noise – physical acuity affects perception.
- Semantic noise – different interpretations of certain words lead to different understanding.
- Syntactical noise – grammar mistakes disrupt communication.
- Organisation noise – poorly structured communication affects receiver's interpretation.
- Cultural noise – not knowing the audience can cause misunderstanding.
- Psychological noise – communication difficulties are caused by different attitudes.

Those that most frequently interrupt communication in the design process are organisation noise and cultural noise. These two forms cause different interpretations of the meaning. If architects use unclear architectural presentations or poorly structured communications, this can lead to inaccurate interpretations. Although the present research focuses on organisation and cultural noise, other forms of noise are also considered. Structured communications, which enable people to overcome noise, were essential to the research. For considering noise in communication, it is important to acknowledge the stakeholders' backgrounds. Organisation and cultural noise are identified as crucial subjects and are taken into account in the design of a communication system and the mock-up platform to be described in the forthcoming chapters. The research investigates stakeholders' experience of digital media in design communication, which concerns the organisation of large amounts of information. An example is taken from the researcher's own experience in working in architectural practices. The architect provides inconsistent 3D architectural representations that cause confusion: if he edits a building's height as a result of a comment from the planner, then presents the work again by showing an old 3D model with recent drawings, can confuse other stakeholders. In the design process, there can also be cultural noise, as different stakeholders have different cultural backgrounds and perspectives on working processes. For instance, Charleson and Pirie (2009), find that engineers are of the opinion that there is a lack of structural understanding by architects, who are often too late in seeking engineering advice. Hence, this research takes the cultural working styles of stakeholders as a subject of investigation and recommends ways of avoiding the delay in communication.

In the design process, architectural presentation plays a significant role in communication. Nowadays, as computing technology improves rapidly, architectural presentation has developed to a stage that is closer to realistic visualisation and works efficiently enough for design communication in some cases. However, there are still some issues in this field. For example, Chen (2004) claims that poor communication processes may be a cause of inaccuracy and misunderstanding. According to Chen (2004:4), whose work is based on Berlo's writings of 1960[12], the communication process between the architect and the client is the compound of a progression of two-way actions. In this communication process, at least one information source and one information receiver exist. The failure of a two-way communication process is the responsibility of both the source and the receiver. The fact that communication is not achieved is because of the differing knowledge of the communicators.

[12] Berlo (1960) describes factors affecting the individual components in the *communication* making the *communication* more efficient. His model of communication focus on sender, message, channel and receiver (SMCR).

In this research, stakeholder opinions and experiences are important sources for finding the strategies that will contribute to design communication. This research also explores digital media use for an interactive communication system that enables communication across the world in this digital era. Collecting data to acknowledge the stakeholders' opinions about and experiences of using digital media helps this research to identify the information that stakeholders need and how they would like to experience the media. This research focuses on stakeholders as active rather than passive users. The benefit of being active users is that they are able to 'pull' the information they want, while passive users have to wait to receive information from the senders. Pulled information is seen in response to a trend of interactive media, which is used in social media and web-based communication today. Being active rather than passive in architectural practice would be a step forward, as viewer reactions reflect their areas of interest. In addition, being active is useful for social networks, in gathering users' intentions and participation. These are important to a collaborative approach to design. Within contemporary forms of computing, architects can find many tools that provide appropriate means to communicate designs, as can be seen from the review of digital media in the previous chapter. However, most digital media used in architecture are for one-way communication where information is transmitted from sender to receiver only. There is a need for a two-way, interactive communication. The following section outlines this research intent, to use an interactive digital media for improving communication in the design process. A series of projects are reviewed and analysed and these lead to extending existing ideas as well as generating and envisioning new ones for resolving existing issues in communication and collaboration.

3.3 Advances in digital media used in design communication

As technology and the Internet have developed, people have increasingly used digital media to become part of a connected society. The review of digital media used for communication in architecture leads to the consideration of interactive media for collaborative design.

At present, there are many tools for 3D modelling. One example is SketchUp, which Lopes (2009) describes as an easily employable 3D design tool that can be applied to basic drafting by anyone (Lopes, 2009:9). However, it has limitations in creating freeform, whereas MicroStation or Rhino can assist in generating innovative building forms. In conversation with between Liu, Sevaldson suggested that his ability lies in letting himself be inspired to find new things by working with generative techniques (Liu, 2005:68). These techniques allow him to make individual models of creativity and prevent him from a limited design form. For such innovation, spontaneous and fast output is important, enabling effective communication of ideas to support creativity. Demonstrating fast output is becoming critical for the digital age. Lumion (2015) offers real-time modelling where the user can instantly see the effects of the changing design. It is useful for communication with clients to show a realistic representation. In addition, it is less time consuming to carry out the modelling, and outsourcing is not required for making images or videos to persuade clients. Additional tools of virtual reality (VR) and augmented reality (AR) are used to help people to experience architecture in real time. Continuing technological advancement, including 3D modelling, rendering, animation, VR and AR, are constantly improving working processes. In addition, programmes such as SketchUp or 3ds Max enable the user to import ready-made templates of a 3D model. Hardware technology also significantly helps people to use digital media. Such hardware includes HoloLens from Microsoft, which extends 3D modelling software by bringing a 3D model to life as a full-scale hologram. This enables people to experience architecture as VR. A combination of hologram and 3D modelling software creates new ways of communication and collaboration for people working remotely across the world (Microsoft, 2015).

Communication in the design process has become global. For example, international companies must communicate via the Internet because of the different geographical locations and time zones of team members working on a project. Bermudez (2011) notes that portability and the Internet can be used to improve the design process; digital power is becoming more affordable. These advanced tools are available to help workflow in architecture. This research reviews tools and platforms used in architecture to help identify relevant contributions and understand what is needed for communication. Therefore, the feasibility of a communication system is investigated to make the best use of the range of available technological tools. Exploring research across digital media disciplines such as a web service or a mobile application, finds potential ways to improve communication between isolated members involved in a project. Consequently, a design communication system that helps create a communication platform should be concerned with all users' requirements, and this forms part of what is being proposed by this research. Using interactive media corporately with user-centred design is a notion for architects to consider in improving design communication, both now and in the future.

The following section introduces projects that highlight the use of communication tools. The five projects described in the review offer strong evidence of development in the area of collaborative design communication.

3.3.1 Overview of projects

This section explores each project to identify the main components of the digital representation or communication tools. The selected projects introduce three categories of ideas generated from literature reviews relevant to improving the workflow, which are realism of computer-generated presentation, virtual environment, and 3D interactive information. These are described further on. The section starts with an introduction to the projects and is followed by an explanation and analysis of their characteristics.

Digital media have developed in recent years and have consequently changed the style of working. Under investigation are projects using 3D modelling technology to communicate virtual worlds and virtual information to viewers with different architectural background knowledge. A review of the various projects informs the methodological consideration of the present research. Five projects were chosen to reflect different communication systems including linear and interactive ones. The projects can be categorised into three types according to their attributes:

i) Realism of computer-generated (CG) presentation
ii) Virtual environment
iii) 3D interactive information

The three types of project explore digital media for design communication through practical work. Realistic representation is normally used to demonstrate materials, such as brick, wood and concrete. The audiences are presented with images. The VR brings the audience into a simulated environment that contains architectural information. The 3D interactive data requires the user to interact with the information. All three types of projects enable viewers to understand how to communicate architectural design and to use the provided relevant data. Although they are all different, each one involves digital media, which is being deployed to help communicate the design.

3.3.2 Review of projects

The projects have been selected from three categories based on the purpose for which digital media is being used. The research exploration across three different categories revealed useful contents and available applications for interactive digital media to engage with communication in architectural practice.

This research considers user experiences with the projects to inform the methodology. The reviews of the projects also provide useful content, which informs the application of interactive digital media to communication systems in architectural practices. The projects are considered in order to identify problems, benefits and potentials in communication. The idea is to enhance methodologies for adopting interactive digital media into the ultimate communication system design.

i) Realism of computer-generated presentation

The project considered under this category depicts realistic presentations using computer-generated (CG) imagery**.** The project is part of a research project by Bates-Brkljac (2012). He explores different types of visual representation used in architecture and finds the best tools for audiences. The project, titled; "*Photorealistic Computer Generated Representations as a Means of Visual*

Communication of Architectural Schemes in the Contemporary Culture", investigates the perceived credibility of architectural presentation as art, science and technology that combine to make communication more realistic by using methods similar to photorealism and other ones used in the film industry. Yet the image produced is still not clearly understood by the viewer. The project examined understandings by different groups of participants and compared the realism of CG representation to the realism of hand drawing used in design communication. The result of participants' ability to effectively communicate design schemes is using CG photorealistic representation (Bates-Brkljac, 2012).

Figure 3.1: **Rendered 3D computer model used in Bates-Brkljac's research (2012)**

The image in Figure 3.1 shows a CG presentation based on a 3D model, whereas that in Figure 3.2 shows an image where 3D modelling was combined with photography. Bates-Brkljac (2012) claims that CG presentation shown through depiction that "looks like real life" makes design more comprehensible. This research, therefore, closely focuses on CG presentation, including CG photorealism, which is lively and has a powerful influence on people's perceptions.

Figure 3.2: **CG photomontages used in Bates-Brkljac's research (2012), which were perceived to be the most realistic forms of representation**

The researcher agrees that CG photomontage is highly effective, especially from the point of view of the planning officer, who is closely concerned with building and context. Designers favour 3D modelling as it represents a piece of art and can be used for advertising. CG presentation is widely used in contemporary practices because it is easily understood and appreciated by audiences. Sharing or accessing files is also convenient as many applications can support it. However, both 3D modelling and CG photomontage can lack accuracy as the image can be technically distorted. This often happens when the image is used for different marketing purposes. This method involves one-way communication as architects offer their perspective with no response from stakeholders. Moreover, producing realistic images requires advanced technological skill and high computer specification, which might not suit small practices and projects. Therefore, it can be argued that CG presentation still has some disadvantages.

The framework of Bates-Brkljac's project informs the present research. It focuses on considering architectural presentations that suit stakeholder requirements. The research considers not only CG presentation but also other tools that have recently emerged in design communication. As such, the research focuses on the use of digital media technology in architecture. New methods and technologies are also explored to find appropriate architectural presentation tools to use with the communication system proposed by this research.

ii) Virtual environment

Two project examples concerning virtual environments are reviewed here**.** The first project is the research of Fukuda *et al.* (2009), who uses 3D modelling with urban information to create a public space.

This project reproduces an urban area, which shows the problems that people and businesses have in leaving the city. There is an increasing requirement for the effective use of open street space. For this project, VR and consumer-generated media (CGM) are seen to be effective communication tools among stakeholders. The VR system and blog used in this project are intuitive and easy to understand. Subsequently, evaluation is conducted by considering an actual design project as a case study (Fukuda *et al.*, 2009).

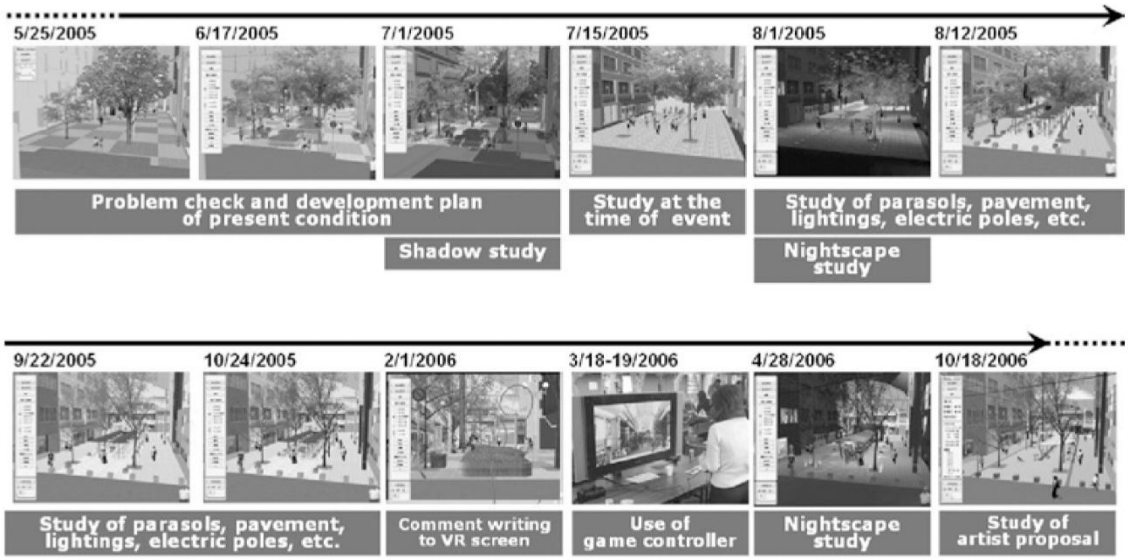


Figure 3.3: **Application process of virtual reality (Fukuda *et al*., 2009)**

This project is concerned with enabling citizens participation in producing a design scheme using VR and a blog, which opens up new possibilities for design communication. The advantage of this project is that it demonstrates design work over a period of time, which can predict changes in design. Hence, it is an innovation for early stages of the design process, but this specific system may be too complicated for small architectural practices as they are unlikely to be able to afford the toolkit and to have the specialist knowledge required. The present research takes the idea of participation and adapts it by obtaining participants feedback and visualising the design to better explain it. While for Fukuda *et al.* (2009), a project is a platform for collaborative design, aiming to depict a particular idea in a specific location, the current research extends this concept so the communication system can be widely used across projects for the built environment.

The second project, by Kumar *et al.* (2011), develops a virtual facility prototyping the framework for an application for stakeholders in the design review of healthcare facilities. A 3D game engine is used to develop the experience-based design review application and the framework creates scenarios based on a design review system. Subsequently, the system is used to develop an experience-based virtual prototyping simulator (EVPS) application. A workflow of design information is developed and evaluated by various BIM enabling tools, and the 3D game engine ‘Unity’ is used to develop the interactive virtual prototype system (Kumar *et al.*, 2011:85–104).

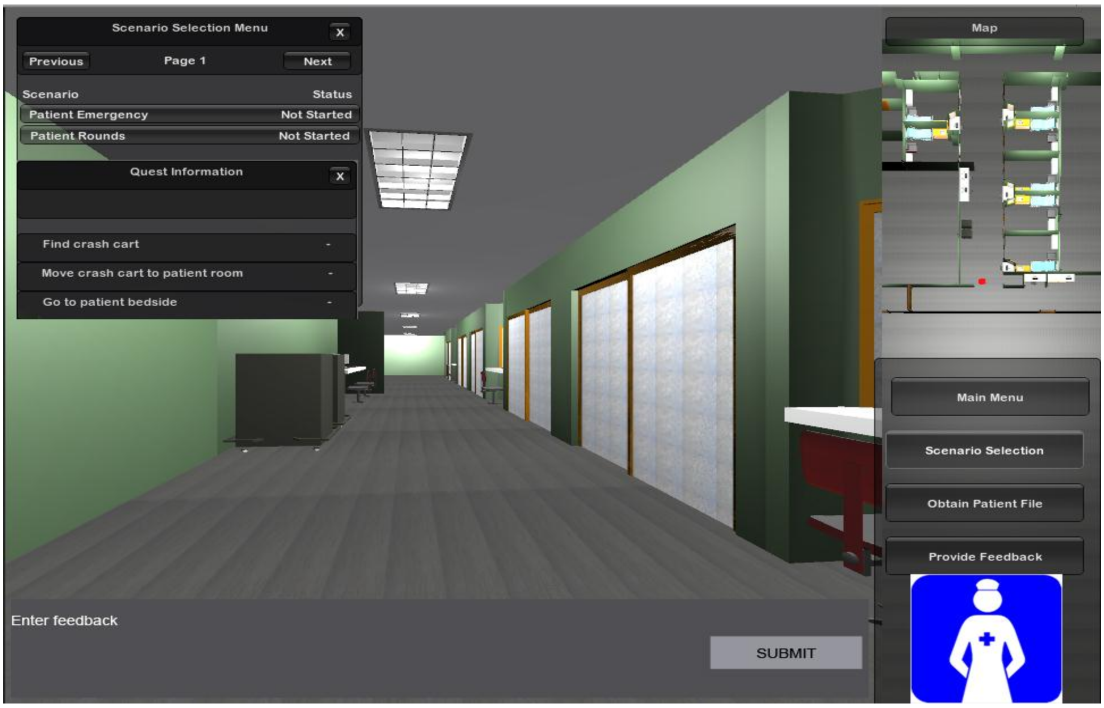


Figure 3.4: **Screen shot from the EVPS for healthcare facilities (Kumar *et al*, 2011)**

This project uses a facilitative system to achieve the best results of the design, considering user interaction with the simulation of using facilities in a specific healthcare context. The framework of this project was interesting to this research, which intends to develop a system that enables communication in the design of the built environment. It encourages users to inform the design of the building to provide feedback and comment on how they experience the design. The system design adapted the investigation into stakeholder experiences to develop through interactive media, which focus on inclusive communication.

The project by Kumar *et al.* (2011) offers core elements, especially interaction for laypeople, and this is key to the current investigation. To create interaction, the interface needs to be designed to enable people to navigate. Combining 3D virtual space with 2D graphics enables development of design communication being proposed in this research, encouraging users to perceive themselves in a virtual world as they manage architectural information. The use of interactive 3D modelling to enhance viewers' perception of the virtual world is something to be emulated. However, the use of plain geometric modelling without artistic rendering and the extensive use of text at the expense of graphic representation have negatively affected the quality of this communication tool.

These two project examples, have attempted to develop communication by using an interactive virtual environment**.** Although many researchers have investigated developing virtual space, it is rare to find this kind of representation used in contemporary architectural practices. The reason it is not used widely is that tools and production time present barriers. Therefore, the research considers a method that can adapt existing tools in architectural practices to a virtual world concept.

iii) 3D interactive information

The project examples described in this section are concerned with using 3D modelling to explain and manage information to understand content easily. The first project uses 3D modelling to visualise a university campus in Canterbury, UK.

The uCampus project by Peng (2011) is set out to test whether an open-source interactive virtual 3D modelling platform can support institutional learning and innovation. The paper reports and reflects on the key findings from the UK JISC-funded 'weCAMP-uCampus' project. A web-based 3D interactive campus visualisation platform is developed and applied using Java and XML-based open source technologies. The project is created from three principles of development: content generation, software design and user engagement. One of the significant outcomes is an approach to visualising large complex datasets incorporating multi-scale and multi-layered 3D campus modelling (see Figure 3.5). To test the platform of uCampus, the Augustine House at Canterbury Christ Church University is examined (Peng, 2011).

Figure 3.5: **An assembly of a uCampus model built entirely in X3D (Peng, 2011)**

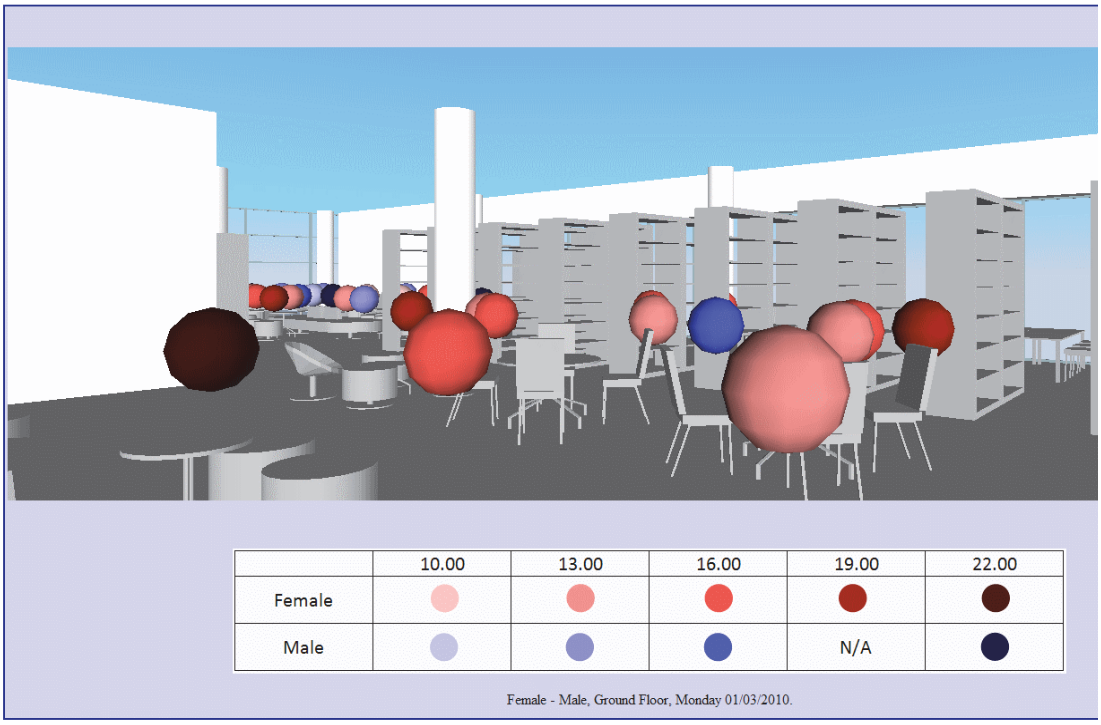


Figure 3.6: **Direct user navigation inside the Augustine House as a multi-layered X3D model (Peng, 2011)**

Figure 3.6 shows an example of how digital modelling represents types of user, as well as time and frequency of using the facility. The project is an example of how data about areas, facilities and users of the building can be brought together. Graphically illustrated data are easier to understand, and using 3D demonstrates information in an engaging way. While the uCampus project is concerned with educational buildings only, there is an opportunity for architects to consider using similar ideas more widely. In addition, the project is another example of an open source web-based virtual campus modelling application which makes it convenient for users to access the information. The project thus influences the present research to consider web-based applications as tools for collaborative design in architecture.

The second project, in the Solomon Islands, develops modelling tools to communicate with people during post-disaster reconstruction, some of whom lack technological skill. Digital architecture is applied to humanitarian design, to investigate one of the most technologically challenged scenarios, by applying architectural computing in remote areas of developing countries. This project presents a case study of on-going disaster reconstruction and forms part of a research project by Yeung and Harkins (2011), on the application of ‘high tech’ approaches to humanitarian design in ‘low tech’ contexts. A system of digital tools, in particular parametric modelling and BIM, are devised to optimise a standard design for specific sites, support specific requirements, and reduce the time and cost needed in the overall design. The authors devise and test the tools, based on a real project to develop a system of digital applications.

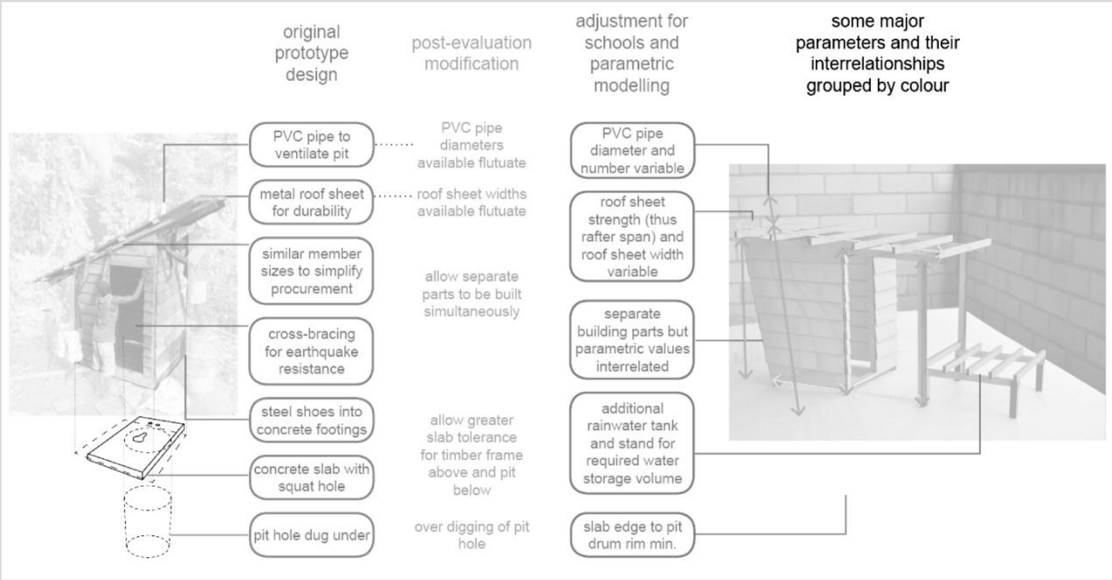


Figure 3.7: **Translation of lessons learnt in Yeung and Harkins’** (**2011**) **work.**

The system described here enables a high level of automation throughout varying stages of the project. In addition, it shows that it can help reduce time and error. The visual variable control created from Grasshopper works with information from an Excel spreadsheet. Today, 3D modelling is used to visualise architectural information and construction. This sample of a small design project primarily uses 3D modelling and text (see Figure 3.7). However, this tool would also be useful for a larger project, which allows visual demonstration to help people understand the project. The present research takes the notion of developing a design prototype to use for isolated collaborative design, in order to mitigate the remoteness of stakeholders.

These two examples of using 3D interactive information in communication will inform the current research in making use of 3D modelling as part of an information management system. The research aims to demonstrate the design of a building and to manage architectural information through interactive media in order to present how to improve communication in the design process. Therefore, an interactive communication system is needed to inform the content of interactive digital media. In addition, developing an interactive communication system with feedback from stakeholders is crucial for the evaluation of the system. Hence, the research should not only concentrate on developing a system, but it should also deliver a mock-up of the platform to demonstrate how the system could operate in practice.

All of the sample projects in this section provide ideas for using selected tools to approach a research methodology. These reviewed projects offer significant ideas for dealing with architectural information and stakeholders who are from different backgrounds, by using digital media as a tool. The review of these projects has informed the present research methodology, where collecting data from participants is a significant approach and knowing their background is crucial. In addition, the analysis of the projects enables the researcher to find effective architectural representations, channels and relevant issues in design communication, and leads to recommendations for interactive media for collaboration in the design process. Although workflows in contemporary architectural practices currently employ tools that are integrated into a network, they do not widely use interactive 3D models for collaborative design. Therefore, the research considers using an interactive 3D model together with other appropriate tools to support collaborative and interactive design communication among stakeholders.

Other researchers have worked on improving collaborative tools, but often these tools are complicated for people who do not have high levels of technological skill. The present research attempts to contribute to design communication by considering tools that are used not only in architecture but also in other design disciplines, with a view to improving communication and promoting collaboration. The intent of the project is to put forward a communication system that is easy to use and enables designers and stakeholders to interact with information, contribute through feedback and collaborate as part of the design communication system.

3.4 Emerging interactive digital media in the communication of architectural design

This first part explores interactive digital media in architecture. The discussion involves the analysis of interactive tools used in architectural design and the possibility of deploying them as part of design workflows. This is followed by a section where the potential of using such media in an interactive design and communication protocol is discussed.

3.4.1 Current interactive media tools

This section reviews the uses of interactive media in the built environment. The review considers existing types of interactive tools used for communication and data management as this is an area of interest for this research. Creators of interactive tools are trying to simulate immersive environments and use them for design communication. They are also using technical systems to enable the interactive design of arts installations that give visitors a new experience. The first kind of interactive tool is VR, a powerful tool that is undergoing fast development by a number of technology companies. In architectural practices, the use of VR is normally restricted to large scale projects with budgets to match. Perhaps the reasons that VR cannot be used widely in architectural practices are the costs and technological skills required. Hence, it would be an opportunity to consider developing VR to be less costly.

The second kind of interactive tool that could offer a potential to this research project is the use of interactive art installation. This requires the observer or visitor to interact with an interface, computer or sensor, until a response to a stimulus is obtained. The stimulus could be the visitor's motion, voice or temperature. This kind of interactive media can also be used for designing building surfaces or urban spaces. As it is not used for communication in the design process, its usefulness to this research has been excluded.

Interactive media can be produced for many purposes; design communication tools and asset management tools are examples. For instance, an application on mobile devices called 'iVisit 3D' by Atlantis Studio is an interactive tool that was developed for architects and designers. It presents a virtual world that allows users to obtain panoramic rendered views and enables them to pan, zoom in or out and ‘pull’ what they seek. Using this application requires ArchiCAD and AutoCAD 360 rendering. As shown in Figure 3.8, the application simulates the real environment through which people can imagine themselves walking or flying in the virtual world. While the application supports presentation aspects, it does not include a data management capacity to facilitate the design process. Therefore, the research investigates the data management aspect as well as working on architectural representation. Furthermore, due to its requirement for user technological skill to install the application and plug-ins, this tool is not appropriate for non-specialists to access. It also does not allow input from stakeholders such as planners or engineers.

Figure 3.8: **Sequence of images showing simulated environment from iVisit 3D**

In another example of using 3D VR, the ‘National Anping Harbor Historic Park’ project in Taiwan enables users to embed information about the city within the web environment (Lan and Chiu, 2006:479–486), as shown in Figure 3.9. The project shows the benefit of using 3D city rendering, which is interactive and allows the users to change viewpoints individually, as well as integrating urban information such as 2D maps and a statistical table. As the platform is used through a web browser, it has the advantage of enabling collaborative interaction and design. Such capability for communication and collaboration between people is important, and this aspect is investigated in this present research. The 3D city model can be used for communication or data management, enabling the user to view perspectives and information. Interactive media can be structured differently according to whether the purpose is communication or data management.

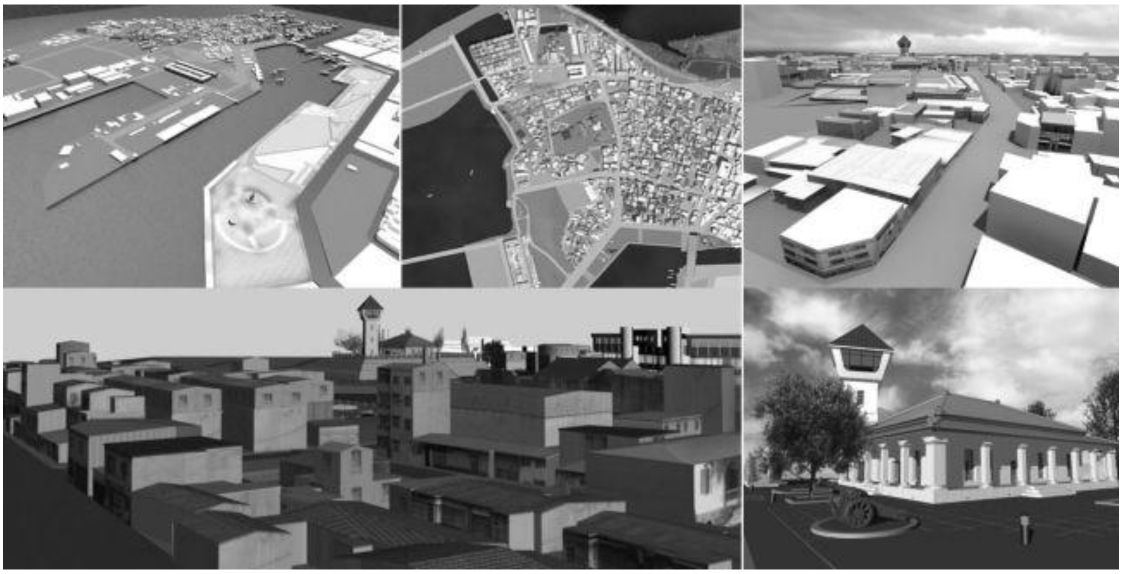


Figure 3.9: **3D city model of the National Anping Harbor Historic Park project (Lan and Chiu, 2006)**

Data management is another purpose of the use of interactive tools that this present research is interested in exploring. For example, integrated space management system (ISMS) created by Kim *et al.* (2015:807-816) used a 3D-based model for asset and space management system to visualise information of Incheon International Airport. Their project works on an asset management system integrated with 3D computer-aided design (see Figure 3.10).

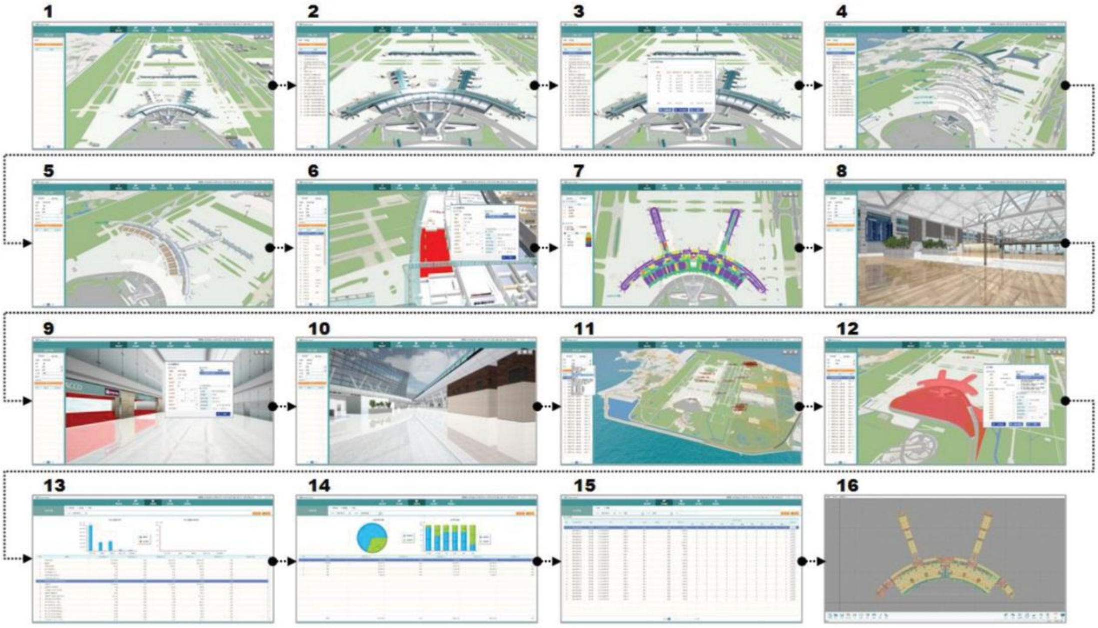


Figure 3.10: **Integrated Space Management System** (**ISMS**) **operation screens (Kim *et al*, 2015)**

Another example is the research carried out by Nakama *et al.* (2015:397–406), collaboratively with professionals who had similar background knowledge levels in the built environment, such as the engineer or architect. They created a facility management system called 'Building Information Management', aimed at energy saving and reducing running costs of the building. The aim of their project was to provide 3D visual information that does not require expert knowledge by users. It enables users to use a web browser to open a platform (see Figure 3.11).

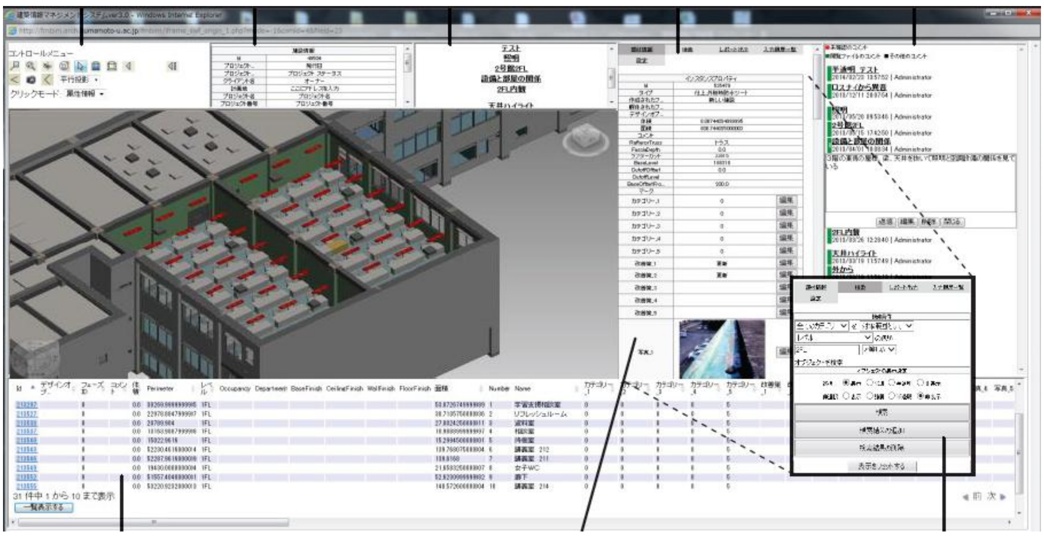


Figure 3.11: **Interface of the Building Information Management system (Nakama *et a*l, 2015)**

Management systems are efficient for their workflows, but a web-based system for communication has not been considered for users who have different technical background knowledge. They are often used for management purposes and not widely employed as collaborative communication tools. Therefore, the present research combines features of a communication system and a data management system. This idea is particularly interesting to the researcher, proposing a communication system that encourages collaboration in design communication by focusing on supporting both specialist and non-specialist knowledge. Therefore, this research is interested in communication systems using web-based approaches. It focuses on the concepts of accessibility affecting professionals in the built environment, using different available software to communicate with each other. This leads to the idea that people can work on general and open software, such as Internet web browsers.

3.4.2 The opportunity for interactive design

This section explores opportunities for emerging interactive communication in collaborative design. The literature review of interactive media considers its use and the limitations of software, cost and skills involved. Finding a tool that has easy access features shows great potential for specialist and non-specialist users.

Central to creating efficient interactive media are a structured system and interface. Users navigate with icons and learn to predict what will come next; they should easily understand both the content behind the icon and what the icons represent. This should be designed not only for the media content but also for a meaningful interface. The literature review shows the usefulness of interactive media and its potential for future development. Nevertheless, interactive media sometimes are hard to access by users due to a lack of technological skills. Therefore, the concept of the present project is easy access, especially for stakeholders who work on different software. Currently, stakeholders encounter problems when opening files from incompatible software. For this reason, the research proposes an interactive communication system that works and can be displayed online through common software such as Internet web browsers.

In order to create interactive media, designers need to know about their audiences. In addition, designers need to identify audiences' requirements in terms of media content, as stated by Wong (2013) in her work on 'pull' media context. Therefore, the present research takes into account the background of stakeholders and their varying roles in the design process to enable them to make decisions about what information to put into a design communication system. It is essential that the architect knows the requirements of stakeholders and employs communication systems through interactive media to present design information and receive information from other stakeholders. In order to achieve the ultimate aim, the present research introduces a communication system that shows architectural representations integrated with interactive communication between stakeholders. Although there is a lot of architectural information in even a single design project, the system tries to simplify complex data by structuring, categorising and organising it. Creating the mock-up will help stakeholders to understand how the communication system facilitates the design process in terms of communication and collaboration.

The practical output of this research is to design a communication system and to use existing interactive digital media tools to collect feedback from participants. The software that seems to have the most potential for use in this research is Unity. This is a modelling software with both 2D and 3D features, able to create media content. A game engine software such as Unity has limitations for 3D modelling, in comparison to other 3D modelling tools used in architecture. For example, there can be errors in the display of surfaces and materials. However, this issue can be solved by building the model in other 3D environments before importing it in to Unity to create the content of the mock-up platform. Finally, the mock-up has to be exported to a web browser (Unity, 2015). The Unity software has an advantage in producing real-time effects on the 3D model, without the pre-rendering that usually takes time in other 3D rendering software. In addition, Unity allows people to actively access the mock-up in real time on the web browser, on which they can view 3D interactive models. This research anticipates that future developments would enable the platform to work conveniently for computers, tablets and mobile phones. It would be a step forward for other software and hardware developers to design products to support collaborative functions.

3.5 Experiencing interactive media

This section outlines the user experience of interactive media and describes trends in using interactive media for design communication in architecture. One form of interactive media that have much influence on people today is social media; the final part of this section explores the impact of social media on the issues at stake in this research. In order to identify important contributions to design communication and collaboration, this research investigates what characteristics of interactive media offer for stakeholders can simultaneously exchange information within a dynamic communication system.

3.5.1 Interactive representation

This section describes the diverse experiences of users who use interactive representations, which depend on their technical backgrounds and affect their perceptions differently. According to Luppa (1998): “The user deserves and prefers an attractive look to their experience. As a general rule, the look should be designed to match the objective of the programme.” The same research offers an opinion on media designers by stipulating that they should be significantly concerned with the objective of the project. They design media to convey messages and information, responding to project objectives that they have already planned. However, media users have different background knowledge and experience of media, as well as different perceptions. These differences present a challenge for this research, as they require adequate methods to support various stakeholders.

The need for users’ interaction with media is pushing designers to create interactive media that responds to users’ aspirations. In order to conceive a communication system that leads to the development of a mock-up, one needs to know about users’ actions and to predict their responses. The design of interface tools (icons, buttons and symbols) in such a system needs to be meaningful to clearly represent messages, information or functions. In addition, the interface design needs to be as intuitive as possible. Regarding interactive system design, Luppa (1998:71) states that the principles and tools of human interface design are advancing rapidly, and the best design allows interaction between users and given information. However, Lopes argues that the trouble with ‘interactivity’ is that the term is almost meaningless. It represents so many different things in several different situations and has little potential to suit all explanations (Lopes, 2009:36). This conclusion leads the researcher to consider how to simplify the complexity of a web-based design communication tool. Luppa (1998:65–66) presents several design principles based on a summary of those published in *The Apple Human Guidelines*:

- Simple design is an idea and good design must communicate and indicate what objects do, so that users can recognise them and navigate them.
- Users deserve and appreciate attractive surroundings.
- Consistency should be valued over individual cleverness.
- The transfer of skills is the most significant benefit of a reliable interface.
- The environment should appear to remain stable, understandable and familiar.
- There must be slight or no difference between what appears to users and what they receive.
- The user should control the action.
- The interface should stimulate the feeling that the user is involved.
- The user should be notified of what happens via message.
- The interface should use metaphors and these metaphors should be enhanced by audio and visual effects.
- Animation is one of the best ways to draw a user’s attention on the screen.
- A way out should always be provided.

These guiding principles will inform the design of the communication system and its mock-up being put forward by this research. However, for a specific application such as the communication system in architectural workflow, specific data from actual end users is required.

According to Luppa (1998), there are guidelines that the designer should consider when producing media. Web designers develop interfaces to be user friendly, so everyone can easily use the platform. For example, Facebook has a simple interface, which uses plain colours to indicate the way information is organised, as its users include people of different ages and cultures. Nerby (2013) states that Facebook started with an understanding of user behaviour to create a means for people to connect with each other for different reasons. By systematically studying user behaviours, Facebook designers thereby created a powerful experience. In the present research, the central idea for the communication system is conceived around the consideration of users' backgrounds, including their requirements as a key point; from this information, a mock-up is designed. In fact, user background plays a role in all areas of design. A designer has to investigate the nature of users depending on a project. In addition, the research explores human–computer interaction (HCI), which strongly focuses on the user interface. In general, the interface determines what is possible for the user to achieve from the computer system. Norman (2013) explains the interaction design principles of HCI as follows:

Visibility – Users will be able to exactly predict what step should come next, if the functions are greatly visible. In contrast, when functions are invisible, it makes their use more complicated.

Feedback – Feedback is about sending back audio, tactile and verbal information. Combinations of these forms of information can represent feedback on what action has been done and what has been accomplished. Feedback can also be used to encourage the user to continue with the activity.

Constraints – The conceptual design of constraining refers to determining behaviours of interactive restriction. There are various ways this can be achieved.

Mapping – An example of mapping between control and effect is the up and down arrows on the computer keyboard being used to represent the corresponding up and down movement of the cursor.

Consistency – Consistency refers to designing interfaces, which are consistent and use the same elements for carrying out similar tasks. A consistent interface is necessary so that whatever environment the icon needs for an operation is clear.

Affordance – Affordance refers to an attribute of an object that indicates to people how to use it. For example, a mouse button cues even a novice user to click it, so it is intuitive. At a simple level, affordance means ‘to give a clue’. It is easy to know how to interact with a physical object when its affordances are perceptually obvious.

This section has introduced the principles of user experience (UX) and user interface (UI) design, thereby addressing HCI. The guiding principles for the communication system and interface design of the mock-up have thus been identified.

3.5.2 Trends in using interactive media in architecture

Architects should constantly consider the trends of the digital world so that they situate themselves in the right environment. In terms of presenting architectural information, instead of ‘push’ processes, the present research approach focuses on interactive media that ‘pull’ audiences to information as well as ‘pulling’ information out of them. This research aims to improve communication in architectural design by proposing an interactive communication system that assists architects and stakeholders to gather design information and connect people in the design process. There is no explicit research on interactive media for communication between architects, engineers, planners and clients. However, there are some implicit relationships with interactive media created by researchers and companies in the architectural industry. Interactive media have been developed for different purposes.

In a digital environment, forms or platforms of work and interactive media are engaged and influenced by the Internet. Digital media is used with three disciplines in particular. Information architecture (IA) is a discipline in which researchers work in a shared information environment. They work together as a community and generate practice, which brings together design principles to the digital environment (Wurman, 1997). Social architecture (SA) is a support requirement of social behaviours, leading to established goals. The social system aims to modify people's behaviours through a workshop or programme then improve those behaviours by seeking member involvement (Gatsby, 2014). Interaction design (ID) is defined as "the practice of designing interactive digital products, environments, systems and services" (Cooper *et al.*, 2007). ID focuses on user behaviour rather than emphasising the outcome or determining how satisfied users are with the outcome. The present research works on both IA and ID. The idea started with IA by focusing on sharing and organising information, then developed to looking at how information is conveyed to users, which concerns ID. These three disciplines are important to designers when they develop communication and information systems, online communities, software, websites, digital products, or media.

Social media has the potential for design communication between architects and stakeholders. Poole (2011) observes that social media use of web-based and mobile technologies, allow for the creation and exchange of user-generated content and provide a structure for people to organise, exchange and collaborate. Social media allows for interaction on a global scale and make it possible for users to add content or commentary and to form communities. Digital space, such as social media networks, benefits from flexibility, as it generates a space for users to carry out a wide range of activities. Therefore, the trends of digital media should be investigated.

Designing systems that support communication and collaboration among small and large groups of people over computer networks is the interest of research work, such as those of Erickson and Kellogg (2000), Shen *et al.* (2010) and Shami *et al.* (2011). Speed and Southern (2010) describe how smartphones are becoming standard and how the navigation of physical and social spaces is changing. Apple iPhone and Google Android contain powerful platforms, such as one to explore rural and urban landscape (Speed and Southern, 2010:164–172). Mobility has become an integral part of society. Understanding social behaviour and the interdependencies among mobile users and their movement patterns can be helpful for data exchange, sharing and delivery services (Kayastha *et al.*, 2011). However, a problem which is often outlined, occurs when people are online or using mobile technologies. They often ignore conversations that take place in their immediate physical space, which can adversely affect collaboration (Gatsby, 2014). Therefore, an online design communication system should be mindful of these users and not work against effective face-to-face communication.

Nowadays, architectural practices increasingly recognise the importance of interactive online platforms. This can be clearly seen from the review in Section 3.4, which deals with new applications. The literature shows that researchers agree that interactive media will be useful for future development. Interactive media is used in daily life for entertaining and working. The interactive systems of social media could benefit communication in architecture. The researcher acknowledges the influence of social media in daily connections and communications. Applying a social media system and content structure to a design communication system used by architects and stakeholders should facilitate the communication process and improve workflow. Therefore, the study of social media is crucial for this research. Examples of social media such as Facebook, LinkedIn, Line[13] and WhatsApp[14] are explored to obtain an understanding of the activities of users and communication systems. The interface design is also examined to understand how users navigate the media.

3.5.3 Impact of social media on communication in the design process

Social media is interactive in its nature and has a huge impact on online users, as it connects people by means of web-based or mobile technologies on the Internet. The network allows individuals or communities to share information about their activities and store it where members can easily access it. Social media should be considered in this research as it has an impact on modern communication, and this implies to communication and collaboration in the architectural design process. This section underlines the characteristics of social media that can be made use of to help resolve the issues at stake for this research.

[13] Line is an application for instant communication on mobile devices and computers. It can create voice and video calls as well as group or individual conversation. It is possible to send images, audio or videos. There are many applications that can be added, such as games, TV and photo editing.

[14] WhatsApp is a mobile application for free exchange of messages.

Described in various forms of online social activities such as collective action, communication, collaboration and networking, social media generates creative content through the playing and sharing of users (Fuchs, 2017). Social media is an innovative tool that allows people to turn communication into an interactive dialogue and enables them to interact with one another using web-based and mobile technologies (Baruah, 2012). Nowadays, social media has an impact on our life and work; it is used for collective online information, communication, interaction and participation in networks. Users can generate content to share and form collaborations. Today, people can reach information from anywhere, as the Internet and mobile devices allow a flexible access. Real-time communication is used to connect people any time and any where. Lehman (2017) states that the world has become smaller and more social; mobile technologies enable architecture to be perceived internally with the real-time communication of social media. In addition, Chayko (2017) finds almost 40% of the world's population used the Internet, with mobile phone subscriptions at over 7 billion. An increase in mobile phone users has generated a social network that provides pathways to sharing resources, opportunities and information between people, as well as establishing community and connection. Her book describes techno-social impacts on the way people live, the way they think and the way they associate with others. It is undeniable that social media is embedded in people's lives today. Therefore, this section requires consideration of the relevant impacts of social media that can be adapted to use in communication and collaboration in the built environment industry.

Social media characteristics and objectives have been studied and identified to create an effective content which aims to reach widespread audiences. DeMers (2013) suggests that strong social media content should generate 'traffic' (making people visit the page), generate a 'following' (inspiring viewers to subscribe and follow a social channel), promote 'interaction' (comments on posts) and create 'revenue' (earning money from posts). Kietzmann *et al*. (2011) explain that use of social media has risen and that corporate communication has been democratised. Several kinds of media have been created, shared and consumed: blogs, tweets, movies, pictures and so on. People must consider whether or not they should engage with social media; it has a significant impact. Although social media has several functions, the emphasis of this research is on the attribute of ‘interaction’, as this enables stakeholders in the design process to communicate in real time, distribute information and engage with it, as well as contributing to a collaborative working process. The interest in interaction does not extend to the quantitative aspect of stakeholders partictipation as the numbers involved in any interactive process are not the focus of this research. The reason is that the design process should operate according to professional working standards rather than informal communication input, which can be affected by motivation, frequency and emotional aspects. These will have an impact on the decision-making process.

The research identifies issues emerging during the design process between stakeholders, such as miscommunication, the range of technical backgrounds, incompatible software usage and inconsistent distribution of information. There is a potential for this research to overcome these issues by exploring social media in terms of its use and impact when applied to the communication of design, as follows:

Range of technical backgrounds – Issues may arise when stakeholders coordinate work, as there are different levels of architectural information. As BIM is used to integrate AEC practitioners working on a single model with multi-layer information (see more details in Section 2.3.3), users require training and this presents a barrier to those with a non-technical background. Architects should consider using a platform that is accessible for the lay person, such as planners or clients, to coordinate information. The concept of social media is to create and share content to audiences: it can be applied to architectural representation, where architects need to create content which includes all information about the design project, such as 2D drawings and 3D models or animations. Stakeholders in the design process are the audience and they may have a variety of backgrounds. As Sawyer (2011) states, cultural differences influence communication, behaviour and values. Dakroury (2014) explains that culture includes norms, traditions, languages, myths and ways of life, and these in turn influence media content. Undeniably, various backgrounds in the design process include technological skill, architectural knowledge, cultural organisation and career type; these factors affect perception, interpretation and communication. Facebook is an example of a social media tool that has been most used for connecting people over recent years, responding to users' preferences according to age, gender and culture. It is designed for a wide range of people from different backgrounds. Visual representation through graphic design should provide friendly interfaces. Site maps should be easy to use; moreover, applications should respond to users' requirements and suit users' activities. This concept should be considered to identify stakeholders' requirements and their activities in the design process. Subsequently, information architecture (IA) and interaction design (ID) should be simplified to improve communication and collaboration within the design team.

Sharing incompatible software – Technological attributes of social media enable users to upload material in various formats such as .jpg, .pdf, .mov and so on. Many social 3D modelling websites such as 3D Warehouse and Sketchfab allow users to upload, share and follow others; users working on various form of software or even different versions may experience problems in opening files. These resources allow compatible file formats that people can share, so the time and cost of modelling are saved. Architectural software vendors attempt to encourage compatible BIM software to architectural practices. Finding compatible files to work with is necessary to introduce to the built environment through social media, because information can be distributed more quickly than before. In addition, the characteristic of sharing through social media is significant for finding and receiving huge amounts of information globally. YouTube is an example of an innovative website in which people can generate content by creating and uploading videos (Sawyer, 2011). This source is for sharing and seeking global information and is beneficial for the architectural industry as knowledge, techniques and creative ideas can be shared.

Misunderstanding in communication – This is distinguished into two issues: misinterpretation of architectural representation (not understanding drawings or models), and misunderstanding of design and information purposes (conveying wrong information to receivers or presenting information that does not meet receivers' requirements). In an era of advanced technology including high speed Internet, social media characteristics as such real-time conversation could help to overcome these issues, as stakeholders can contact each other and access information more quickly, more conveniently, and with greater flexibility and less cost. Real-time communication is an important attribute for this research to explore, as it connects people through technologies that enable users to exchange messages simultaneously. This encourages people to communicate and to clarify vague information immediately, allowing stakeholders to speed up the design process. In relation to this, there are free voice call and video call tools, that can be used to capture and send images in real time through chat rooms, email or third-party applications such as WhatsApp and Skype, where users can also get feedback and comments simultaneously.

The capability of VR simulation represents another advance in technology. The Internet allows users to view and create connections in a social community such as Facebook, which has 360° features to view an environment, and Sketchfab, which enables users to upload 3D models that can be displayed, edited and shared. These attributes of social media impact the methods of architectural representation. As viewers can access and explore the models by themselves, problems such as misinterpretation or sending wrong information are mitigated.

Inconsistent distribution of information – Architectural information contains a collection of data that forms a series of architectural representations. As this is a complex data type, problems may occur when information is presented inconsistently, causing confusion and leading to misunderstandings and conflicts. Presenting and storing information on a timeline, as seen in many social media applications, shows viewers the oldest to the latest information. In addition, storing information showing the date and time helps users to find material directly and consistently, and it can also be used for reference. There are some examples of social media that are not only used for communication, but also to store information and memories. For instance, Dropbox stores files for both private use and for sharing, keeping information until users delete it. Conversely, some applications are just for fun, such as Snapchat which stores a story for 24 hours then will no longer show it, or Instagram which keeps images and videos until the user deletes them and has a story feature which can play videos for 24 hours. For the built environment industry, communication is at a professional level and information is important, must be accurate and exists in both current and archived forms. The research considers that the characteristics of social media to archive information in the long term would be beneficial for workflow, even when the project is finished; information such as specifications and material suppliers can be applied to further projects.

Stakeholder behaviour – The design process involves many stakeholders, they might be slow taking actions or delay involving. The use of social media impacts the way people act within the process and update information. This can be applied to communication methods used during the design process, allowing stakeholders to monitor the work in progress.

People can still be connected when on the move; bridging the real and the virtual worlds, and followers are aware when people are ‘available’ or ‘hidden’. Kietzmann *et al*, (2011) propose the idea of a ‘honeycomb framework’, which demonstrates social media functions that each party can adopt to develop applications depending on different purposes. One of the functional blocks in this framework is presence. This function impacts stakeholders’ acknowledgement by showing a presence or a status, in order to know who else is available. This is an advantage in that if someone wants to speed up the process when another party might require privacy, stakeholders can notify others of their status and avoid getting interrupted. In addition, it is possible for people to hide their status, but keep monitoring the project at the same time. Regarding social media functions, public presence is the users’ responsibility and is up to users’ consciousness. This is a relationship medium allowing a high level of communication.

Participation required/politics – Stakeholder participation is required for decisions to be made at each step of the design process. There are political power concerns in the design process. Although social media concepts empower motivation and voting, which allow users to demonstrate their power by the number of ‘likes’ and views, decision making in architectural terms is not concerned with such activities. Instead, there are political concepts used for media content creation; the focus of this PhD research is to consider the impacts of social media to find opportunities that improve communication in the architectural industry. In addition, social media includes emerging tools for democratic participation (Brabham, 2009; Dahlgren, 2012; Tapscott and William, 2007). Benkler, 2006 states that “culture becomes more self-reflective and participatory”. This approach of using media has a significant impact in bringing people from different backgrounds together and encouraging interaction. Chayko (2017:9), states that, “with the Internet and digital media, new norms (expected behaviour), new values (beliefs) and a new kind of culture can develop.” According to the *2010 Undergraduate Fellows Report* produced by the Berkley Center for Religion, Peace and World Affairs at Georgetown University: “New social media means that everyone is a publisher and everyone is a critic.” Communication in the online context allows interactive dialogues that establish an understanding of different points of view.

All characteristics of social media mentioned in this paper are critically examined as they influence the thesis proposal. Changes are made to everyday technologies and stakeholders must adapt to a digital society, in which people’s behaviour has changed, including work and lifestyle. This research concerns whether the architectural design industry exploits such innovations.

This section has explored the impacts of social media that can be applied to communication and collaboration in the architectural design process, to overcome problems and conflict. This research aims to not only mitigate issues and address gaps in communication, but also to introduce social media trends that can modernise communities and encourage the employment of innovative technologies such as applications, software and devices. Communication and collaboration tools are not new inventions in architecture computing. Software vendors invest and continue to develop this area to bring professionals together, allowing them to work smoothly and collaboratively. However, there is a lack of evidence to show that architectural businesses are working across social media disciplines. There are many possibilities, such as the exchange of large amounts of data over the Internet that means corporate information is available for users to access, real-time communication that enables simultaneous conversation, and self-driven content creation which gives users an identity. For these reasons, the built environment industry should consider communication from other disciplines to exploit advantageous characteristics that can be applied to the architectural environment.

3.6 Discussion of interactive media for design communication

This chapter has discussed models and theories of communication, which underpin the research. The literature review of digital media tools already in use enables the identification of opportunities to improve design communication, by investigating stakeholders' requirements of digital media in architecture. The ultimate challenge for this research is to propose a dynamic communication system for interactive media design, and to encourage use of the Internet to enable stakeholders to have an input into the design process. The research explores views and background experiences of stakeholders in order to acknowledge their requirements, as they are the media users.

The chapter reviewed the use of digital media, including interactive ones, which continue to have a significant development in communication for different purposes in the creative design and other industries. The review included a number of projects where the use of interactive media facilitated management, communication and collaboration. The principle of interactive media is to allow users to engage with the media content. In the light of this potential, it is a challenge for this research to point out and find ways to exploit such benefits in design communication in contemporary architectural practices. Architectural representations tend to be a one-way communication tool used by architects to convey information to stakeholders. On the other hand, interactive media allow stakeholders to input messages and information. The benefits of social media are substantial to communication and collaboration in the design process, in which information can be stored, retrieved or shared online.

This research finds that 3D modelling is widely used by practitioners within the built environment industry for their design process; CAAD software has been developed to facilitate production, editing and presentation. However, the investigation suggests that interactive 3D modelling has more value than being used simply for design. An interactive model enables stakeholders who do not have much architectural background knowledge, such as some clients, to understand the design, and it can be used for artistic purposes. Computer game design widely uses interactive 3D models. Hofstatter *et al.* (2014) have a background in architecture and have now developed their careers in digital architecture, computer gaming and critical urban study; they use computer games to generate and promote democratic norms through engaging in play that is compatible with complex everyday urban life. In addition, social media has generally impacted on working norms. Hence, this research questions whether the development of digital media applied to architecture has been slower when compared to other disciplines. According to Aksamija and Iordanova (2010), understanding the future of architectural practice is challenging, as a result of available computational tools, which are changing design processes and communication. Therefore, this research values an interactive media that has high potential to encourage stakeholder participation in the design process and can be used to its full capability.

The following chapter outlines a proposal to put forward an interactive system for communication and collaboration in the design process. The system would be based, among others, on views and experiences of professionals in the field of architectural design.

Chapter 4 Use of digital media in architectural design: interviews with users

Chapter 4 Use of digital media in architectural design: interviews with users

This chapter outlines the qualitative methodology employed in this research. The work described in this chapter seeks to gain an understanding of the issues relating to the use of digital media by different stakeholders. In doing so, it intends to identify users' requirements for an improved design communication system. The research also aims to identify significant data to inform an interactive communication system in the design process. Based on this data, guiding principles are outlined to develop an interactive communication system, which is described in the subsequent chapters.

The first section of the chapter explains the reasons for selecting the qualitative method used for data collection. This is followed by a description of the process used to collect data, which is given in two sections. Section 4.2 describes the method of sampling. It addresses the choice of participants, their roles in the design process, the projects they are involved in and the locations of the participants and/or projects. Section 4.3 explains the methods used for collecting data, transcribing it and keeping it secure. The fourth section presents the methods of data analysis, the theories underpinning it and its significance. The fifth section concludes with a set of guiding principles used for design communication, which will inform the development of the interactive communication system described in the forthcoming chapters. Finally, the last section summarises the findings of the chapter.

4.1 Approaching qualitative methods

Using qualitative methods in this research is important as it enables the researcher to gain an insight into the experience of stakeholders' use of communication tools during the design process. Semi-structured interviews were selected to gather information and identify unique data.

Researchers in this field have adopted qualitative, quantitative and mixed methods (e.g. Kumar, 2013; Bates-Brkljac, 2012). In this case, a qualitative method has been chosen, to gain insight into people's understanding of identified themes (Speed, 2007; Abdellatif, 2012). The framework of this investigation is to study the shortcomings of current design communication tools and to explore the attributes of digital media in order to propose some improvements. Therefore, qualitative research has been selected as it enables this research to investigate current issues and to explore them in depth. A qualitative methodology is used to understand people's experiences, beliefs and perspectives (Patton and Cochran, 2002). The use of such a method allows the research to document how people interact in a single, unique situation (Silverman, 2015:14). In this case, each of the participants has a unique experience despite the commonalities of the professional practices.

In contrast, quantitative research can only identify variance. Social sciences highlight that many variables affect human behaviour, which makes it too complex. Quantitative data on its own cannot be used to understand such complex behaviour. Designers borrow techniques from social sciences to develop methods for gathering useful data, including behaviours, attitudes and aptitudes of potential users (Cooper *et al*., 2007:50). In agreement with Silverman and Cooper *et al*., this research employs qualitative research because information from individual interviews is required to understand stakeholders' experiences related to their roles in the design process.

Qualitative research is concerned with situations in their natural setting. Such an approach endeavours to make sense of interpreting the meaning people bring forward (Denzin and Lincoln, 2005:3). Patton (2015:14) concludes that qualitative findings are based on three elements: an in-depth, open-ended interview; a direct observation; and a written communication. This research aims to find the extent to which certain digital technologies are used, how users value such technologies and how digital media and the Internet can be exploited to achieve effective communication that promotes collaboration as part of the architectural design process.

The research takes an inductive approach to investigating a small group, representing a conceptual design framework. According to Collins (2010:43), research in creative industries uses the inductive approach to understand the nature of the problem then make sense of the data gathered. To gain an insight into a context and an individual experience, the use of the interview as a qualitative method will help generate important data, for example, what digital media work effectively for which stakeholders or what conflicts of communication exist between stakeholders. These data help the researcher to identify significant issues and solutions. The use of qualitative approaches has led the research to answer the questions that it is trying to address, because these approaches have allowed the researcher to formulate questions that deal with multiple situations about the use of digital technologies in architecture. Identifying issues and obtaining users' opinions about the benefits of using digital media in design communication has helped to generate ideas that inform the development of solutions to communication within the design process.

Silverman (2005:238–239) notes that semi-structured interviews enable flexible conversation that can be informed by unexpected data. Such interviews are used as a methodology for this research as they enable independent data collection. The conversation can be extended depending on the participants' experience. This method is widely used to gather information, which other methods do not offer. In addition, the interview is used because of its particular nature and specific focus, which can reveal issues that may not have been explored by other research.

According to Cooper (2007:56), the interview enables the designer to learn from users of the product, about the context of how the product fits into their lives or workflow. Such context consists of users' perspectives, their motivations to use the product, their expectation about the product and problems of using current products. Using semi-structured interviews has allowed the researcher to achieve significant data from a range of participants about various types of projects and various practices. In Section 4.4, the data from the interviews helps the researcher to identify topics relevant to understanding design communication. The semi-structured interviews, through the free-flowing conversation permitted between interviewer and interviewee, have also given the researcher the opportunity to identify other issues that structured interviews may have been unable to raise. The data analysis in Section 4.4 enables a better understanding of the requirements and attributes of digital media from stakeholders’ points of view.

The following section describes the process by which the participants involved in the interviews were selected.

4.2 Sample selection

In the design process, there is involvement from various stakeholders such as architects, engineers, clients, planners, suppliers, software technicians, lawyers and so on. This research is interested in identifying the input from typical stakeholders who often get involved in the design process using digital media, and who can have an influence on what is being designed. For this reason, only the first four categories of the stakeholders identified above, are included here.

Prior to the selection of the sample of participants taking place in the interviews, an Internet-based survey of a larger number of architectural/design offices was carried out, looking at their published portfolios. A sample of participants to take part in the face-to-face interview process was selected. This study used an approach similar to that of Moloney and Dave (2011), who interviewed designers with a view to seeking their responses to a number of questions relating to the use of design media. In the current research, a range of different sized companies were chosen to reflect the variety of types of architectural project. All the participants were based in London, which is considered to be one of the major leading global cities. It has even been described as the world capital of the 21st century due to its global outlook, urbanisation and networks. The city is representative of one of the most important fundamental processes of the day and of the current restructuring of society (Kearney, 2012). It has economic advantages and a multicultural society. In addition, English is the international language just as software and digital communications are global. Another reason for choosing London is that many international architectural practices are based there. Hence, choosing London reflected the spirit of using digital media in the design process because architectural representation acts as an international language and software is available globally.

Baker and Edwards (2012) state that it is impossible at the inception of a project, to determine the number of qualitative interviews necessary to finish it. In addition, other researchers state that there are no rules for sample size in qualitative inquiry as the sample size would need to take into account the time and resources available, and how the findings will be used (Patton, 2015:311). In order to decide on the number of interviews needed to carry out the research, a researcher must examine the purpose of their study. Stake (2006:22) observes that 15 to 30 cases should be chosen to show uniqueness of interactivity between programmes and their situations. This research has followed this advice regarding a sample size appropriate for the purpose and commensurate with the resources available. A sample of 20 participants to take part in the face-to-face interview process, was selected on the basis of an initial Internet-based survey, as mentioned above. This number corresponds to Stake's (2006) recommendation. To collect varied information and points of view, architects and engineers were selected from various sizes of practice. Planners were selected from specific geographical areas of responsibility, covering central and greater London, and including a conservation area, a residential area and a business area. As these areas have different restrictions, it was expected that a variety of data would be collected. The clients were also selected on the basis of the size of projects they had commissioned in the past. Therefore, the variety of data was ascertained by the type, size, and area of projects.

4.2.1 Characteristics of participants

This section describes the professional characteristics of each participant. This research includes stakeholders who have the most impact on the design process. Each person's role has a different influence on the decision making. Identifying characteristics as a code enables the researcher and readers to understand the connection between data and participants' roles. The code is described as follows:

'A', stands for architects, who design and manage the project from beginning to end. They might be an individual or a team. Their creativity influences the design, based on technical structure, budget, local authority and so forth.

'E', represents engineers, who collaborate with architects to produce an ultimate design by influencing structural, electrical and mechanical aspects.

'P', stands for planners, who are concerned with the well-being of people in a community; the project must follow the policy of local authorities. They care how the project is designed to suit the environment. Therefore, they have an influence on appearance, materials, surroundings and environment, height, and access to the building.

'C', stands for clients, who have power over the project as they own it. They can be one person or the board of a larger development project. Clients require an effective design, and have an influence on the design regarding the cost and time schedule.

In the generated codes, these characters are followed by the initial letters of the participant's first name and surname. For example, the code A01PG represents the first architect interviewed, with the initials PG.

Participants are visited again during the research for evaluation of the communication system. Each participant is given a code and this code is used for data from primary interviews as well as transcripts from the collection of feedback, in order to avoid confusion.

4.3 Data collection using interviews

Ethical issues relating to working with the participants were considered, in order to safeguard their rights. Such issues often arise in data collection (Collins, 2010:82) and must be considered when the research involves interview. According to Patton (2015:495), interviewees' thoughts, feelings, knowledge and experience can be evoked through a good interview, as can those of a good interviewer. Participants need to be able to trust the interviewer. They need to know that the researcher is thoughtful, transcribes the data accurately and shares it securely. Participants' points of view can conflict; therefore, participants need to know that the researcher will value different views and not form judgements.

Prior to conducting the interviews, ethical clearance was sought and obtained from the Research Ethics Committee of the University for the Creative Arts. Any research project to be carried out must meet the legal requirements governing the University. The ethical clearance application included, for example, an explanation of the purposes of the research, how participants were recruited, obtaining consent forms from participants and keeping data confidential. The researcher had to be trained by the University and become familiar with the basic requirements when working with participants. The data collected through interviewing the participants was anonymised and participants were informed that they were free to withdraw at any time.

Data collection was influenced by the work of Bates-Brkljac (2012), who sought responses from stakeholders regarding their perceptions of various presentation tools. Bates-Brkljac's framework included semi-structured interviews along with sets of differently produced architectural representations, which were presented to and discussed with groups of participants. The groups comprised politicians (elected members of the public), young architects and other professionals in the building environment industry (engineers, building surveyors and planners). The same approach to selecting participant groups was adapted for this research, where various types of participant were chosen for semi-structured interview. However, unlike Bates-Brkljac's method, this research employed individual interviews to allow participants to talk freely about their views on the use of digital media and raise any issues that were important to them. According to Ritchie and Lewis (2003:138) and Gillham (2000:1), an interview is a managed verbal exchange and, as such, its effectiveness depends on the communication skills of the interviewer. Face-to-face interviewing is appropriate where intensive meaning is significant and the research is mainly focussed on gaining insight and understanding. The data gathered from interviews implies the significance of personal statements as data. It is important to identify the collaborative quality of research data; the role of the interviewer must be considered, especially in terms of minimising bias and influence (Newton, 2010). This research shows that the face-to-face interview enables interviewer and interviewee to establish a relationship and communicate freely. Often the conversations between interviewer and interviewee lead to more information being gathered than the questions would have generated if asked remotely via an administered questionnaire. Participants are free to provide information.

Bates-Brkjac’s (2012) method was adopted for this research, involving participants comprised of professional architects, engineers, planners and clients. Given the qualitative nature of this research, the researcher intended to explore the stakeholders’ subjective experiences in using digital media as part of a collaborative design process. This exploration was carried out by considering two aspects of that experience: satisfaction and obstacle, both of which are seen as keys of improving communication. The data was categorised and sorted to determine how interactive digital media can be used collaboratively to improve communication between professionals in the built environment industry, from different professional backgrounds and with different roles.

Data collection began with emails sent to invite participants to attend face-to-face interviews. The semi-structured interviews were scheduled after participants’ responses were received. The interviews ranged from 20 to 60 minutes. Longer interviews would enhance the depth of information obtained. In order to gain their trust and establish a rapport, the interviewer asked the participants to meet at a venue of their choice. Some interviews were held in the participants’ offices; others were held in London council buildings or cafés, depending on the interviewees’ preferences. Four sets of open-ended questions were used in the semi-structured interviews for the four categories of participants. These interviews enabled the sharing of experiences. Knowledge of participants’ working cultures at their place of employment, as well as career pathways, were all considered significant data to this research. A series of guiding questions (see Appendix C) were used as a basis to structure the interviews (see Table 4.1). The questions were developed to identify:

1) The participants’ backgrounds and organisational backgrounds to acknowledge the various types of projects the participants had worked on and how they communicate within their practices and with other stakeholders;

2) Architectural information that participants gave, acquired and sought through digital media;
3) The participants' experience in using digital media for project design; and
4) The potential for employing interactive media for communication in the design process.

Table 4.1: **Question numbers and areas of discussion for each of the participant categories**

Areas of discussion	Architect	Engineer	Planner	Client
A: Participant's organisation	1 question	1 question		1 question
B: Information exchanged	1 question	1 question	1 question	1 question
C: Design/presentation tools	3 questions	5 questions	4 questions	4 questions
D: Interactive digital media	2 questions	1 question	1 question	1 question
Total number of questions	7 questions	8 questions	6 questions	7 questions

The open-ended questions helped to identify the types of digital media and the ways in which they were used. Gathering participants' views on the use of digital media informed the investigation of the significant attributes, user interfaces, the feasibility and the potential development of the communication system, being the ultimate objective of this research. The research has also probed into the possibility of using interactive media such as websites or mobile applications in the communication design process. The resulting data guides this research to develop a communication platform, described in the forthcoming chapters. The researcher had aimed to hold 20 interviews, but three participants were unable to have a face-to-face session. These people were asked to fill out questionnaires with the same questions as the interview and return them by email. Their answers were also useful and included in the data analysis. Some of the interviews were audio-recorded, after obtaining permission from the participants. In some other interviews, notes were taken, as the participants did not want to be recorded. After the interviews, the participants were asked to come back to give feedback on the final outcome of this research.

After the interviews were conducted, the data was transcribed and securely saved.

4.4 Data analysis and results

This section explains the procedure followed to carry out an analysis on the data collected from the interviews described above. The semi-structured interview method yielded a large amount of data, which was manually analysed to find significant categories. Diagrams are used to illustrate various patterns of the data under three headings: benefits of using digital media, problems associated with their use, and suggestions for improvement. The data from the categories were then used to inform guiding principles, which underpin the communication system design being proposed by this research.

4.4.1 Performing data analysis

The qualitative data was analysed according to the techniques suggested by Collins (2010:170), by transcribing the audio records and notes into text documents and reviewing them repeatedly to identify meaningful answers and to enable the capture of the main points raised during the conversations (see Appendix D for transcripts). In order to interpret the data, a series of categories were identified, which in turn enabled the sorting of information into those categories according to relationships between data sets. The information from participants was extracted from their repeated answers and similar experiences. Some answers were general and predictable, but some were unexpected. Data analysis enabled this research to find ways to improve communication and workflow in the design process.

Significant answers informed the thinking behind the communication system design. Some of what the participants said was considered at the planning stage of the system. For example, participants were asked about the problems they encountered with architectural representation. One planner (P02AR) noted, "Sometimes architects do not choose the right viewpoint of the building. They are often too close to the building, so that they can't see anything they want to see, particularly the mass of it." According to this participant, planners can use an interactive 3D model to choose the viewpoint that they want to see emerge, which could solve this issue.

In addition, accessing work can be difficult because stakeholders use different software that is often incompatible. The idea of easy access was expanded when another planner mentioned the problems they had experienced:

> P04DI: "What can be a problem is accuracy as there is too much artistic licence. Not a serious problem, but it is something that planning officers need to be aware of when they make a decision. Also, the council does not always have the greatest IT equipment. It is the disparity between the quality of the equipment that the design industries are working on and the computer that we use, which is not capable and makes it difficult to get some of the information from the same particular software (most CAD files need to be transferred to PDF)."

Therefore, the suggestion in this research, of easy access to exchanged information during the design process, is crucial for interactive communication systems. The following quotes by a planner and an engineer firmly support this idea because using incompatible software causes difficulty in accessing files. The planner and engineer observed:

> P02AR: "There is often the issue that we don't have the same programme as architects have so we cannot view them."

> E01MT: "We use BIM but it is too expensive; that is why BIM is not used widely. BIM is very useful for mega-projects – public projects such as hospitals."

This research initially focussed on 3D rendering models, based on the assumption that they would be most useful for presenting design work. However, planners insist that 2D drawings should be included, as these are often used to make decisions. According to one planner (P02AR): "The image must be according to the drawings; the drawing is the basis for us to use to make decisions."

In the design process, communication between stakeholders is referred to as 'external communication', while 'internal communication' is that within the architectural firm. For architects, the types of architectural representation to include in the communication system cover a variety of media, as stated by one of the participants (A02PN): "I call planning external communication – we submit 3D rendering, visualisation, elevations, sections and layout plans."

Therefore, any improved communication system should include various types of media. Participants were asked if they were interested in employing 3D representation through interactive media in the communication process, given that the stakeholders can interact with it. The following answers, one from a planner and one from an engineer, support the idea of using interactive media such as a website:

> P02AR: "Yes, it is very helpful; we often have only drawings and static images – never fly-through 3D visuals. There is often the issue that we do not have the same programme as architects have so we cannot view them [3D visuals]. If they have programmes that we can change and see buildings from different viewpoints, that could be helpful."

> E03DE: "2D and 3D, they both have their play. I like the 2D to show where beam positions are and other details. But the 3D is very useful to see the relationship of the structure. Otherwise, we have not done many 3D so far."

This view is also supported by one of the clients who, regarding the advantages of using 3D presentation, stated:

> C01AD: "I think walking through can help to understand the design. It is quite difficult to imagine the size of the room and how people interact with it… I think the more chance people can talk on the construction and design process, the better you get what you want."

Another architect (A02PN) agreed with this point of view when he stated: "Yes, interactive media is very useful. In the future, websites will be a very important tool."

Given that the information gathered from the interviews is not merely based on personal opinions of the participants, but also extends to their experiences as part of their respective organisations, this gives more significance and weight to the answers given by individual interviewees. Using digital media in the design process was the focus of data collection and analysis. The three categories described earlier (benefits, problems and suggestions) were used to analyse the responses.

4.4.2 Results of data analysis

The use of graphical representation of data, in the form of diagrams and graphs, makes the results of the data analysis easy to understand.

Figure 4.1 shows the benefits that participants identified in relation to using digital media for design and communication. Connecting lines are drawn between each participant's category and the benefits they value. The stakeholders all agreed on the following advantages:

- better design communication,
- availability of reference material and reviewing made easier.

The results also show that planners and clients identified 'realistic simulation' as being of a benefit to them, while architects and engineers agreed that 'sharing information' within the office and practice were considered beneficial. The remainder of the benefits identified by the stakeholders as a result of using digital media for design communication include:

- It can be a useful marketing tool.
- It can be used for editing work.
- It is portable.
- It is effective for solving logistical problems.
- It is good for showing context for urban proposals.

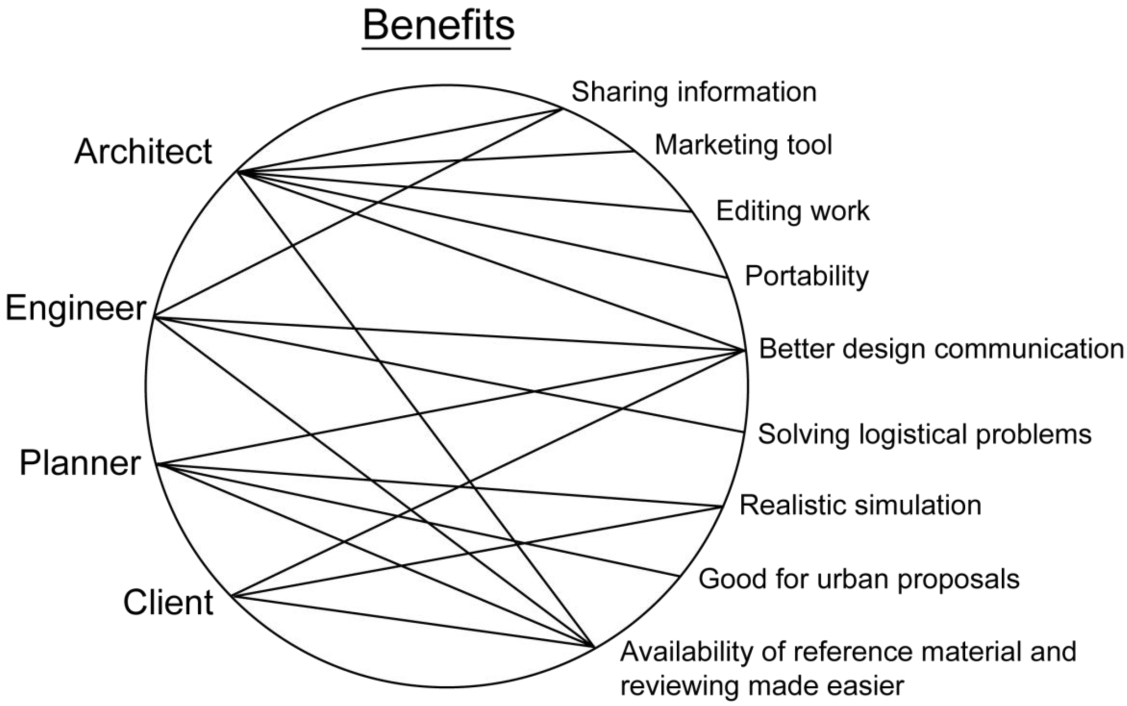


Figure 4.1: **Benefits of employing digital media in design communication**

Figure 4.2 shows the number of participants that indicated each benefit of using digital media in the design process, as an advantage. It highlights that the most frequent benefit identified was ‘better design communication’, as 17 respondents (85%) had this point of view. This means that digital media aids participants to understand design. The next most frequent benefits were related to using digital tools for ‘sharing information’, ‘realistic simulation’ and ‘availability of reference material and reviewing made easier’. These benefits were identified by 20% of the respondents. Given their popularity, these factors should be considered for developing the collaborative design and communication system. The least frequent benefits indicated, concerning the ‘portability’ and ‘solving logistical problems’ were highlighted by only 5% of interviewees.

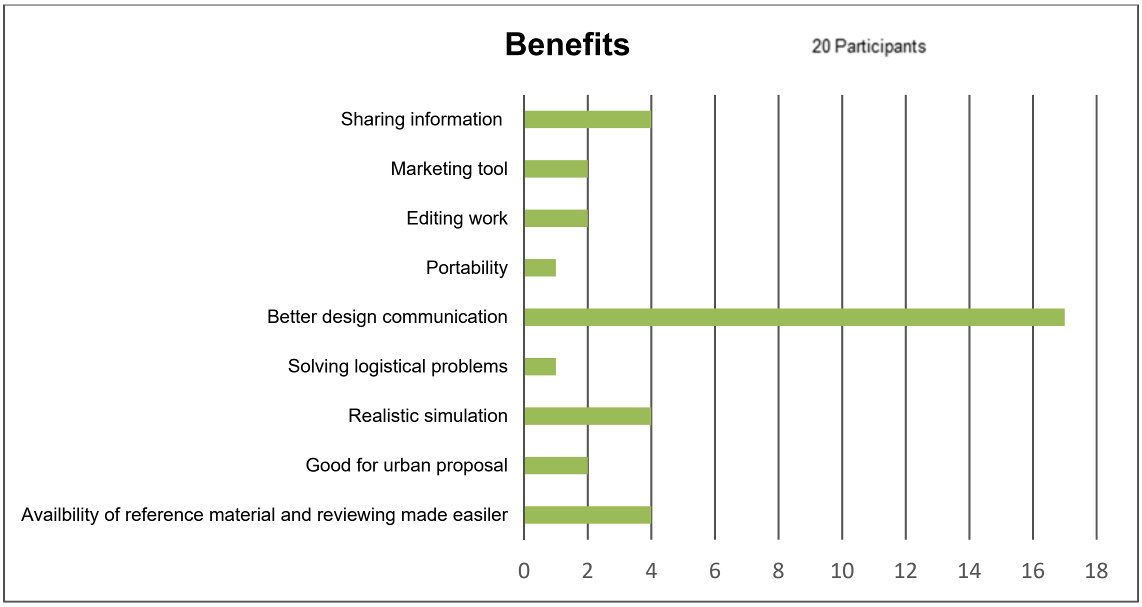


Figure 4.2: **Participants' indication of benefits of using digital media in design communication**

Figure 4.3 shows the issues that each participant category encountered with using digital media for architectural representation in the design process. Most categories of participants report problems with opening media files. Beyond this, different participants seem to identify different issues that relate to their respective use of such technologies. The lines connect participants' categories and the problems they encounter. For example, architects, engineers and planners all report file transfer as a problem.

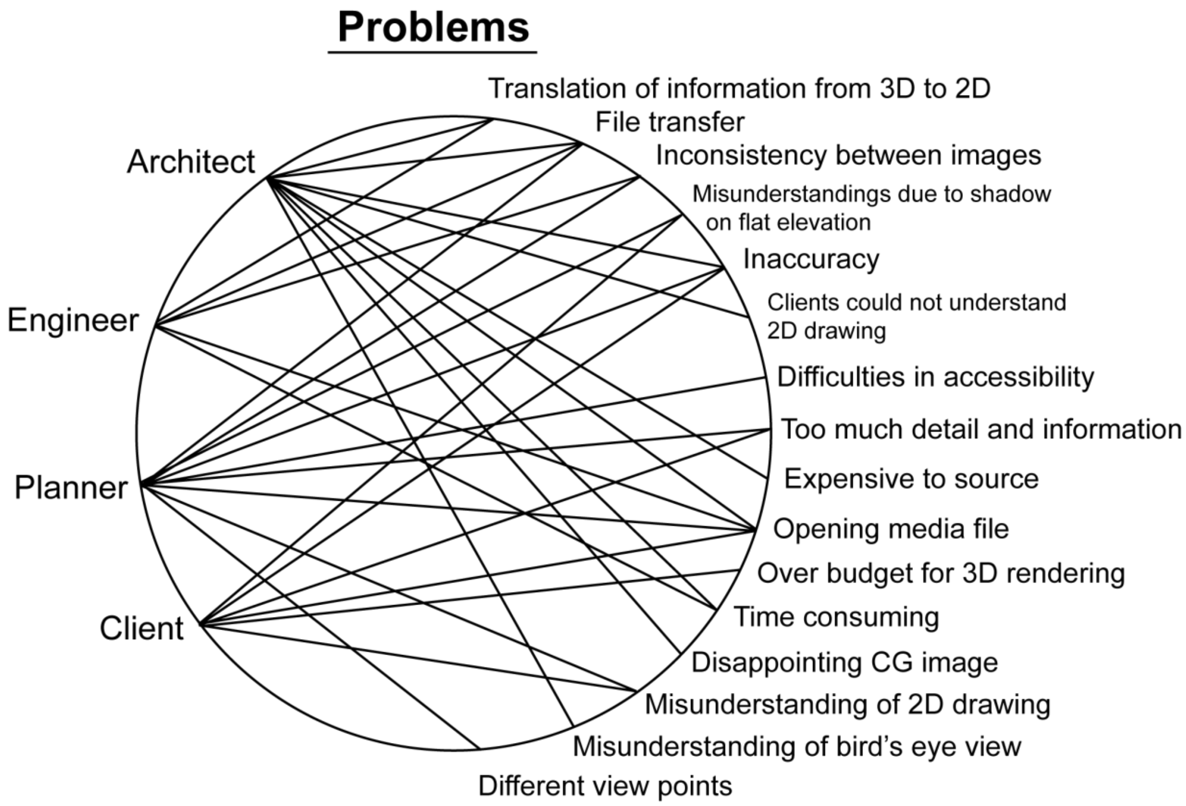


Figure 4.3: **Problems in communication in the design process**

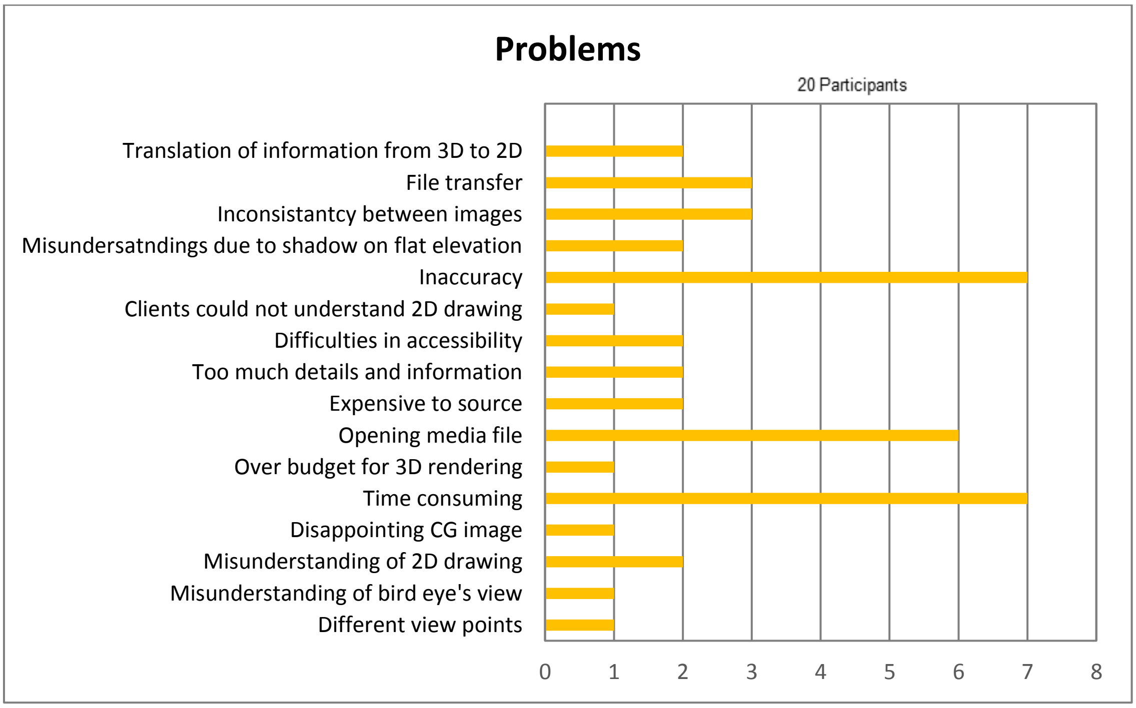


Figure 4.4: **Participants' indication of problems in communication in the design process**

Figure 4.4 shows the number of participants that highlighted each problem that they encountered in the design process. It reveals that the most frequent problems were ‘inaccuracy’ and ‘time consuming’, each indicated by seven respondents (35%). This means participants thought inaccuracy caused misunderstanding in design communication and that producing digital media delayed communication in the design process, resulting in stakeholders sometimes misunderstanding the purpose of using digital media. The next most frequent problem identified was ‘opening media’, raised by 30% of the respondents. This related to difficulties in using files, which require compatible software and appropriate versions. These problems have informed the attributes required for the collaborative design and communication system that this research intends to develop. The least frequent problems were concerned with misunderstanding of architectural representations and the cost of digital media (suggested by only 5% of interviewees).

Answers from participants were categorised in response to the research questions. For example, in Figure 4.3, the responses are categorised as problems, while Figure 4.5 illustrates suggestions made by the participants to improve the design process. Some of these suggestions were unexpected.

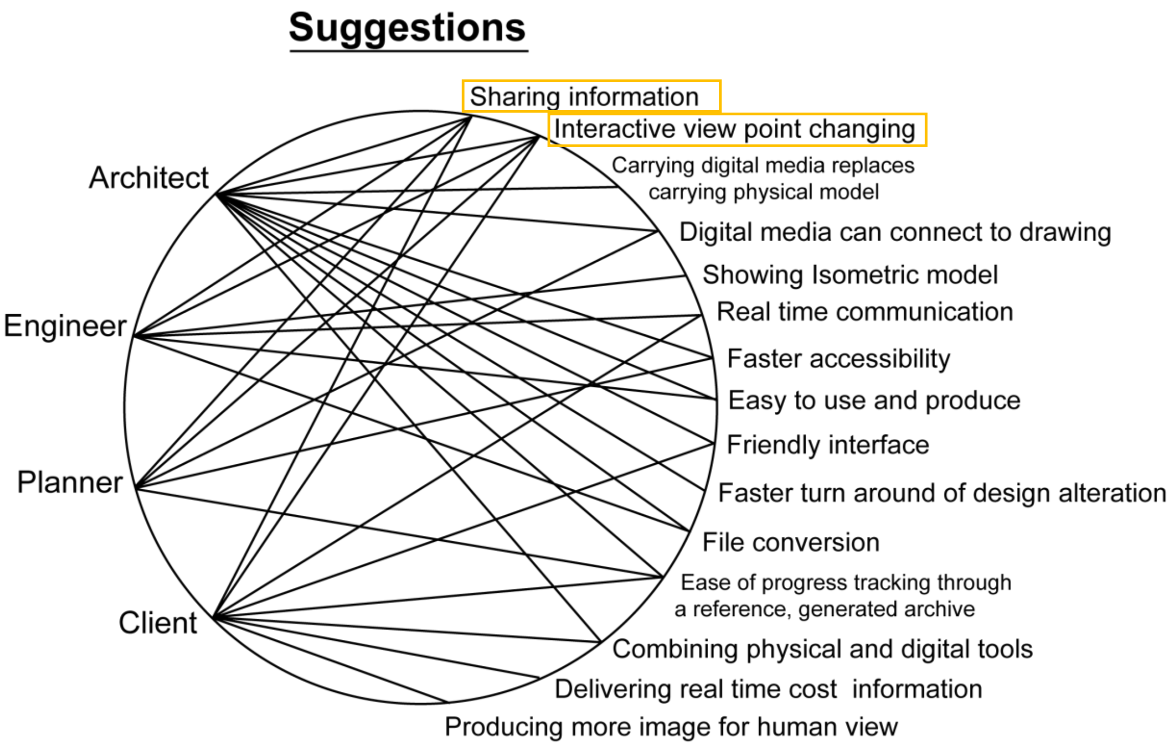


Figure 4.5: **Suggestions for improving communication in the design process**

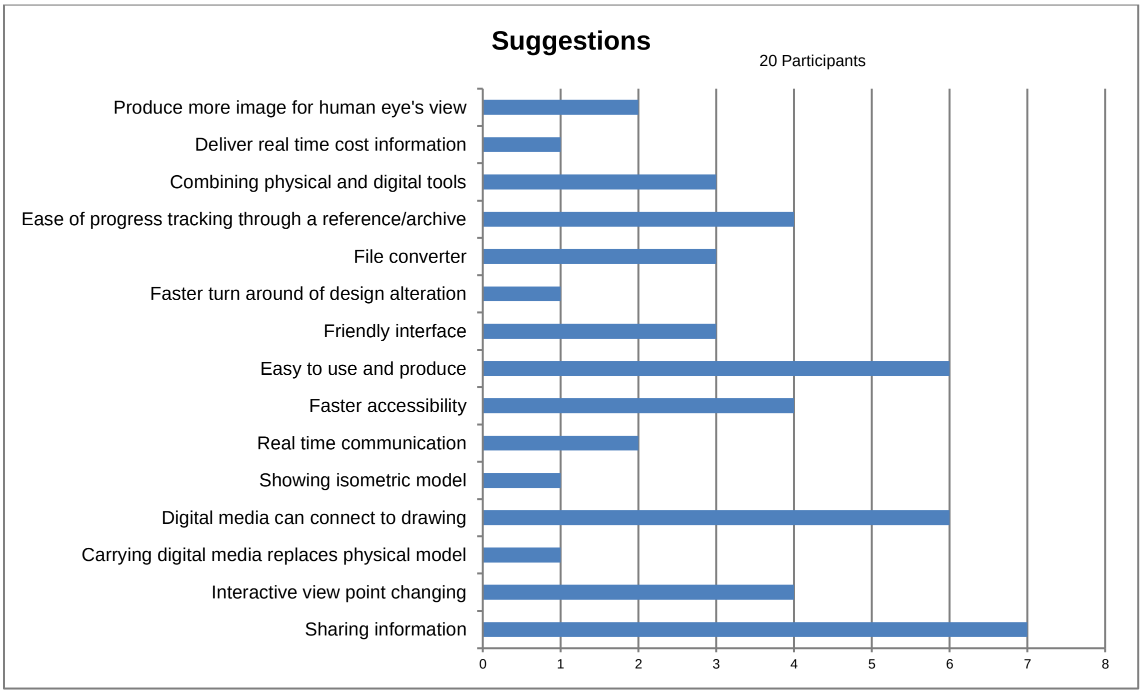


Figure 4.6: **Participants' suggestions for improving communication in the design process**

Figure 4.6 shows the number of participants that identified each suggestion made for improvement of the communication system. The most frequent of suggestions was 'sharing information', made by seven respondents (35%). This means participants thought the capacity to share information between stakeholders was the most important attribute of a communication system. The next most frequent suggestions related to how to make digital media 'easy to use and produce' and to ensure that it 'can connect to drawings'. These suggestions were made by 30% of the respondents. Given their popularity, these suggestions would inform the search for attributes of the collaborative design system in order to facilitate sharing and accessing information for all parties. The least frequent suggestions concerned technical modelling and the desire for instant results (suggested by only 5% of interviewees). Therefore, ideas about real-time modelling were discarded from this research. Most other suggestions from participants were considered in the design of the subsequent interactive communication system. This research considered the views of users of digital media in design and communication covering issues relating to the use of such media, including their benefits and suggestions for improving the current situation. This has adequately delivered the objective of this research, to put forward a design and communication system that better serves the users. In using suggestions from participants, users are considered as central and a design and communication system can be put forward, informed by the participants' views. Such views have helped identify some guiding principles to create a concept for the interactive communication system design: interaction, accessibility and inclusivity. These principles are considered when designing a communication system to respond to participants' requirements. Figure 4.7 shows the groupings of suggestions under these guiding principles.

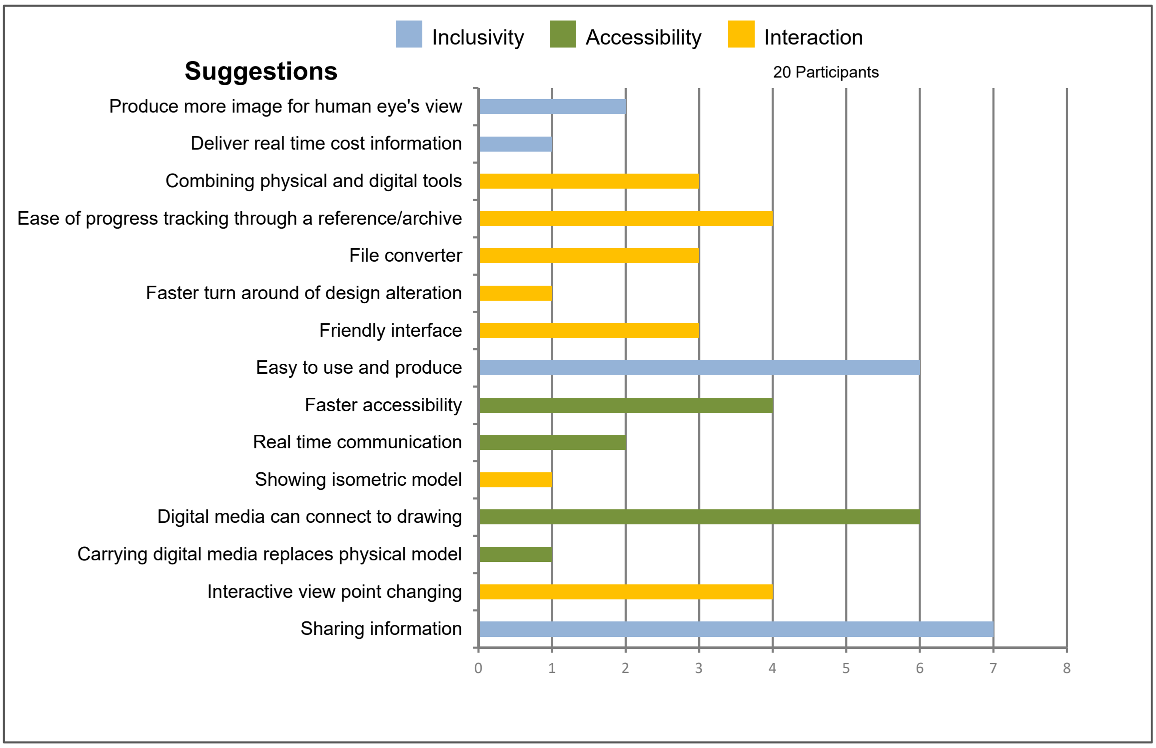


Figure 4.7: **Three guiding principles used to develop an interactive design and communication system**

A number of important factors were identified as a result of the analysis of interviewees' responses in relation to the three categories. The first involves the use of 2D drawings and 3D modelling such as plans, elevations, sections and 3D rendering models to present architectural work. Participants are of the view that stakeholders are still using these media and likely to keep doing so. The second factor is the need for innovation in architectural communication, modelling, accessing, networking and real-time communication. The third factor is to provide the opportunities of interactive media in the design process, including walk-through 3D models and virtual environments. Different participants experience architectural representation media in different ways.

Some clients do not quite understand 2D drawings; they prefer 3D perspectives, as these enable them to imagine the real space and understand the design. The engineers and architects usually work in both 2D and 3D. Nevertheless, the planners always require 2D drawings, as they make decisions based on these. The data shows that using 3D modelling is a concern for stakeholders; similarly, the engineers and planners offer similar opinions and suggest a focus on understanding graphics and content. This was different from the architects' points of view that are focussed on cost, time and computer skills. Other issues raised include the following:

- Solving Logistical problems – One of the engineers said he used 3D animation to identify problems with the flow of people and luggage in a public project, such as an airport. 3D animation needs to be accurate in this case, as it affects the design of volume and circulation of people and luggage around the space.
- Too much detail – This matter was explained by clients and planners as occurring when the architect puts too much work into producing shadows, which can obscure details of the building and make it difficult to understand its depth.
- Realistic visualisation – Clients do not think that realistic visualisation is necessary and worth the extra cost in the design process; they can understand unrealistic 3D. However, they thought that realistic visualisation could be useful if an architect does not charge too much for its production.

The data analysis reveals that the idea of using interactive digital media to improve communication in the design process, in terms of architectural representation and connection, is agreed upon by most participants. Only one participant does not agree, because he does not use digital media much in his own practice as he finds it difficult to access and use. This participant challenges the research to develop an interactive system for design communication, which would also be easy to use and easily available through an open source.

The finding that participants are interested in having interactive media in the communication process supports the objectives of this research. However, participants are still concerned with technological skills and equipment for using interactive media. As a result, the researcher has decided to design a system based on currently familiar and available communication tools, adding dynamic dimensions of interactive media capabilities to form a collaborative design and communication platform. In addition, the results make it clear that the system should be easy to use by all stakeholders.

Most participants indicate that interactive media would be very useful, both now and in the future. Computing technology and Internet-based networks enable people to produce tools for real-time communication. Some participants agree that real-time 3D models would help to clarify design communication if they were able to edit them. This would be an ideal feature for the future, and a way in which interactive media could contribute to design communication. Today, although editable 3D real-time modelling exists in various 3D modelling software, only specialists can use it. This research does not investigate such editable modelling, as many applications have already been developed in this field. In addition, to include real-time modelling for stakeholders in the communication system to be proposed here, would demand a much higher technology level and budget. Hence, this research emphasises the idea of real-time communication rather than real-time modelling. This view seems to be supported by the evidence that some practices have already considered employing interactive media such as blogs in their offices. However, up to now, these tools have been considered only for communication within their own practice, i.e., internally. This research focuses on both external and internal communication between stakeholders, hence highlighting the need for real-time communication. Stakeholders using an interactive communication system are enabled to share information during the design process.

The following section puts forward a number of suggestions to develop a more effective communication system for the design process by considering interactive media as tools.

4.5 Improvements to communication in the design process

This section explores existing communication between stakeholders in the design process, taking into account the matters raised by the interview participants, discussed in Section 4.4. Making use of the information gathered from interviews, this section elaborates on the three guiding principles that will inform the development of an interactive design and communication system, by way of improving the current communication protocols in the design process with a view to enabling a collaborative and inclusive approach to the design workflow.

Referring to the data from the interviews, the planners are of the opinion that the architects should determine what information is delivered and how this is done. However, planners who have limited architectural backgrounds sometimes face difficulties in understanding the design. For example, they note that architects may present elevations with shadows, where important details are hard to see due to the shadow on the drawing. According to the planners, architects should try to avoid this while maintaining their aesthetic ideas whenever they submit a project. If architects draw a flat elevation, this does not represent real life as the actual building would never be seen in this way. The participants who are architects suggest that 3D modelling provides the best means for clients and planners to understand the design, as it is more powerful when people can see the building as if it is real. This view is also supported by research. For instance, Chen (2004) proposes the use of 3D architectural visualisation as a tool to improve architectural communication methods. In his work, he indicates that the main problem in the design process is the different knowledge domain of communicators such as architects and clients, and he comes up with solutions to the issue by using 3D visualisation to help clients in collecting distributed information from the technical illustrations to generate the mental imagery. Moreover, a series of 3D images or 3D animations distinguishes the information of the architectural concept into small chunks. Digital 3D modelling offers an effective perspective which enables people to perceive details that are close to realistic and thus to better understand the design. However, the researcher suggests newer tools, such as interactive 3D models, which empower users to interact, rotate, zoom and walk-through constructions. These ideas are taken forward in this research, suggesting interactive 3D models to be made more efficient by adding functions such as real-time comments and sharing facilities.

Charleson and Pirie (2009:97–104) found that engineers are of the opinion that the lack of structural understanding by architects, who are often too late in seeking engineering advice, supports the idea of including real-time communication in the design process. Data analysis, evidence from the literature and the researcher's own experience and point of view, have led to the identification of the following guiding principles for developing an interactive design and communication management (IDCM) system, to improve the current communication methods in the design process:

Interaction: This allows users to act with visualisation and information. This research finds that many possibilities emerge from digital interactive media, such as web and mobile applications. The web application investigated in this research is a 3D model which users can interact with to help them explore an architectural design. Users can perceive the designs in many ways: as still images, walk-throughs or by flying over the simulated environment. An interactive model should enable stakeholders to access information in the system that facilitates the workflow, such as using compatible files, enabling the comparison of designs and being portable as a medium. Users see the effect of building design information by themselves without relying on the architect 'pushing' all the information to them. Furthermore, interaction between various stakeholders allows simultaneous activities to occur during the design process such as sharing, posting or giving feedback.

Accessibility: It is important for stakeholders to be able to access the system from any particular design software. Participants report difficulties when opening files or accessing the media that professionals such as architects, send to them. The reason for this problem comes from a lack of technological skill and standard software availability. This issue also occurs between different professionals such as architects, engineers and planners. Convenient access is crucial. Solving this issue would involve employing a web hosting service so that anyone with this application and an Internet connection can access the information. Moreover, such an application would permit independent and even remote working. The Internet and digital technologies have changed working styles and made working from a distance, nationally and globally, both possible and affordable.

Inclusivity: This feature allows both specialists and lay people to use the system. Stakeholders in the same project should have the same building information, which should be updated for everyone at the same time. Not only is the latest information important, but also archived building information. In the design process, collaboration among stakeholders is needed to review and solve problems that might occur. The architect needs to be able to change the design, which may result in many revisions of design drawings, which could be needed for reference. The issue of confusion over currency of documents is addressed by including all revisions in one package. However, this research focuses on revisions that have been issued. Therefore, the system is used for external, rather than internal, communication. The system should be tracking the design process so that users can see the full history in an archive when they select a revision that they want to look at. Such a system would be beneficial for project workflow.

This section underlines three guiding principles that underpin the IDCM system development as these adopt using innovative technologies to overcome issues in the design process and stimulate traditional communication to be more interactive.

4.6 Conclusion

This chapter has described methodology to carry out the research related to the gathering of information from participants, with a view to identifying what they see as requirements for an improved system for collaborative design. A qualitative approach is undertaken, as semi-structured interviews are used for data collection. Participants involved include an architect, an engineer, a planner and a client. Data are transcribed in order to find categories of information that have implications for improving communication and collaboration. The data analysis presents the interviewees' views on the advantages and issues associated with using 3D modelling and digital media in design communication. The benefits include better design communication and that information can be shared and tracked. However, significant issues have been raised including incompatible working systems, giving inconsistent design information, misunderstanding of design and communication, it is expensive to source and that high levels of technical skills required for using design tools. These, alongside their suggestions for improvements, are taken into account by the researcher. Subsequently, this chapter makes suggestions for improving communication and workflow. The research finds that an opportunity exists to introduce an interactive communication system for use by the stakeholders in the design process. Therefore, three guiding principles, interaction, accessibility and inclusivity, are outlined for developing this communication system, further described in the forthcoming chapters.

Chapter 5 An interactive design and communication management (IDCM) system

Chapter 5 An interactive design and communication management (IDCM) system

This chapter outlines the main findings from the data analysis explained in the previous chapter. It describes how these findings provided a framework of the future communication system in architectural practices. The chapter defines three guiding principles that were used in the development of the system: interaction, accessibility and inclusivity. The communication system being proposed here is informed by the findings from the data analysis and the projects discussed previously. The research demonstrates an IDCM system by means of providing a mock-up for stakeholders, in order to collect feedback. The use of the mock-up is presented in this chapter through the storyboard that demonstrates how communication and collaboration between stakeholders can be improved.

The following discussion is divided into four main sections. The first section explores the IDCM system for which the stakeholders' requirements have significantly influenced the design. The introduction and development of the IDCM system are outlined. The system brings together requirements and behaviours of users in the design process and is integral to a real-time application system. The second section describes the use of the IDCM system, and its capabilities for communication in the design process. The third section illustrates the design concept and idea, through demonstration of a mock-up of a web application that uses the IDCM principles as a structure for its design. In addition, this section demonstrates the use of the IDCM system from users' perspectives in the form of the storyboard. The last section discusses the design of the IDCM system and the mock-up.

The process of designing the communication system was informed by the researcher's need to know users' backgrounds and their requirements of information for the system. Consequently, the researcher has developed the design of the system through interactive digital media and has then reviewed the process. Figure 5.1 shows the process of developing the interactive communication system of this PhD research. It is a guideline to inform the framework, which was structured with theoretical and practical elements. The model is based on Kumar's (2013) prototype procedure.

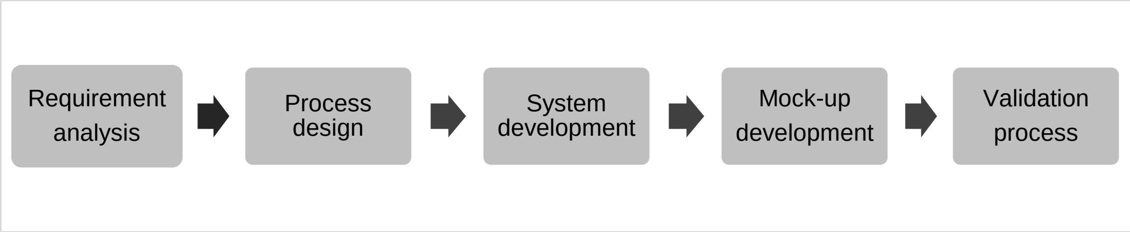


Figure 5.1: **The design procedure of the interactive communication system**

5.1 Exploring the IDCM system

This section focuses on designing schematics for an interactive communication system for the design process. Exploring current architectural representations together with an interactive communication system is the key idea behind the IDCM system design. This is an interactive communication and management system that is Internet-based and facilitates communication among architects, engineers, planners and clients in the architectural design process. The system has been designed from stakeholders' requirements and media users' behaviours. The output of this research is to provide a guideline for others who have an interest in the development of communication systems for design workflows.

5.1.1 Introduction to the IDCM system

This section describes the findings of the research that have informed the development of the system. The system was designed based on a traditional communication system, adapted to accommodate social media activities. The findings of this research were informed by data synthesis and analysis. The data analysis has resulted in recommending that the IDCM system should address the following attributes of digital media:

Interactive 3D model – This research has found that an interactive 3D model, which users can engage with by means of a walk-through navigation to explore the architectural design, would help users to better understand complex design matters. One of the clients taking part in the research claimed that generic perspective presentations produced by most architects were often misleading. The bird's eye view distorts human perception of the size of a building. Planners claim that the architect does not give them enough images for design consideration. Therefore, an interactive model should enable stakeholders to choose the view of the model as they prefer.

Convenience and accessibility – One of the problems that a layperson experiences is the difficulty of accessing the files and electronic documents of architectural representation which architects send to them. The cause of the problem is a lack of technological skill and incompatible software. This issue also occurs between different professionals such as architects and engineers. Therefore, the idea of easy access is crucial. This can be achieved by creating a web application which uses a browser and an Internet connection that is accessible to all stakeholders. The IDCM system supports communication and encourages users to access information more independently. However, a certain level of security is required, as the data in the design process must be kept secure until the owner of the project allows the material to be published. Therefore, the registration of users and gaining approval from the architect/project manager controlling the project, is required.

Data management – Archiving is a significant aspect in the design process. The inspiration for the archiving methodology came from the data analysis, which revealed that the design development requires the collaboration among stakeholders to revise and rework the design. One of the participants, an architect, explained that during the design process, the architect sends drawings to the engineer to work on. The engineer might then return the drawings, having highlighted some problems with the structure of the building that may be impossible to build. The architect then needs to change the design again, so there can be many revisions to design drawings that stakeholders need to look back at. On the other hand, the client might prefer a previous version of the design; as a result, the architect needs the earlier drawings available to work on. Different practices involve different numbers of revisions; an architect may make more revisions than an engineer, for example. Consequently, this research focuses on revisions that result from external collaboration between practices rather than from internal communication within a practice. The IDCM system anticipates supporting users in the tracking of design iterations so that stakeholders can see the history of the archive when they select a document. The IDCM system supports simultaneous tracking of plans according to sections, elevations and 3D models from the same revision, providing an efficient workflow.

Sharing information – Nowadays, sharing is a trend that supports working collaboratively, as social media offers people connections around the world. Social media has opened up opportunities for people to work with and contact others, even when they happen to be somewhere else. However, in built environment design and management, there is a distinct lack of use of the explicit advanced technology of social media for communication in the design process. Hence, there is scope to empower people to work through digital platforms and to communicate within a working environment, which generates connected working communities rather than the conventional working environment of isolated people. With the capability of interactive media, in terms of connection via the Internet, all stakeholders can connect and catch up on information. Working online, people can easily share ideas, give feedback and provide information. This beneficial feature is admired by all participants taking part in the interviews. Sharing information is significant and has high potential to improve the workflow. The potential benefit of this finding includes sharing not only the information with members within the IDCM system, but also the information or data from other web applications such as Google or LinkedIn.

This section has described the IDCM system and identified some significant attributes for digital media found from the data analysis. The research has made use of these attributes to help communication and collaboration as well as to improve the workflow in the design process.

5.1.2 The development of the IDCM system

The data analysis has provided information for the researcher to design the system of communication. The attributes listed in Section 5.1.1 have been identified as a starting point of the IDCM system. The system has been designed to respond to real-time activities. Actions such as commenting, posting and tagging allow each stakeholder to give instant feedback to other stakeholders and keep them updated.

Figure 5.2 illustrates the generation of initial diagrams used in the development of the IDCM system, with the functions and relevant information identified after each category was connected. Within the design process, the system is intended to help the user with the interface, navigations and functions within the web pages and to facilitate the planning of various relationships. Initially, the system was drawn up as a diagram, which was then translated into a mock-up that visualises the outline of data management and enables the users to understand how the system works. The mock-up was required to communicate the design of the system to participants for generating and analysing feedback. The challenges of designing the system included developing the right paths, and forming the correct sequence of communication, in a way that maximises dynamic interactions between stakeholders.

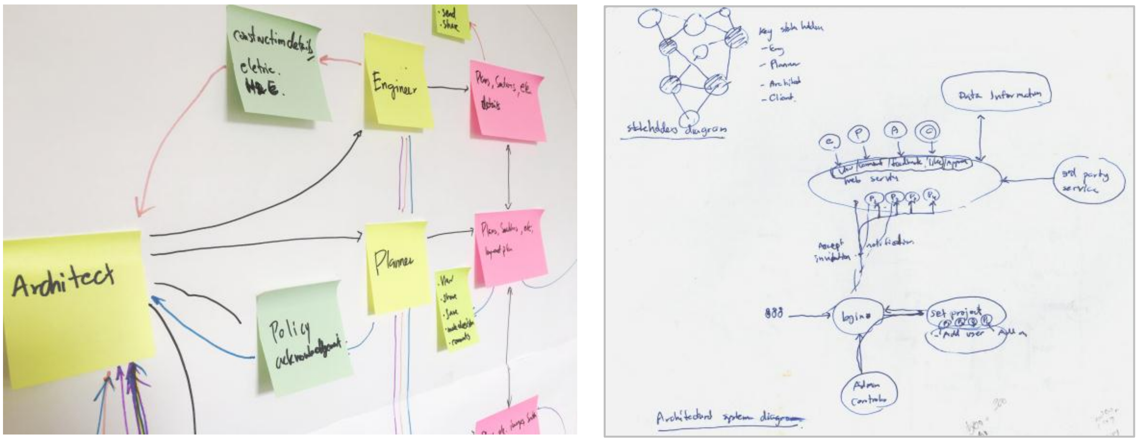


Figure 5.2: **Users, actions and relationship paths** (**left**) **and the initial sketch of a hierarchy diagram** (**right**)

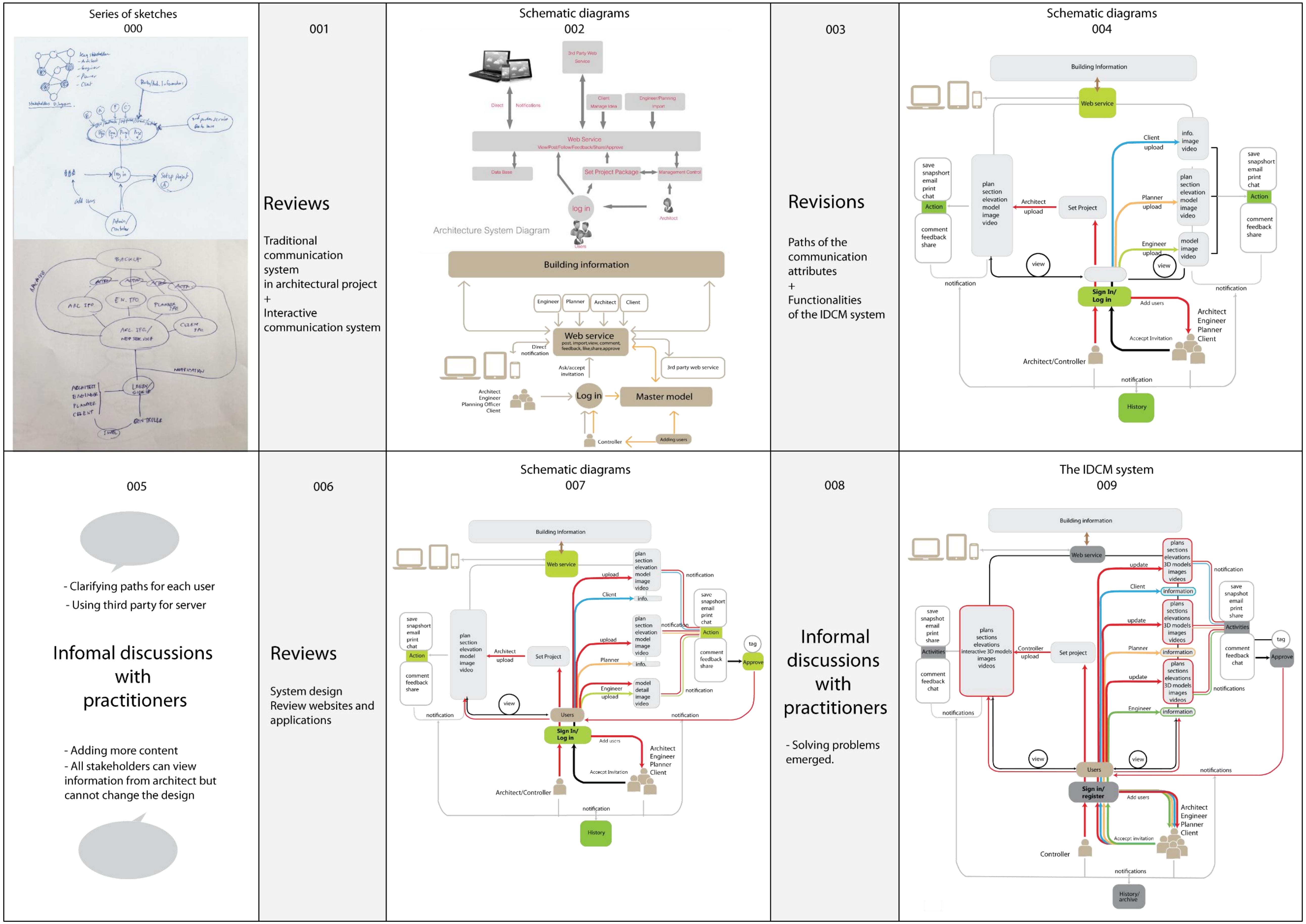


Figure 5.3: **The process of developing the IDCM system and its design stages** (**see Appendix E for more information**)

Figure 5.3 shows the steps of the design process for the IDCM system. At the start of the process, the objective was to consider participants' requirements in order to inform the design of the system. The design began with drawing an outline of communication, based on a traditional communication system in the design process. The next stage shows the addition of elements of dynamic communication referring to significant attributes of applications and websites (reviewed in Chapter 3). The diagrams were sketched (see Figure 5.4, stages 000–001) and reviewed in response to discussions with the research participants, who are considered as stakeholders (see Figure 5.5, stages 002–003).

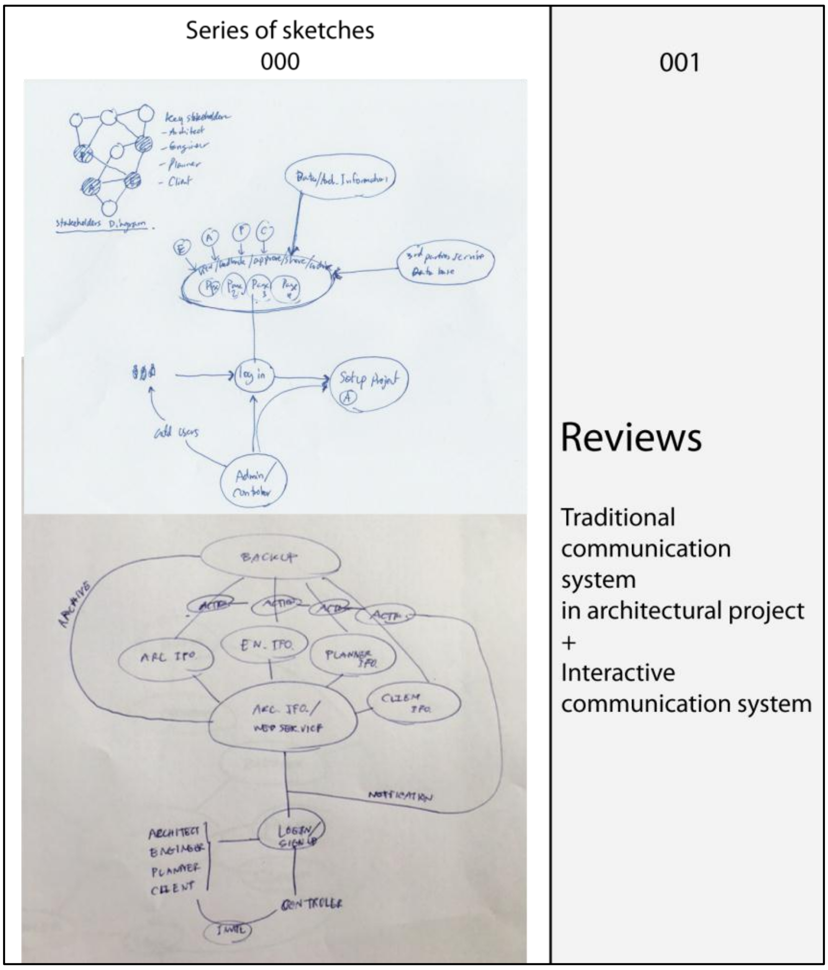


Figure 5.4: **The IDCM system design, stages 000–001**

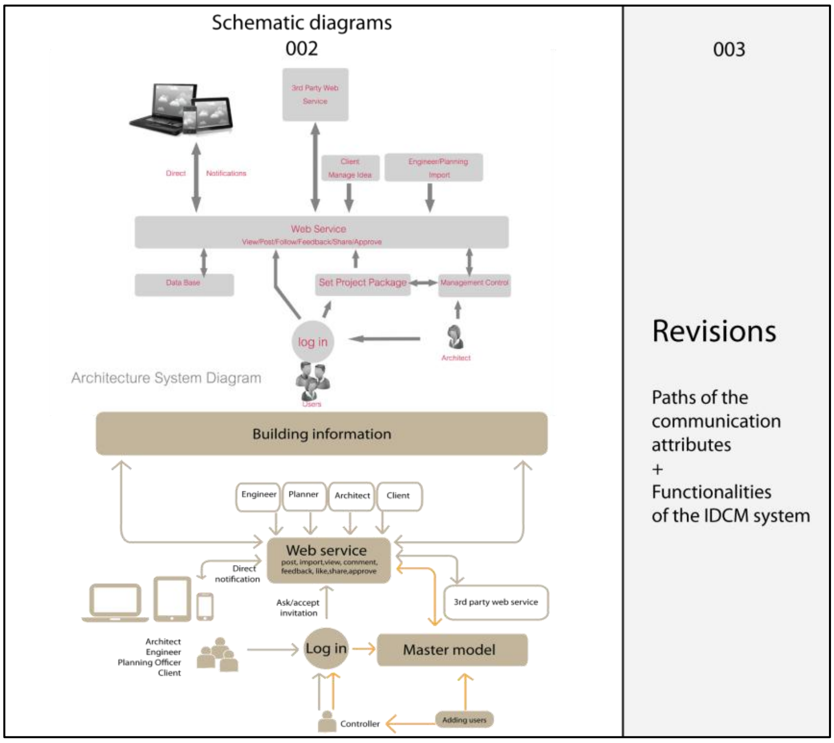


Figure 5.5: **The IDCM system design, stages 002–003**

Figure 5.6 shows two diagrams. Stage 004 demonstrates the system after revising paths and relationships according to the identified attributes and functionalities of the interactive communication system. Related to this, stage 005 shows the process of the system discourse, including the addition of content and clarification of functionalities.

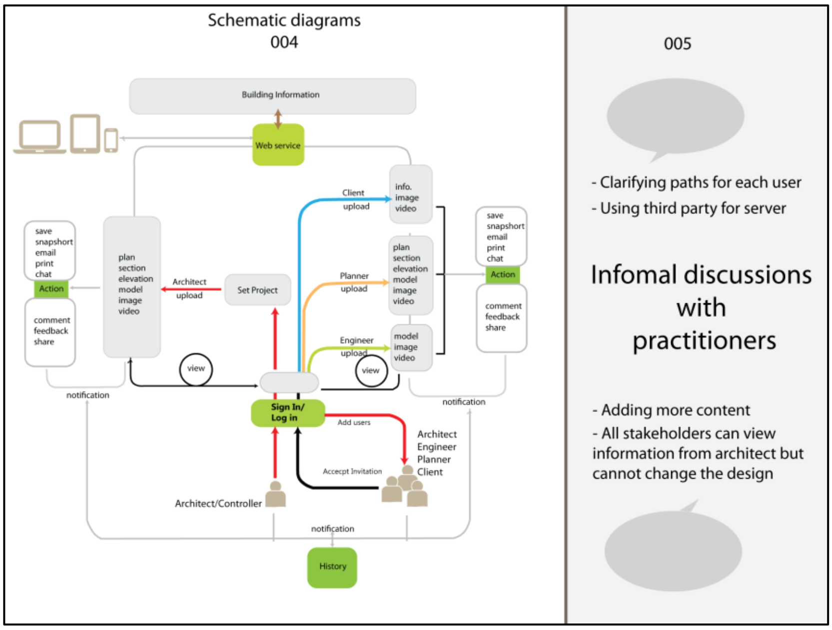


Figure 5.6: **The IDCM system design, stages 004–005**

In order to develop the proposal further, the researcher reviewed websites, applications and frameworks in a wider area of interest, not solely focusing on those relating to architecture (see Figure 5.7, stage 006). The review informed the research of significant attributes. Dropbox[15] and Facebook are examples of tools for sharing and accessing general information. Sketchfab[16] and 3D Warehouse are examples of tools for sharing 3D items. Moreover, applications which work on mobile devices were also reviewed such as iVisit and AutoCAD 360[17], which were explored in terms of display of architectural representations and their interactions. Line and WhatsApp were used for designing the security system and setting group chat privacy. This was essential in the development of the IDCM system so that it would become a fully functioning platform for interactive communication and continue to have the capacity to expand in the future (see Figure 5.8, stages 008–009).

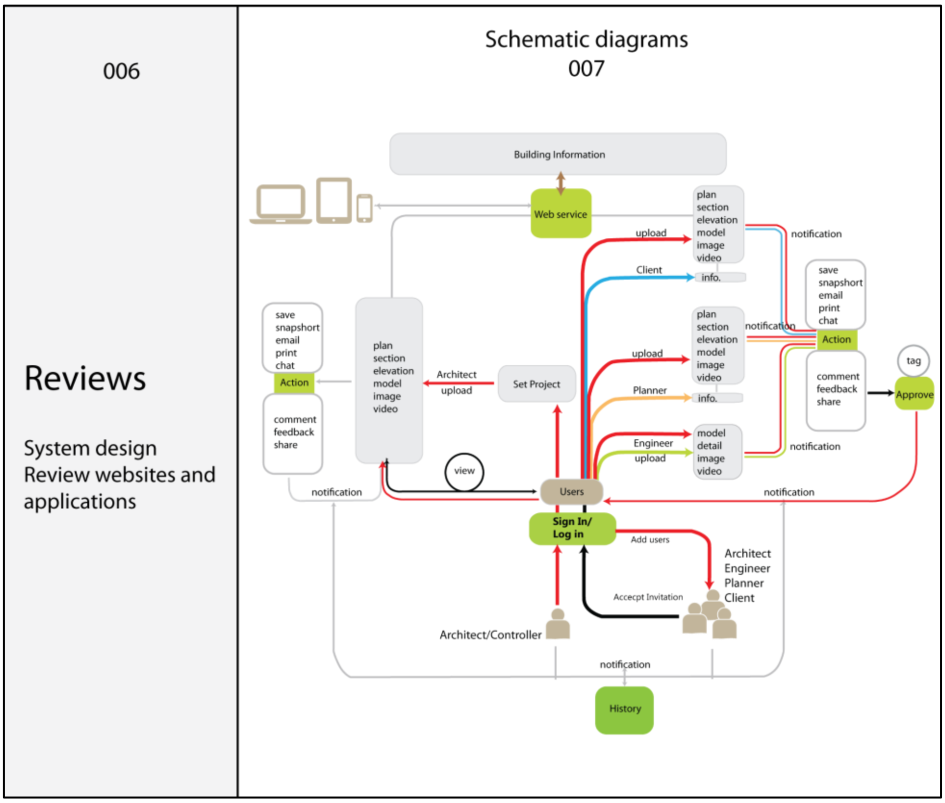


Figure 5.7: **The IDCM system design, stage 006–007**

[15] Dropbox is used as file host, working in a similar way to a hard drive. However, it is an online service. It can be used to share files.
[16] Sketchfab is used to publish, share and discover 3D content online and in virtual reality (VR).
[17] A mobile application enables AutoCAD viewers to view, create, edit and share AutoCAD drawings.

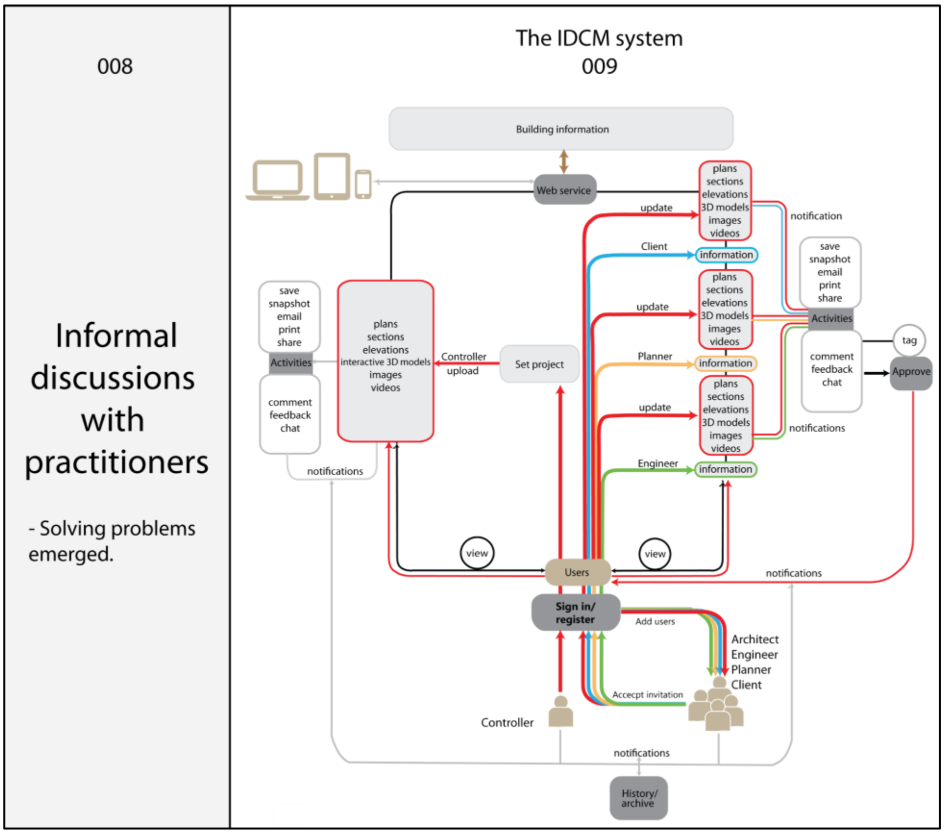


Figure 5.8: **The IDCM system design stage 008–009**

The IDCM system includes dynamic relationships between users and design information. The system is a basic structure of web application that makes use of certain types of architectural representation tools such as interactive 3D models, 3D rendered images and 2D drawings, to suit the stakeholder requirements, as revealed by the survey (see Chapter 4). In order to make this process trustworthy, it was necessary to explore methods that participants are currently using. The survey work carried out as part of this research shows that most architects and engineers are interested in working simultaneously on 2D drawing and 3D modelling. This has come about as a result of the introduction of building information modelling (BIM), which has impacted on the design workflow in architectural and engineering practices in recent years. Clients can better understand design in 3D modelling. Planners still work on 2D drawings, but they sometimes want 3D to see views of the building in context.

The data from the surveys show the types of architectural representation that architects provide for each stakeholder. This data has led to formulation of the issue underlying this research, namely that architects always provide architectural representations for stakeholders. To convey architectural designs, artists use media such as 3D rendering images, animations or 2D drawings. These media are all delivered through a linear communication system (as previously discussed in Chapter 3). Hence, the idea of using a medium that supports dynamic communication has emerged. An interactive tool that stakeholders can act upon via digital media would help to reduce difficulties and problems of user communication in the design process.

The design at each stage refers back to the literature review and data analysis that underpin the creation of the system. Figure 5.9 shows the relationship between the design and the research.

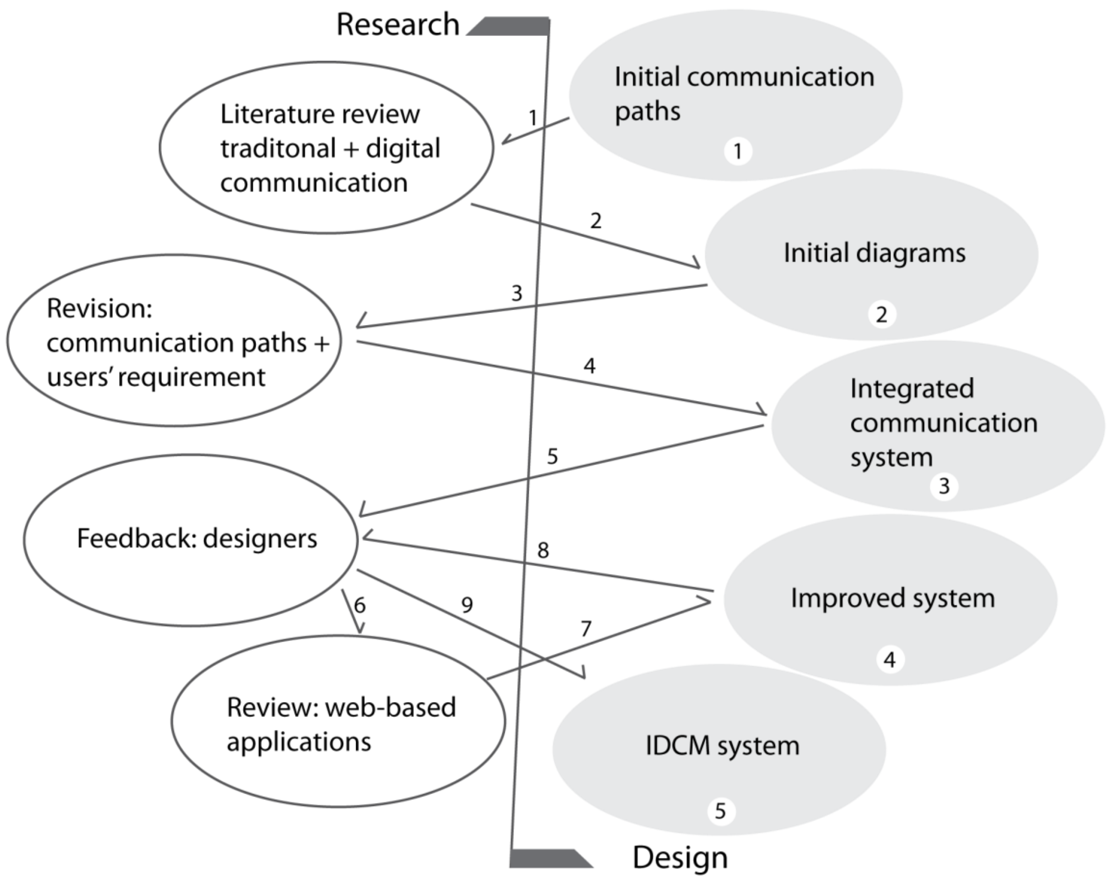


Figure 5.9: **Relationships between research and design**

5.2 The use of the IDCM system

This section explains how the IDCM system can be applied to the communication and management of information in the design process. The users of the system are stakeholders including architects, engineers, planners, and clients. The IDCM system has been developed to improve the process of traditional communication in the design process. Adding this system helps users to work more effectively on an Internet network and also provides a data management tool. Data management is a complex issue that always features in traditional communication. The IDCM system can work on a computer and can be extended for use on mobile devices. The features of the system developed as part of this research are intended to address issues arising from participants' responses during the survey.

Figure 5.10 shows the traditional system of communication in the design process. The architect produces the architectural information package, including 2D drawings and 3D modelling. The package is sent to each stakeholder by email or post. The stakeholders then typically have a face-to-face, telephone or conference meeting via digital media (such as Skype[18]). There may be some feedback or comments after the meeting, and stakeholders may return to the design again before the next meeting, repeating the circle of the design process. If there is no change to the design (especially in small projects) then it is approved, which marks the end of the process.

Unlike the IDCM system, traditional communication in the design process does not use interactive architectural representation or social media within one platform. Communication occurs with each of the stakeholders through individual design packages, which include separate architectural representations for each stakeholder. In Figure 5.10, there are three separate sets of architectural information for client, planner and engineer. The architect can see all architectural information, but other stakeholders cannot see each other's information.

[18] Skype is a video or voice call to an individual, or a group conversation through an Internet network.

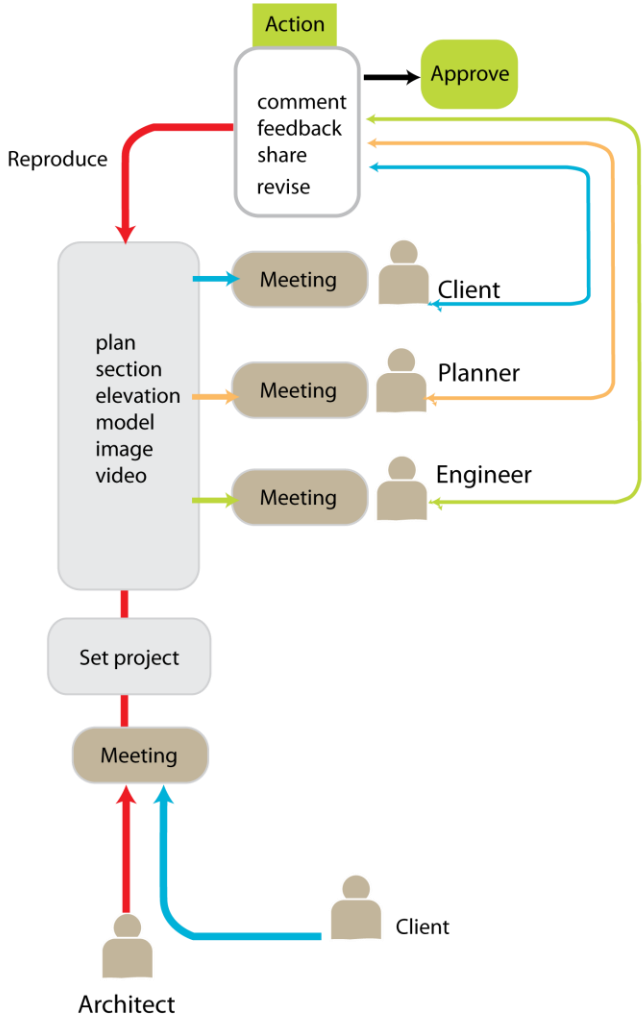


Figure 5.10: **Traditional communication system in the design process**

Figure 5.11 shows the working relationship between the IDCM users and the type of information they interact with. The architect, who is the project controller, registers and signs in to set up the project from the beginning of the process. He/she invites other people such as co-architects, engineers, planners and clients to become users. Once the users accept the invitation, they have to register their details, which at this stage are important to the system to drive the users to the right path of their page. Each user can see the architectural information that the architect has set out on each page. The information is tailored for different stakeholders' requirements, and the content of the media is designed based on the results of data analysis from the present research. For example, a planning officer working on a 2D drawing needs plans, elevations, sections and a 3D model, in order to consider what the building will look like in context. The benefit of this system is that the user can access an interactive 3D model. The user can view the design, make comments and save or share the information within the system. Once the user reacts to the design, there is a notification sent to other stakeholders to let them know what has happened in the design process.

One significant feature of the IDCM system is its ability to archive the revisions of designs, as this allows users to then track previous editions. This is sometimes necessary, as users may need to go back to refer to an earlier design. Once a user selects the revision, the system will track the same revision on the 2D drawing, 3D model and relevant information, so they can work more efficiently to avoid using an incorrect drawing or model.

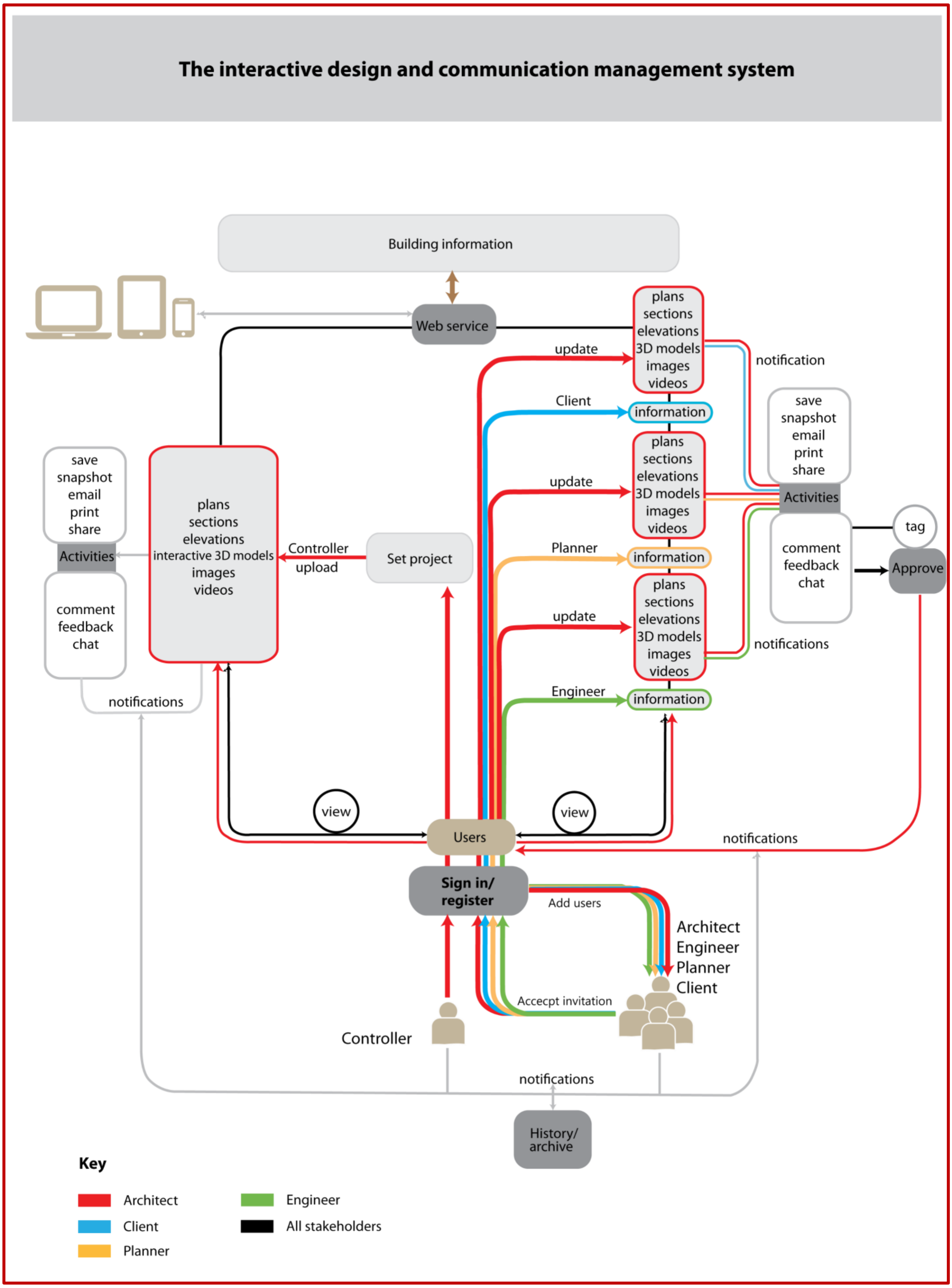


Figure 5.11: **The IDCM system in the design process**

5.2.1 The IDCM users

The architect/project manager, who is the controller, signs in and sets up the system, then he/she invites stakeholders including other architects, engineers, planners and clients. Each project might have different numbers of members depending on the type and size of project. An individual user owns an individual page. The users can see all pages, but they can upload information only to their own page. Users receive notification of actions shown in the history. They also see changes on the design and comments from other stakeholders. The architect/controller invites members by email or links to members' social accounts such as LinkedIn[19] or Facebook. In this way, sharing data from third parties will reduce costs for the system and save time for users. The registration details are thus imported from an existing database. The architect/controller sets up the package of design information by uploading relevant drawings, 3D models, images or video/3D rendered animation. Architectural representations are uploaded to one page for the architect, who will also upload specific media for each page of each stakeholder. Individual stakeholders can upload their own documents as well, thereby giving helpful information on their page.

Other stakeholders can interact with the web application. Engineers can explore an interactive 3D model that the architect uploads by walking through it virtually or changing its perspective. They can see the drawings, plans, elevations, sections or other details. They can also view images and videos relevant to the project that need attention. Engineers can upload their material for the architect to work on, such as an animation of how to solve logistic flows within the building, a 3D model for structural assembly, an image or other relevant information. Engineers can identify file extensions such as .dwg, .dfx or .pdf (see Table 2.1) in the upload section.

Planners' pages operate in a different way from those of engineers, as planners do not produce drawings or modelling. However, planners can still exchange information with the architect. For planning consideration, the architect focuses on drawings and modelling. In the planning path, the planners can consider the design through an interactive 3D model, drawings, images or video. They can

[19] LinkedIn is an application that works on mobile devices and computers. It is a professional networking tool that allows registration of members to establish a network of trusted professionals.

upload relevant information for the architect such as policies, regulations and decisions which are concerned with the project.

Clients' pages are similar to those of planners, as clients do not produce media. They are more concerned with design concepts, area, specification and cost. They can also upload their relevant information, such as images or catalogues. File types are indicated by the extension and language type in the upload section.

All stakeholders can interact with the architectural representation from the architect. They can view, capture images, email, print, comment, give feedback or share the information, both within the system or outside the system. Further features on the IDCM system, including 'invitation' and 'sharing' functions, are supported by third parties such as LinkedIn or Google. The system employs media already existing in the industry. Actions that have happened in the past are archived in 'history', and notifications are sent to all stakeholders when any users upload, post or make a comment within the system. The notification feature helps prompt simultaneous communication among members as well as keeping users up to date on the latest information.

5.2.2 Significant features of the IDCM system

This part draws attention to some features that contribute to design communication, in more detail than was given in Chapter 4. This research introduces the IDCM system and explains how the guiding principles outlined in Section 4.5 are applied in practice in the IDCM system. The application of the three guiding principles is explained as follows:

i) Interaction – Allows fast input and feedback. This research has developed an interactive 3D model which users can engage with, walk through, rotate and use to zoom in and out. The model allows users to explore the architectural design and understand its complexities. The interactive 3D model can also solve problems. For example, 2D drawing shading used to communicate depth, can obscure the detail on a design. An interactive 3D model solves this by representing a design which the viewer can zoom in and zoom out of, or even change the view point. An interactive system able to create communication within this context is needed to connect the design process with stakeholders throughout the period of the project. Interactive digital media via the Internet can form networks and connect information from all stakeholders. Working on the Internet, stakeholders can easily share ideas or information. This ability is valued by all stakeholders participating in this research, as it would significantly improve the workflow.

Social media supports a collaborative working environment and connects people from around the world. However, designs of the built environment have not widely taken advantage of the benefits of social media, although there is potential for an opportunity to enable people, and architects in particular, to use web applications for design communication. The benefit would be particularly important because the design process involves stakeholders working over long periods. The IDCM system not only allows users to interact with a 3D model or other works, but also encourages interactions between users. One benefit of interaction can be the use of interactive digital media to enable people to connect and share information online. The advantage of this is the ability to share not only the information between the members on the IDCM system, but also information from other websites or sources.

ii) Accessibility – The principles of accessibility are put into practice in two ways. Firstly, the IDCM system works on web browsers because people do not need special skills to use these. Secondly, real-time communication enables access because people can see others who are online and they can join in the conversation. The IDCM system uses real-time communication as well as asynchronous communication.

One additional point about access to the IDCM system is that it is controlled. People need to be a member of a team working on a project to access the information. A project manager controls who these members are and therefore who has access.

Real-time communication offers stakeholders interactive access to the latest information. Stakeholders are notified of uploaded information by a brief history of posts which shows when the user clicks an icon in the screen. For example, users post, share and comment on the building information. In addition, a chat function allows stakeholders to see who is online and available for communication.

iii) Inclusivity – This feature allows all stakeholders to collaborate and to identify problems which occur in a project during the design process. Quite often, architectural representations involve a high volume of data and large files, so architects may need to send files and messages separately. The IDCM system allows stakeholders to upload their files for other stakeholders to read and to save a message telling others about the upload. When the receiver opens the screen, they are able to see the uploaded file and the message together. Building information is included in one place where material is chronologically organised from the oldest to latest information, for example, archiving revisions is a function of inclusive data. Inclusivity also means using digital media to include multi-functional usability, as the advances in digital technology enable architectural information and conversations to be included together within one application. In addition, the client might prefer a previous design that the process has gone through. As a result, stakeholders are included in the system to participate in the design process. Inclusivity thus supports a participatory workflow that allows democracy to emerge in the project.

This section has described the end users of the IDCM system. The system offers multiple functions for different users, for different purposes according to their requirements. The section highlights significant features which are specific for IDCM users to improve their workflows. The system can be used intuitively as a web application with a straightforward design for end users. The next section presents the design and the use of the mock web application.

5.3 The demonstration mock-up

This section describes the design process of the demonstration mock-up of the web application. This project developed the IDCM system through the design of a digital demonstration mock-up in order to collect participants' feedback, therefore it shows all functions and an interface, the designs of which were inspired by users' behaviours. The concept is based on the understanding that users should not need high levels of technological skill to use the web application. The design employs familiar navigation and representation of icons similar to those on popular social media websites or other applications, which exemplify the ease of use. The design interface takes on the appearance from other interfaces, colours and graphics from the software that stakeholders use in their professional work, focusing on computer-aided architectural design (CAAD) and 3D modelling software in the built environment industry. In addition, the standard features of social media such as posting or sharing actions are taken from social media interfaces to enable users to act effortlessly.

5.3.1 The process of designing the mock-up

Before starting the mock-up design, the researcher explored the digital tools currently used by architects and engineers. Software such as Microsoft Office[20] tools, computer-aided architectural design (CAAD) tools, visualisation and simulation tools were considered (see more details in Chapter 2). Analysing the attributes and interfaces of these tools has enabled the design of the mock-up to be appropriate for users, such as architects, engineers, planners and clients, whose views were sought.

The mock-up was developed to test how the user responds to the IDCM system. At the beginning of the design process, the researcher used the Adobe Flash[21] application to create interactive media such as web pages. Flash is quite easy to use because its interfaces and commands are similar to Photoshop[22], which designers use widely in both iOS and Microsoft[23] environments. However, when it comes to website creation, this research found that Flash was not suitable. Due to the lack of accessibility when it exports data to a web browser, Flash websites are unfriendly to search engines. There was also a problem that Apple and Android did not support Flash on mobile devices. As this problem emerged, the researcher decided to enable the mock-up to operate on a computer, and the creation of a web application became the best choice for the reason of easy access for all users. In addition, Flash does not offer the creation of 3D modelling which is needed for the walk-through function required by the system.

This research had to find a way that designers and stakeholders could share information as well as show 3D interactive modelling. The selected digital media

[20] Microsoft Office includes Word, Excel, PowerPoint, OneNote and Outlook.
[21] A multimedia software used to create animation, allowing browsing and gaming.
[22] Photoshop is software used to create and edit 2D graphics, operated by Adobe.
[23] An operating system which runs on computers, smartphones and tablets.

to be demonstrated for this project was a mock-up of web application, as a central communication tool in the design process. It was developed particularly for submitting designs to a range of stakeholders in a project. Therefore, this project produces a mock-up to show the idea of front-end design and to present how the final web application would work, and how it could help communication between stakeholders.

The mock-up was designed using the IDCM system as a structure, to organise a number of pages and a hierarchy of functions. The design started from a series of sketches of diagrams and references to other websites. Web pages and social media were explored to learn from their features. Consequently, a schematic design was created and revised in order to develop the final design. A problem occurred in the schematic design, where there was a lack of data management and functionalities due to limited information from stakeholders. The more participants the researcher interviewed, the more information was revealed. Data results were analysed in terms of data management, user behaviours, content of media and graphic design. The design process is shown in Figure 5.12 (see enlarged version and more images in Appendix E), and emphasis on early drawing of schematic design is shown in Figure 5.13.

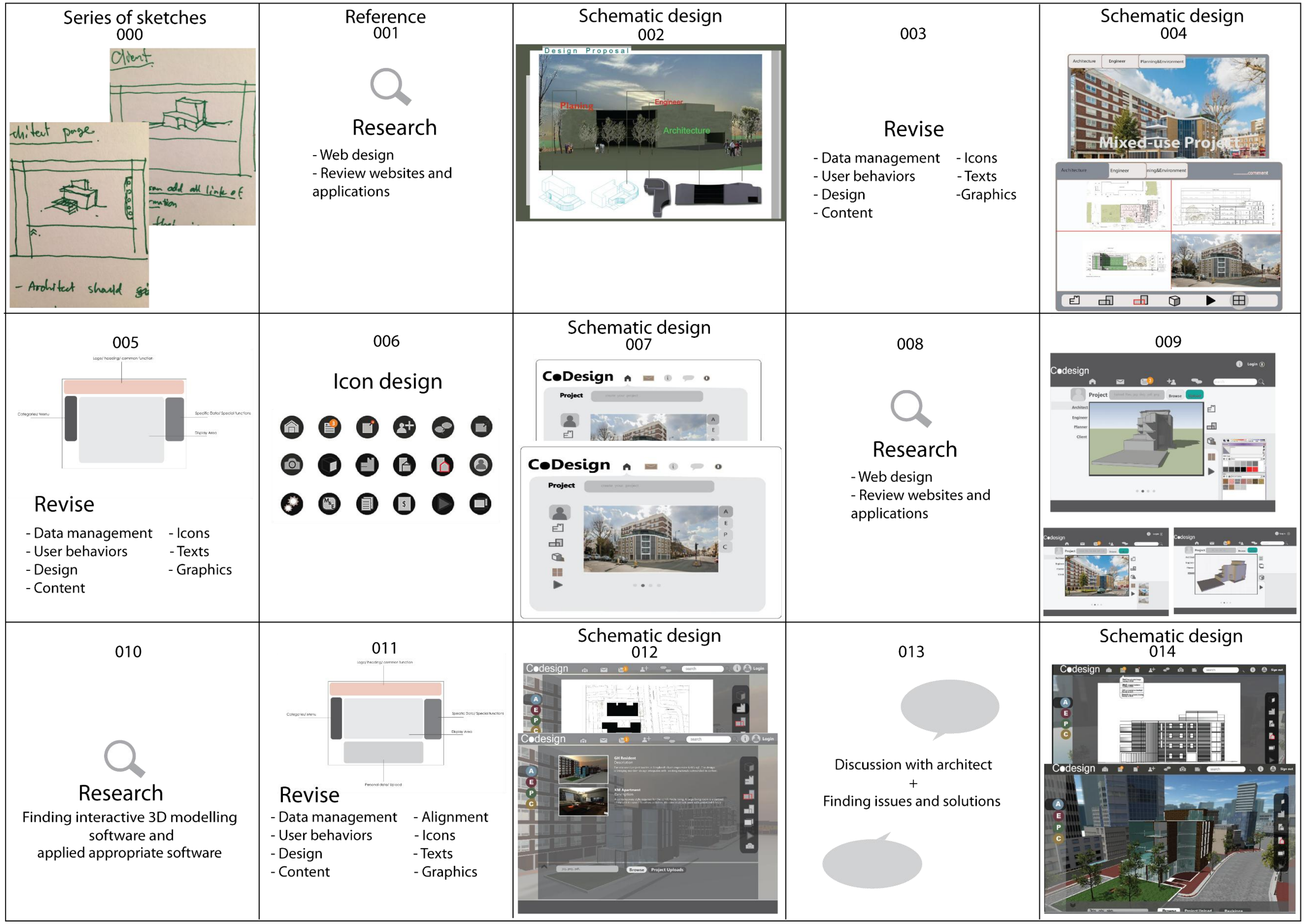


Figure 5.12: **The design process for the mock-up**

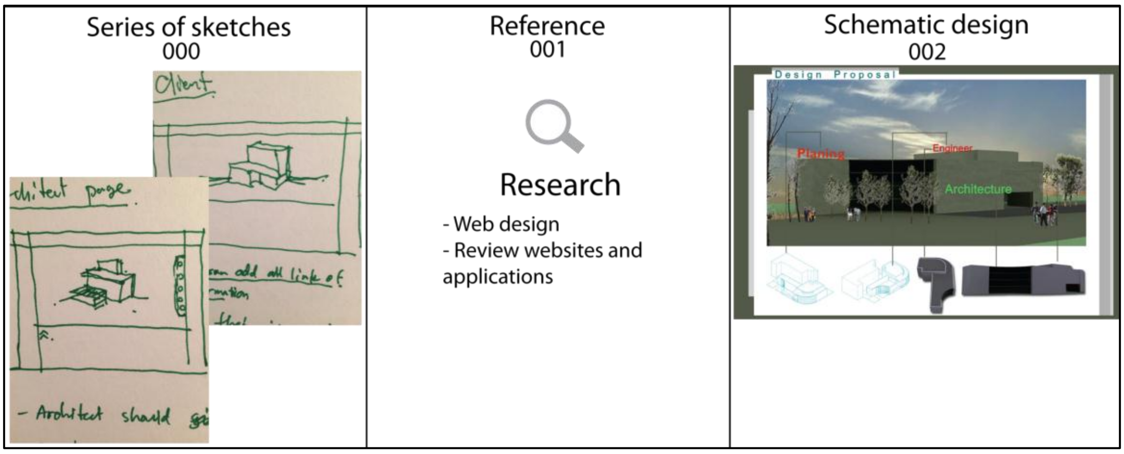


Figure 5.13: **The mock-up design process, stages 000–002**

In Figure 5.13, stage 000 shows a series of sketches. Stage 001 shows the research stage, where the researcher looked at web designs and applications in projects reviewed in Chapter 3. The 'National Anping Harbor Historic Park' project and the 'uCampus' project are considered in terms of 3D modelling and data management, the research obtained structuring information relevant to end users, which informed the hierarchy of each page. Stage 002 shows the schematic design of the interactive digital media (see Figure 5.13). At the early stage of the mock-up design, the information in this schematic diagram came from the researcher's interviews (see Chapter 4) with various stakeholders. The interviews also revealed two important areas which the researcher had not previously considered. These were: the need for stakeholders to be able to collaborate in the design process, and the need for them to be able to organise data. Functions lacked organisation when the amount of information became overwhelming.

The interface design was adapted to the needs and requirements of users by adding more functions. The colour theme of the web page was more challenging because of stakeholders from various age groups having different preferences. An appropriate design was needed to suit professional users aged 25–65. At this stage, decisions on ideal size and style of text and graphics also required more in-depth studies. Moreover, they needed to fit with the general solution for the desktop screen. Icons were repeatedly redesigned in order to better represent participant feedback (see Figure 5.14, stages 003–004). Icons had to be meaningful to users with different visual background and knowledge. Thus, the design of this mock-up considers the concept of design relevant to professional life and social life, to enable a friendly interface and ease of use. This stage focussed on classifying architectural representations as well as classifying users. The issues of design in this development stage were: unorganised building information, and that the mock-up design did not show user identity. The identity of each user is important as it allows other users to know who is online and involved in the project. At this design stage, functionality of real-time communication did not emerge.

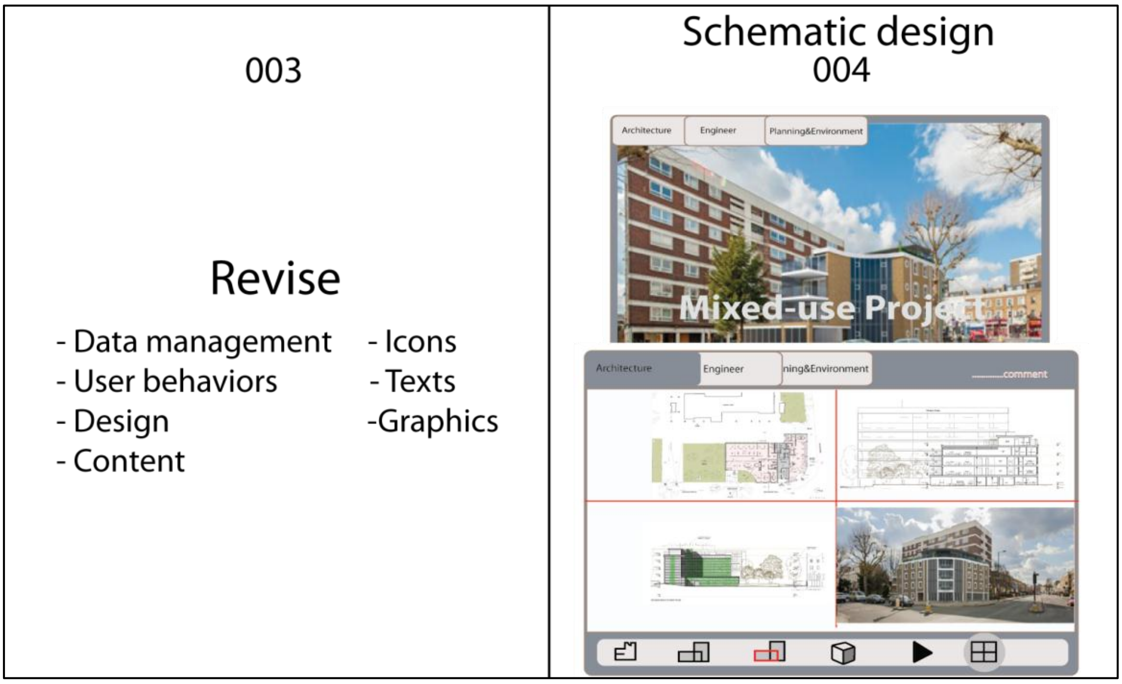


Figure 5.14: **The mock-up design process, stages 003–004**

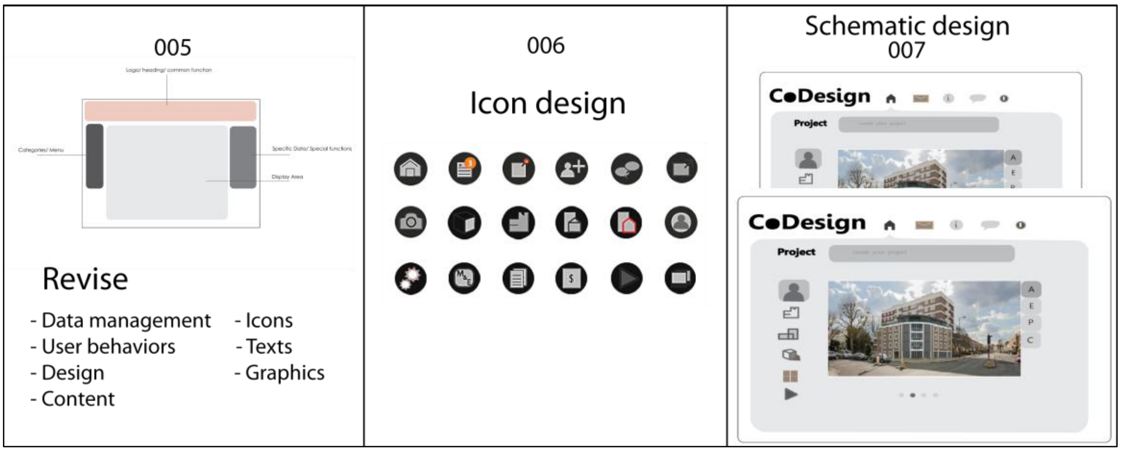


Figure 5.15: **The mock-up design process, stages 005–007**

The schematic design in stage 007 (see Figure 5.15) helped to categorise and arrange function icons, then located them in the best position on the pages. Each button needed to be in sequence. The difficulties at this stage included making efficient representations on icons so that users could respond and would be comfortable with navigation. Therefore, this research needed to explore more websites and applications to find out users' responses to interfaces and navigation (see Figure 5.15, stages 005 and 007). Two further areas of clear presentation were therefore developed: 1) showing user identification, and 2) showing real-time communication. From this design stage, the mock-up was developed in order to show user identity. Real-time communication such as a chat function, was clearly presented.

Stages 008–009 in Figure 5.16 show the development of schematic design. After reviews of websites and applications, the interfaces of the mock-up were developed to improve the layout of design within the page. This stage of development moved the surface design to the interface with graphics and icons, adding the actions and functions behind the icons. Adobe Flash CS was used at this early stage to test the interactive system's schematic design before starting to use the 3D game engine[24]. This was a quicker way to test the effective relationship of paths and functions. Game engine software requires more time and capacity for computer processing than Adobe software, as it produces larger files. Therefore, this research used a 3D game engine for the creation of 3D interactive modelling at the final stage.

[24] The game engine software used in this research is Unity, made by Unity Technologies.

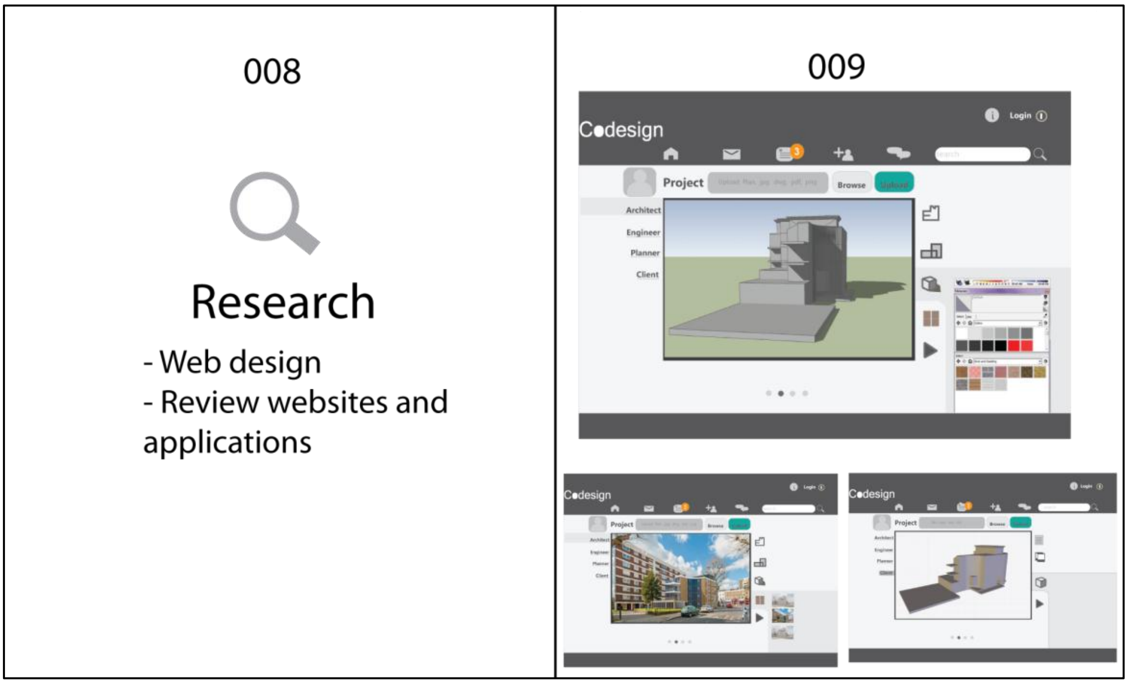


Figure 5.16: **The mock-up design process, stages 008–009**

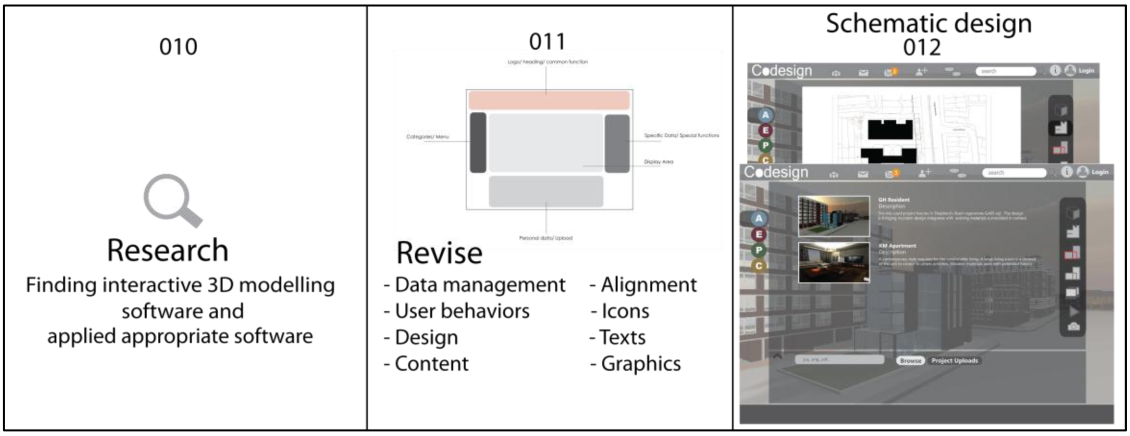


Figure 5.17: **The mock-up design process, stages 010–012**

Using Adobe Flash CS limits the capability of showing interactive 3D modelling with a walk-through function, even though it is efficient for a 2D interactive interface. The survey data shows that the proposed system requires 3D walk-through modelling. Therefore, this research had to find a tool that could visualise 3D modelling in terms of interactive capability, as well as being able to display on a web browser. Stage 010 (see Figure 5.17) shows the step of finding software that could produce a 3D interactive model, as well as creating the mock-up of the web application. Tools in the architectural industry were explored. There is a lot of software which produces interactive visualisation, showing the results in real time. These tools can be used for real-time collaboration. However, some tools have limited accessibility due to the necessary technical knowledge they require of users. Therefore, this PhD research has explored other areas of visualisation and has found the computer game industry a relevant inspiration. Some computer game software has already been used in architectural representation. In reviewing more tools which could display 3D interactive modelling and operate on web browsers, the researcher reviewed across the disciplines of architecture and computer game design to find a method to produce a demonstration of the mock-up. The research ultimately focussed on computer game software, as it can create a virtual 3D environment as well as a web application. Research from Keough (2009) suggests using the software Unity 3D (Unity: Game Development Tool) to help create virtual 3D modelling, with a web browser to be used or created. Unity 3D was selected to produce the mock-up, as it is a well-known modelling software in the computer game industry. Stage 011 shows the process of revising the mock-up, and stage 012 presents the schematic design of the mock-up. The design was well managed into categories of information, but functions still had to be reorganised and aligned.

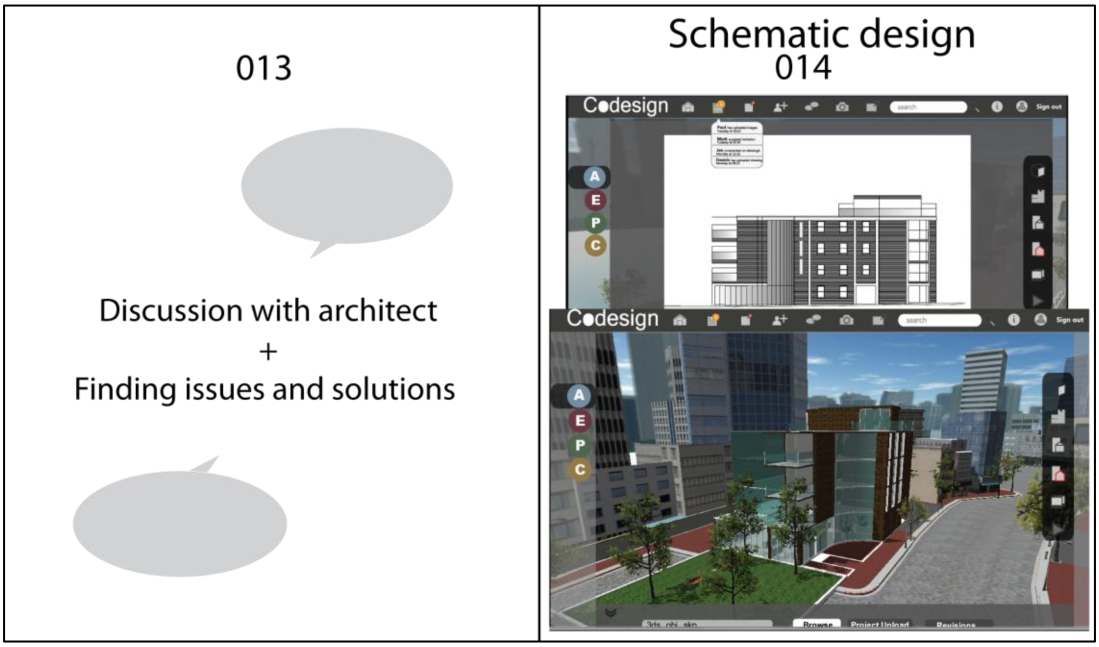


Figure 5.18: **The mock-up design process, stages 013–014**

The last revision to the mock-up is shown in Figure 5.18 (stages 013–014). Stage 013 shows discussion on the previous design, which identified issues including graphic design and navigation. This process was carried out with an architect, who was one of the participants in the fieldwork (interviews). The process was essential to developing the final version of the mock-up (see enlarged version and more images in Appendix E).

This research focuses on ‘pull’ media (as discussed previously in Chapter 1), a two-way form of communication, in order to encourage a collaborative workflow. The use of Unity 3D allows a 3D model to be produced that enables the creators to interact with the audience. There was a limitation for 3D modelling in Unity in this case, in that the tools used to create 3D objects were not practical for the researcher. To solve this issue, the researcher created a 3D model using SketchUp, which is widely known in architectural practices. The model was then exported into Unity to make a demonstration of the website. Unity software has the advantage of producing real-time effects such as rendering materials and shadows on 3D models. Cutting the rendering stage reduced the time required for the modelling process; most other software requires rendering. It usually takes time to see how a model looks.

A further advantage of the Unity software includes exportability of the work to the Unity Web Player, which performs in the same way as other web browser applications. This exportability can support the present interface design through which the project can offer 3D interactive modelling as well as functionality in the form of a web application. In addition, Firefox and Internet Explorer can support the playing of files that have been exported from Unity. The experiments of this project for an IDCM system and a mock-up show the potential of digital communication in terms of a front-end design. This research anticipates that in the future, the system could be developed with specialists to enable the mock-up to work conveniently on all computers, tablets and mobile phones. In addition, this proposed system would form the basis of further software such as Unity, BIM software and hardware development.

The summary of the mock-up design is demonstrated as a diagram (see Figure 5.19), showing the relationship between design and research. The initial design stage reflects the theories and the literature review, software, applications and websites. These processes enable the researcher to identify the design of the IDCM system, icons, interface and data management.

A series of design drafts is underpinned by the IDCM system. Survey data from the stakeholders’ experiences in the design process were used to categorise data. The user-centred strategy was adopted and became central to the initiative of the mock-up design; functions and hierarchies of information were compared to traditional communication and applied for development of the system. Architectural representations required for the system, relevant to the literature review in Chapter 2 and interview data survey in Chapter 4, were used to categorise necessary design information. In addition, human–computer interaction (HCI) principles enabled the researcher to understand stakeholders and identify barriers affecting communication within the design process. The design of the mock-up can be developed further according to feedback from end users after trialling the mock-up.

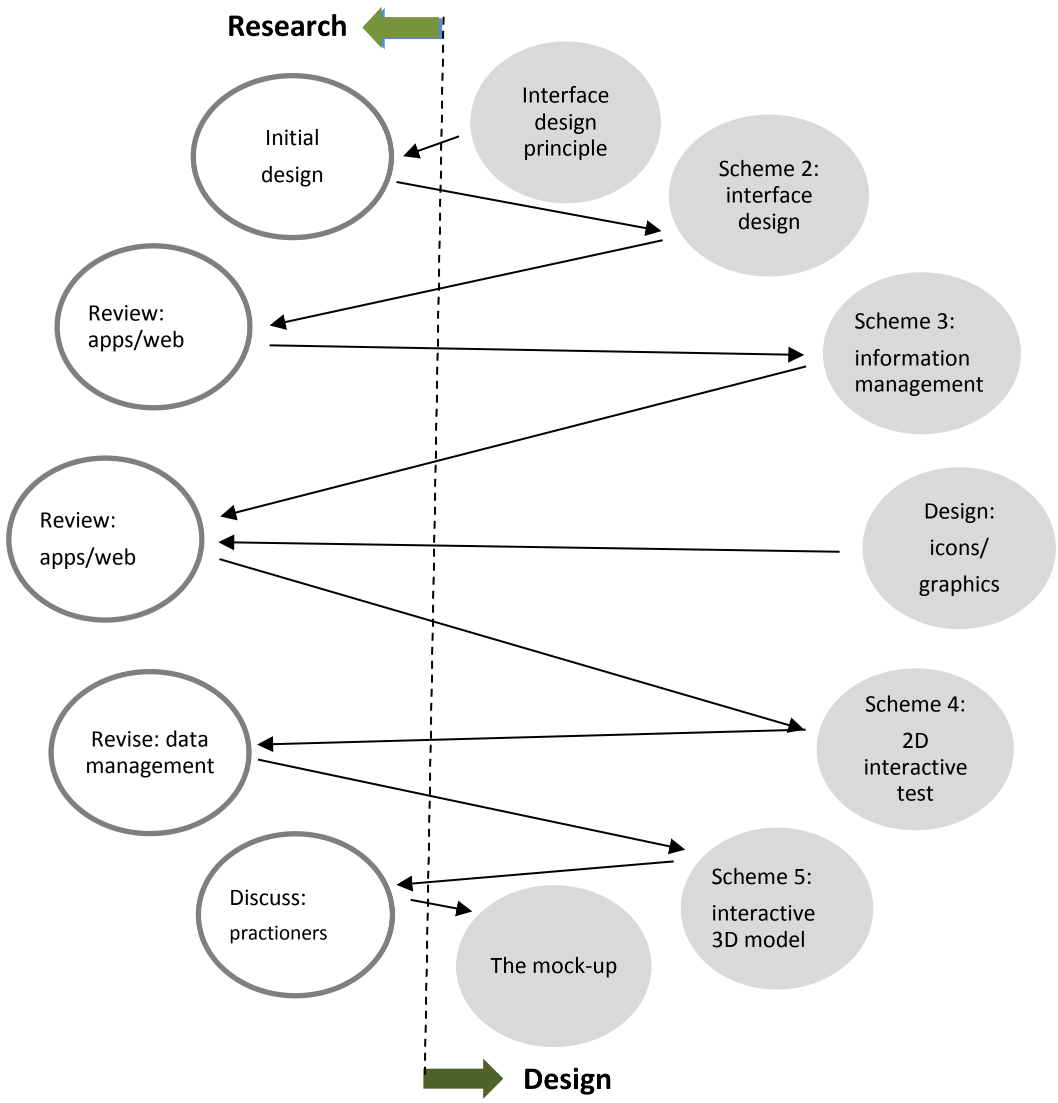


Figure 5.19: **Summary of the mock-up development, showing the relationship between design and research**

The next section outlines the interface design for the mock-up, which was created upon knowledge generated from critical approaches to digital media, applications and websites, described in Chapter 3. Icon design was developed from conventional software and applications generally used in communication design, as these would be familiar to professionals in the built environment industry as well as to non-professionals.

5.3.2 Interface design: paying attention to user interaction

This section outlines the design of the mock-up interface. Interface design is concerned with enabling users to navigate the correct functions. The mock-up is intended to inspire a user-friendly interface. Having users of different ages and backgrounds, in terms of their knowledge of architecture, presents a challenge. To achieve a universal and inclusive design solution, several significant aspects were considered.

One of these aspects was the colour theme, which was difficult to design to suit all users. There are many theories in web design disciplines regarding the relationships between users and colours. In order to make the text readable, the background should be light, but there are different preferences among users. For that reason, the researcher decided to use a background, which was selected from an image that an architect uploaded to the project. The researcher simply made the background less opaque than the original image. Consequently, the colour of the background became lighter to make all graphics, images and text stand out.

Another aspect was the graphic and text style. The style was designed to be simple while providing an intuitive interface. Standard icons representing social media communication activities were simplified from the social media application symbols that users are familiar with (see Figure 5.20). For graphics and text, size was a significant concern as icons needed to be easy to read on any device. Therefore, icons were designed using 24 x 24 point, which is convenient for both Windows and Mac environments. The best typeface size for text depends on a number of factors including size and resolution of screen display. Generally, the largest suitable font size is considered to be 16 point and the smallest, 12 point. The size of the page was designed to be at a minimum resolution of 1024 pixels x 768 pixels. The text was designed in a simple style to stand out from the background. The right-hand side of the page shows the categories of architectural information. The categories are represented by symbols that are usually seen in architectural software and representation, so the users would find them familiar.

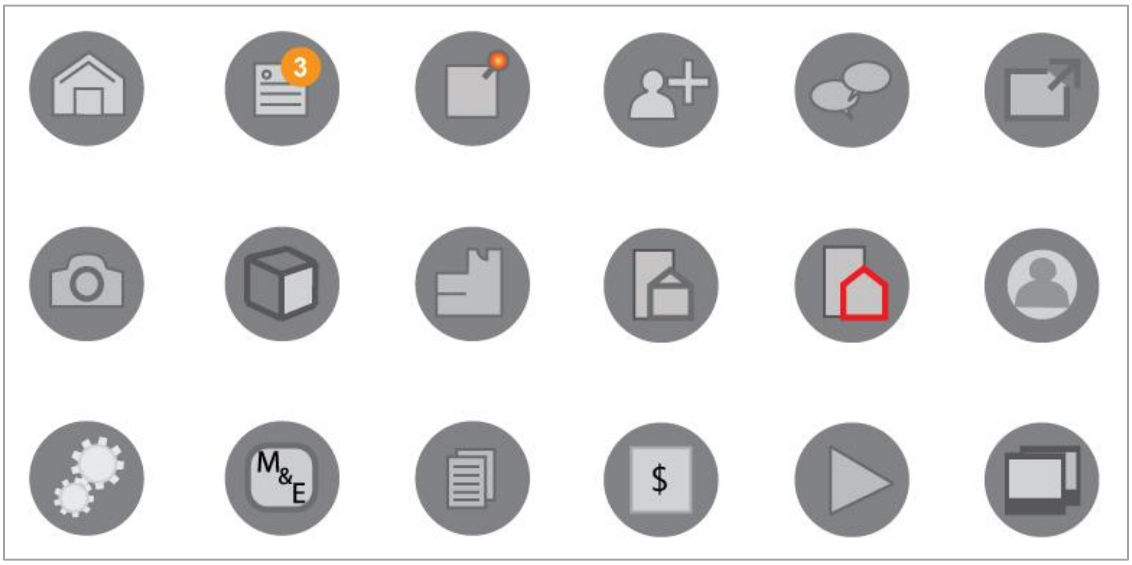


Figure 5.20: **Example of icons designed for the IDCM system.**

Alignment was a third significant aspect, which was important to enable classification of information. In this project, users were able to input their work or messages. The alignment of function icons needed to be clear so users could see where to put their information. Alignment here was designed in order to create elements as well as take on more complex hierarchical roles. This research required users to focus on the display of architectural representation as a priority; therefore, the largest area of each page displays design information, depending on stakeholders' preferences (see Figure 5.21). However, Jones (2011) recommends that for web applications, the 'sign in' icon should be placed at the top right-hand corner of the page. This corner area should also show the profile and the account. In this case, the web page has adopted these same conventions. At the bottom of the page, an area is provided for each of the stakeholders to input their information. This can be clicked to enlarge it, to give the users a bigger area that shows more details.

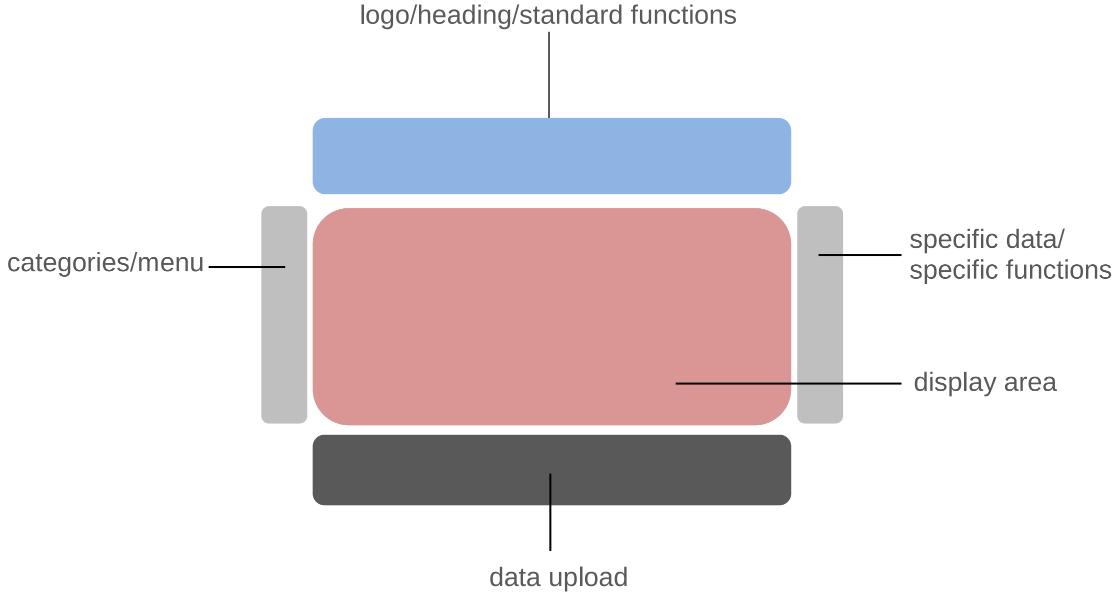


Figure 5.21: **Zoning design for functions management of the mock-up**

Figure 5.22 demonstrates the alignment within the page. Area 1 shows stakeholder types, where ‘A’ represents ‘architect’, ‘E’ represents ‘engineer’, ‘P’ represents ‘planner’ and ‘C’ represents ‘client’. Area 2 shows the standard functions to be deployed by the system users. The menu bar in this area contains functions that will not change, even when the user moves to another page. In Area 3, the functions are for architectural representations and relevant information. Area 4 is the space where stakeholders can upload their information, showing text which indicates the types of file that can be uploaded. There are guidelines to help stakeholders understand what kind of information to input. In addition, Area 4, can be enlarged to replace Area 5, which is the area displaying the architectural representation. The revisions archive is also displayed in Area 4. This is a good position from which to view data and to show its history, as the area can be enlarged. Area 5 mainly shows interactive 3D modelling, drawings and images.

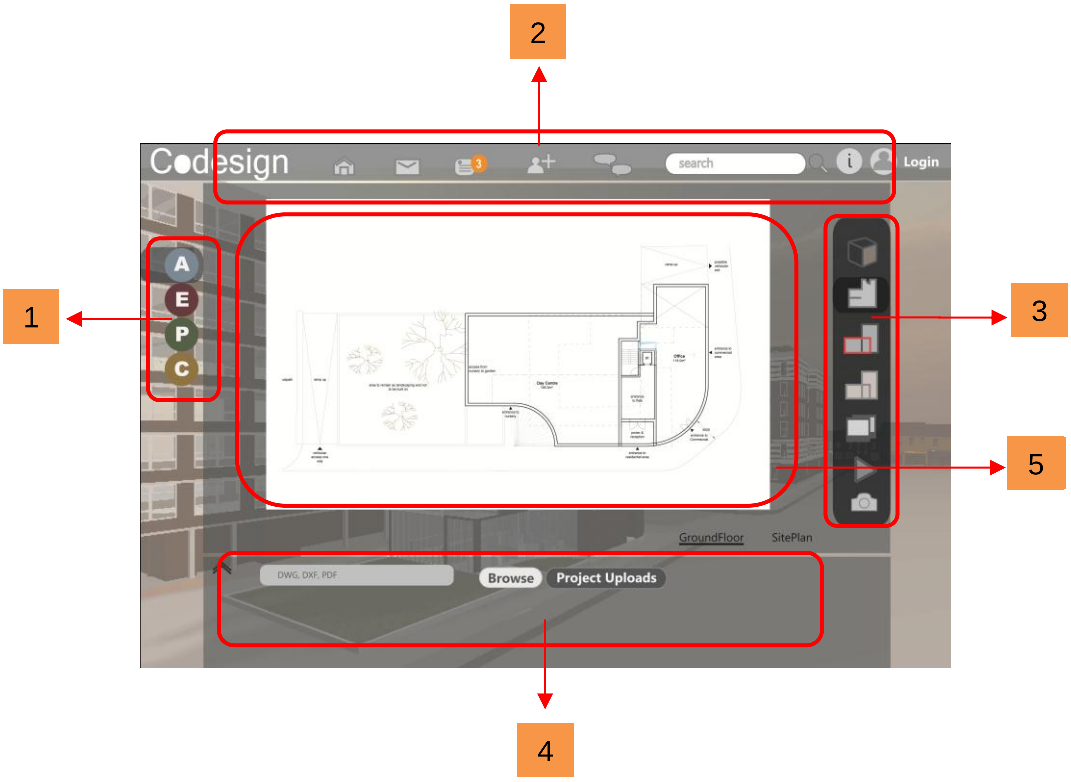


Figure 5.22: **Diagram showing the display alignment in the mock-up**

The mock-up has helped the project to clarify the design of the IDCM system and clearly indicates the problems and the solutions encountered during the design process. ‘Co-design’, as the mock-up was named, was tested with participants in order to receive their feedback for future work.

5.3.3 A representation of users’ story

The section gives a description of the features of the mock-up and represents users story in the design process in the form of the storyboard. ‘Co-design’ is used to demonstrate how the system promotes communication and collaboration. It encourages users to upload, consider and share architectural information, both remotely and instantly. Co-design employs the IDCM system, which the present research has created for architects, engineers, planners, and clients.

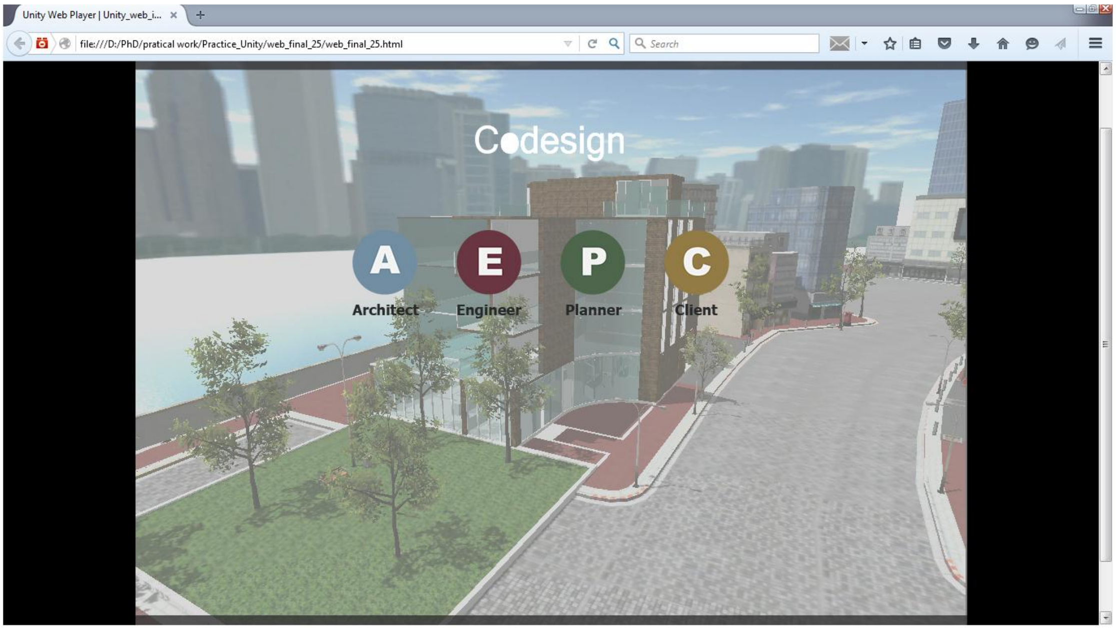


Figure 5.23: **Screen view of the mock-up, showing first page display**

The home page (see Figure 5.23) allows users to sign in with just their email and a password. Users first register by entering their personal details (name, surname, occupation, email and password) – for the registration page, see Figure 5.24. Once users have signed in, they are able to select the project that they are working on (see Figure 5.25).

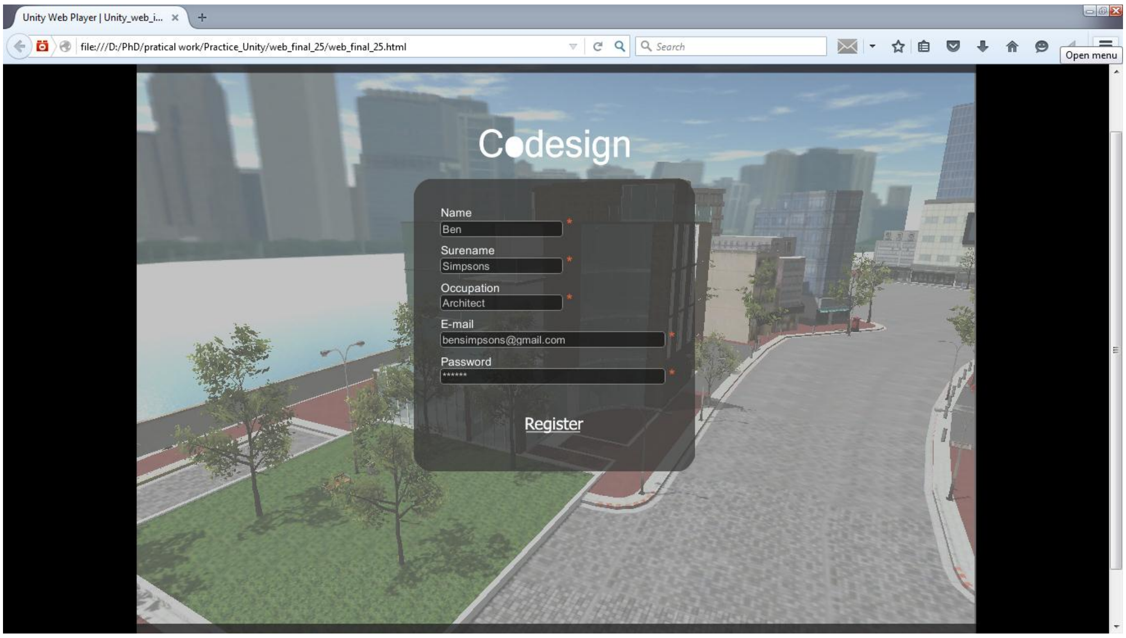


Figure 5.24: **The registration page of the mock-up allows users to enter information securely**

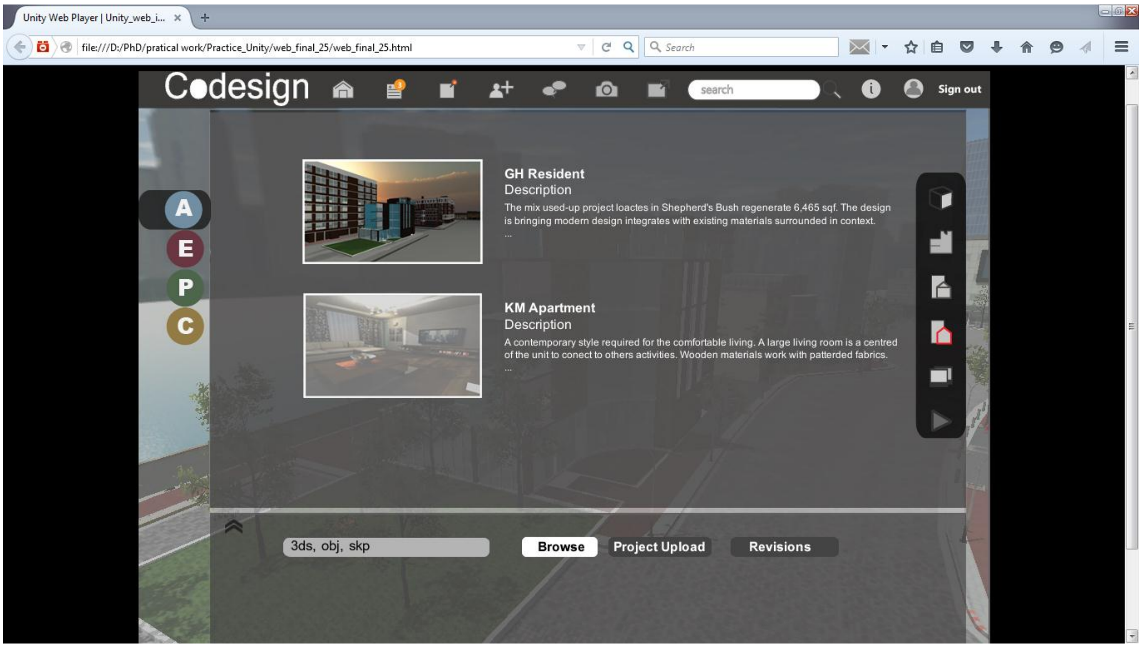


Figure 5.25: **Project management on the IDCM system, shown through the mock-up**

The top of the page shows the standard functions such as the home button, and the archive of activity notifications. Here, users can also give feedback and invite people to the design process from Facebook, LinkedIn or by email. In the case that users would like to communicate with other stakeholders in real time, they can use the chat function, which shows the status of other stakeholders who are online. The camera function allows users to take snapshots to save and share with other people. Other functions at the top of the page include 'search', 'site information' of the web application, 'user identification' and 'sign in/out' options (see Figure 5.26).

Figure 5.26: **The mock-up interface**

The bottom of the page allows users to upload their information. There is a tab bar where text indicates the file types that the users can upload. The text will change according to the type of architectural information that the users choose, by clicking on the right-hand side icons. Users can then browse their files and upload. Next to the project upload button is the special feature of the system, which shows the current revision that users are working on. Users can also browse through previous revisions and track all changes of information (see Figure 5.27).

Figure 5.27: **A mock-up screen showing the effect of some revisions on the model.**

Another feature of this system is an interactive 3D model, which allows stakeholders to walk through a virtual environment for an immersive experience. Figure 5.28 shows the views from the inside of the building, which observers can 'experience' differently, depending on their position. Please see Appendix E (DVD) to explore the fully functioning mock-up and the IDCM system demonstration.

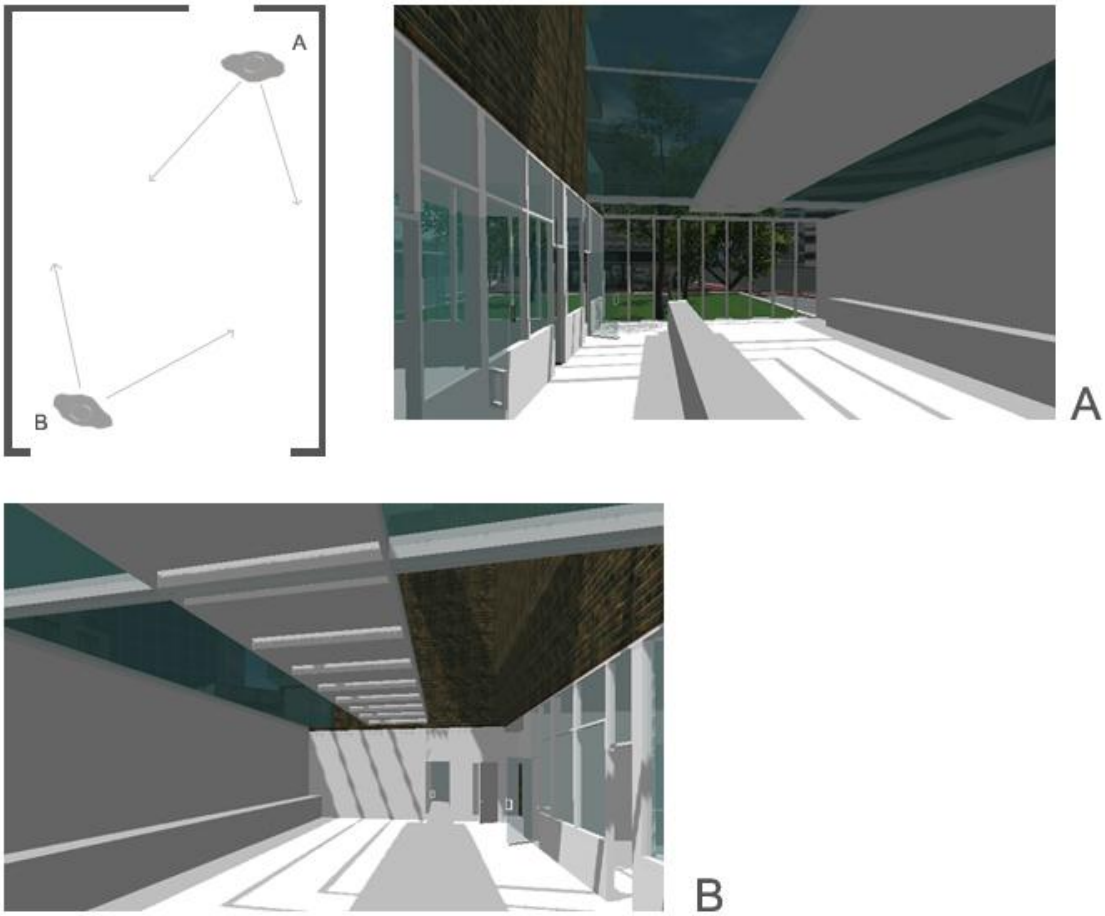


Figure 5.28: **Internal views from the interactive 3D model.**

To demonstrate how the system will be used in the design process from a stakeholder's perspective, storyboards are employed. A story is created from the real experience of the interviewed participants, combined with the researcher's experience in architectural practice (see Figure 5.29).

Interactive communication system use through storyboard

The storyboard aims to pesent the operation of the interactive design communication system from a user's perspective. It demonstrates how the design process / communication / collaboration between stakeholders can be improved.

01

Architect: I need to set up the project so that engineers, planners and clients can participate in the design process collaboratively.

Architect: This is my first time, I need to register.

Scenario: Architect setting up the project and uploading information for other stakeholders.

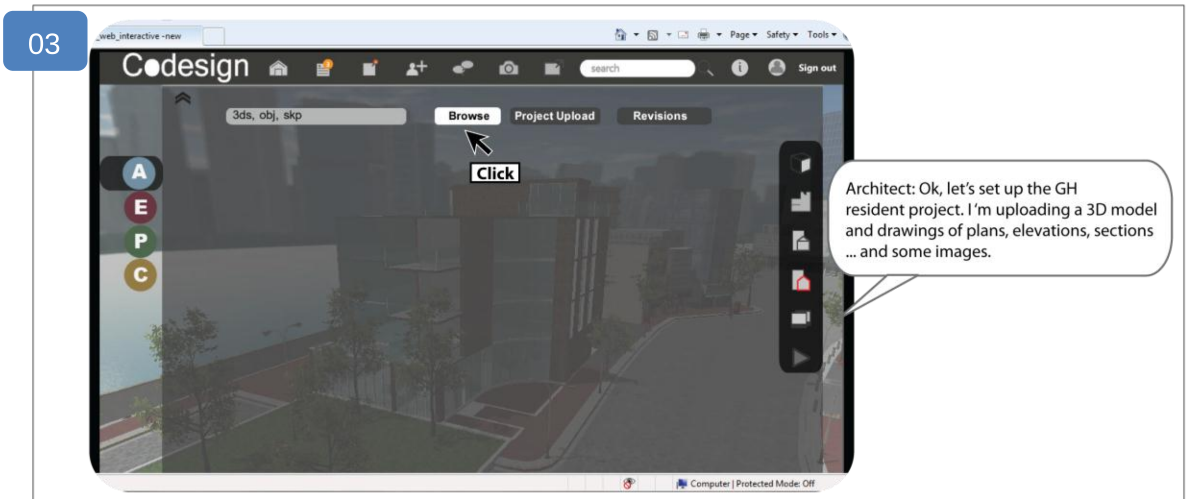
Key: Stakeholders working together on the project are included in the communication and design process. Initial character indicates role of users.

02

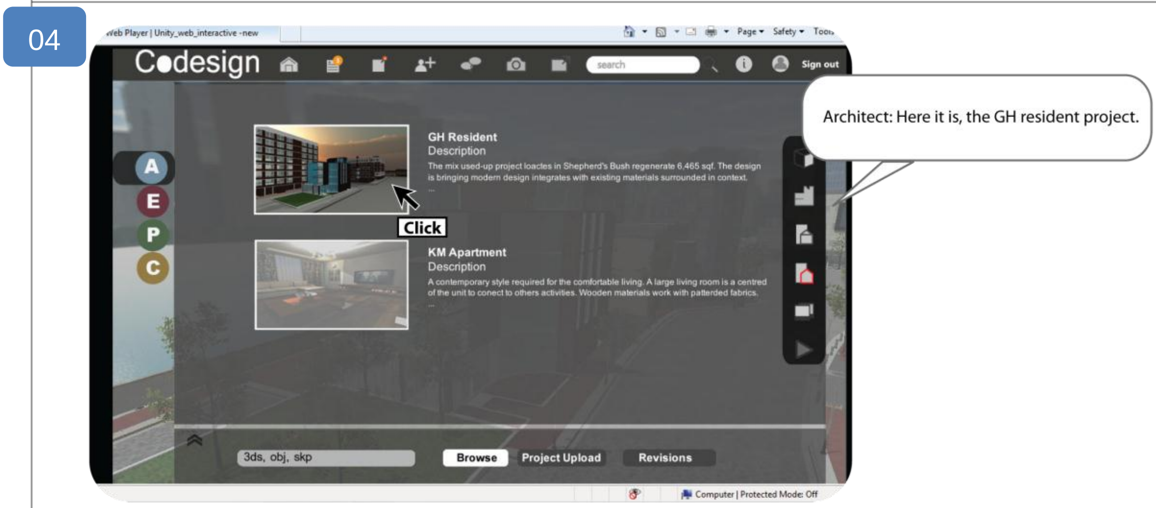
Architect: The system requires information such as name and occupation in order to show my identity.

Scenario: Architect creating an account and signing in to the system.

Figure 5.29: **Storyboard showing how to use the communication system**



Scenario: The architect browses files and uploads relevant information.



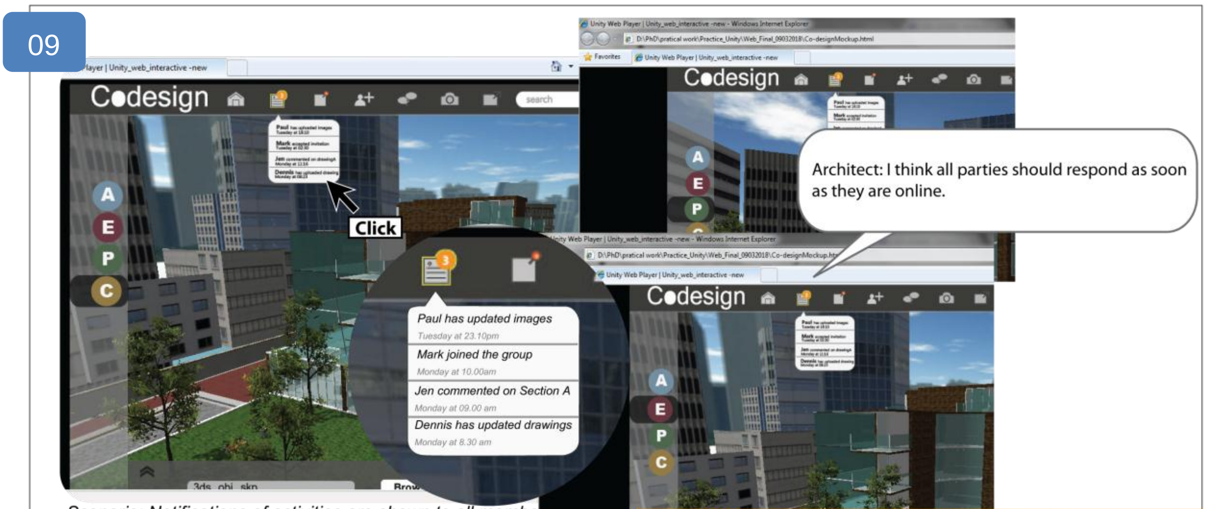
Scenario: Arcitect selecting the project.

Scenario: The application shows presentations including 3D models, plans, elevations, sections, images and videos.

Key: Interactive model allows virtual walk-through that enables all stakeholders to consider the design.

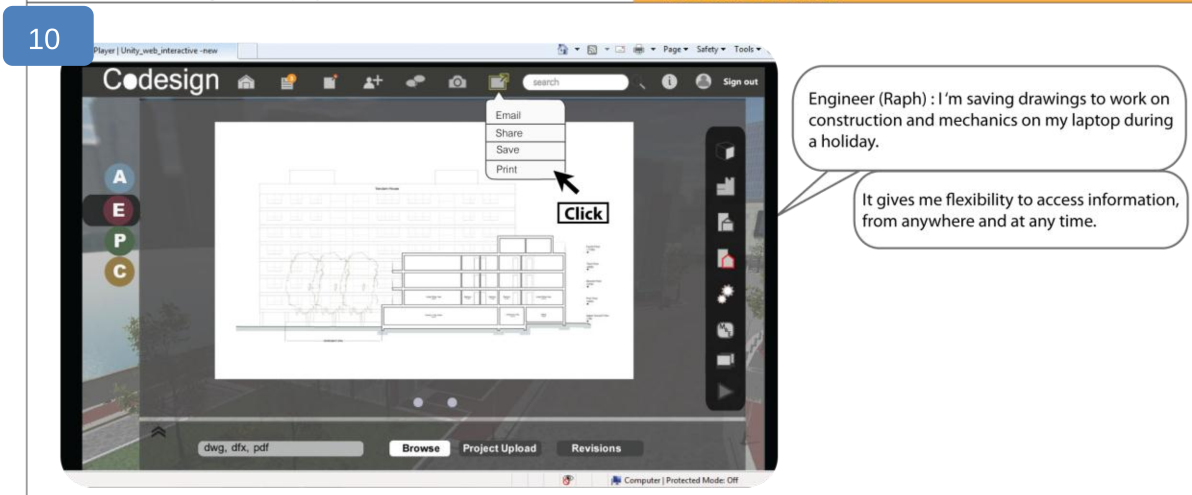
Figure 5.29: **(continued)**

Figure 5.29: **(continued)**



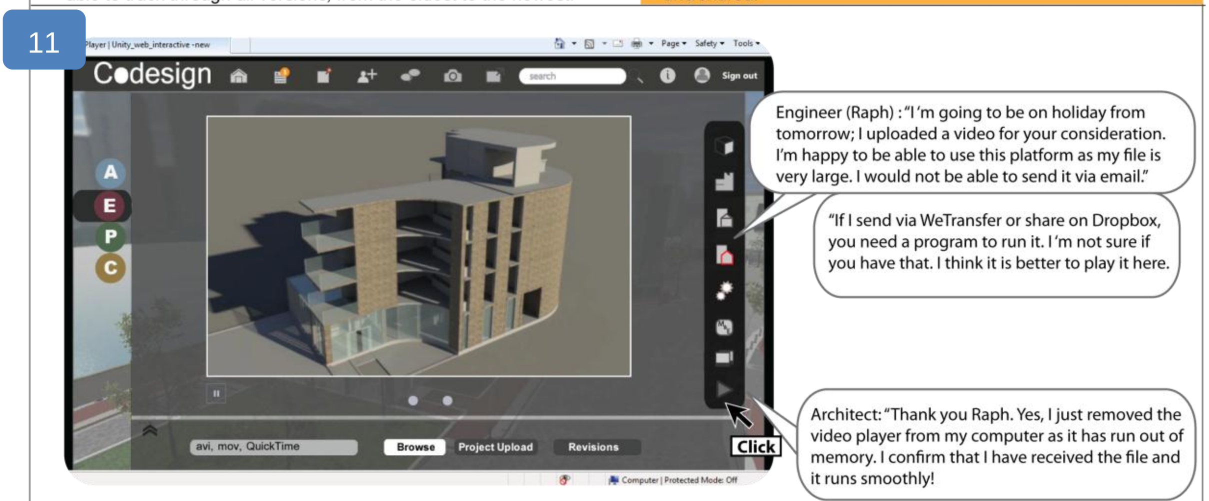
Scenario: Notifications of activities are shown to all members so they are aware of changes in the project.

Key: Notifications request interaction of stakeholders. These can be archived.



Scenario: Engineer saves drawings and shares them, as well as being able to track through all versions, from the oldest to the newest.

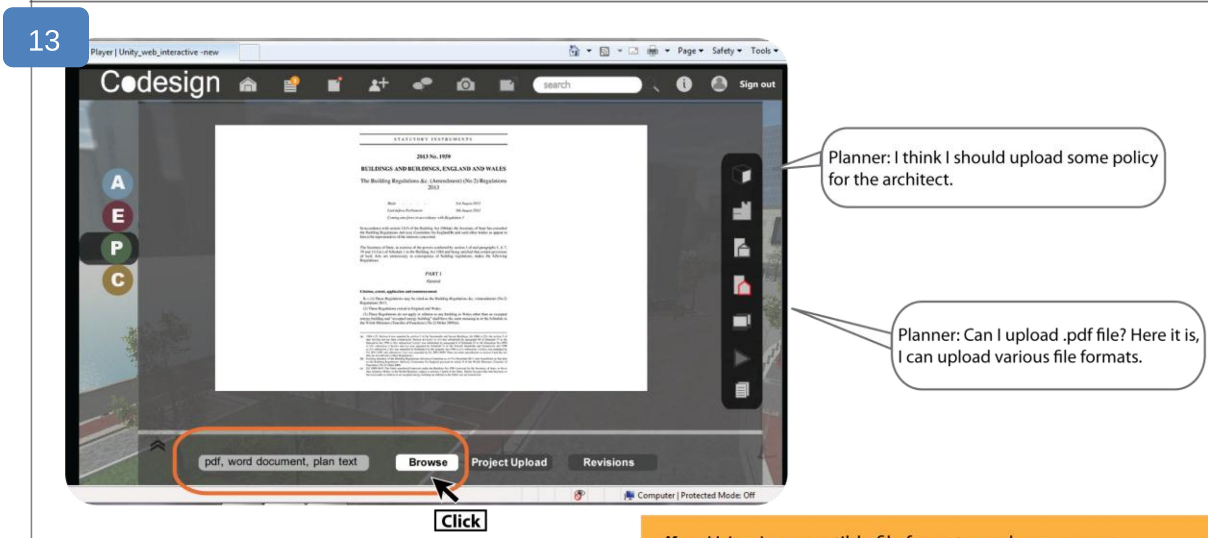
Key: Information such as drawings and 3D models can be saved and shared.



Scenario: Engineer uploads 3D animation for architect to see the process of how the building will be established in order to manage the time schedule, and sends message to architect.

Figure 5.29: **(continued)**

Scenario: Engineer and architect chat after having received feedback from planner.



Scenario: Planner uploading policy. Compatible files can be upload.

Key: Using incompatible file formats can be overcome.

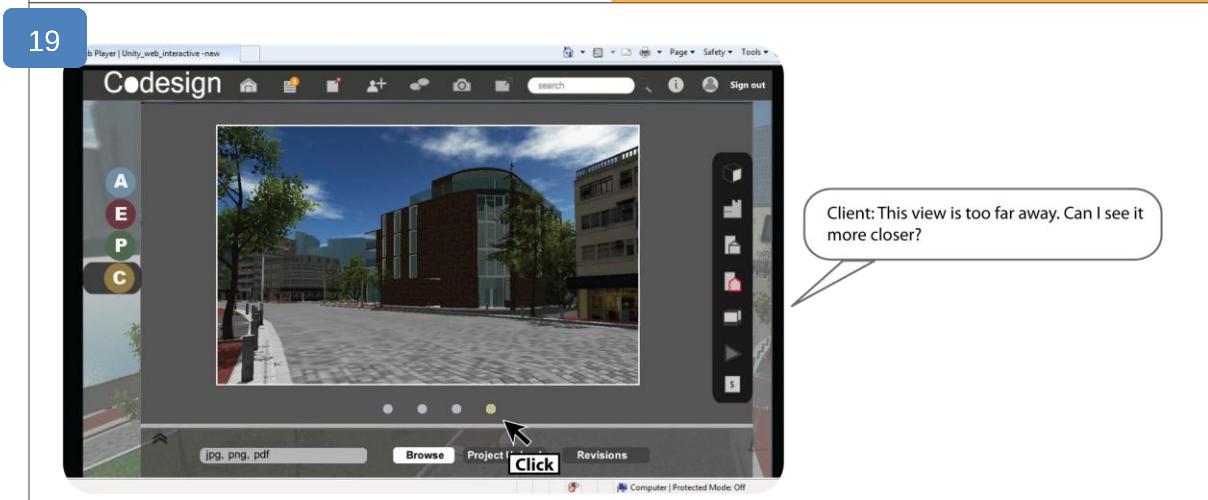
Scenario: Client selecting revision to reconsider.

Figure 5.29: **(continued)**

Figure 5.29: **(continued)**

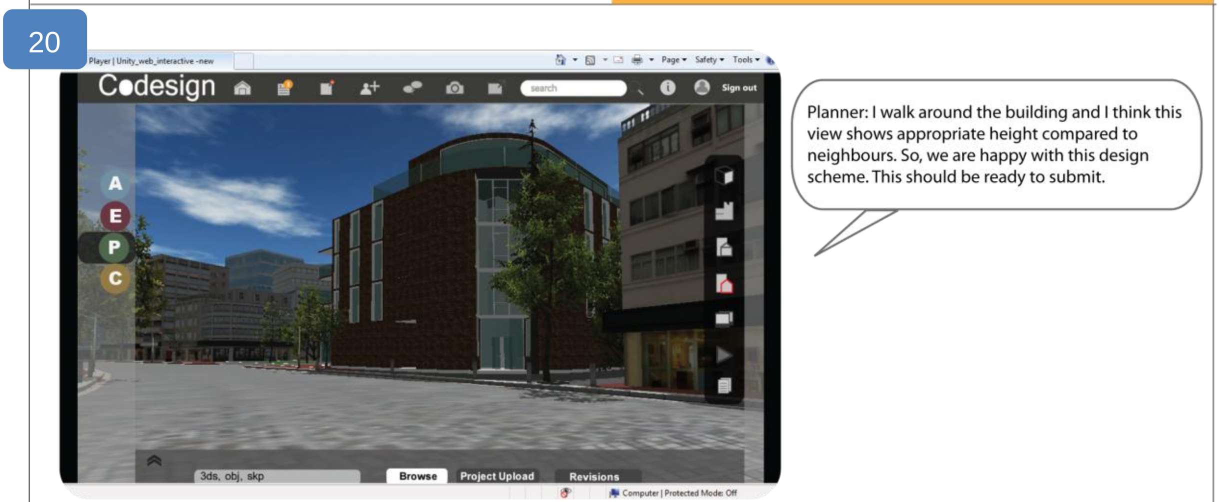
Scenario: Client viewing inside of the building.

Key: Interior design space can be immersive.



Scenario: Client viewing images that architect has posted.

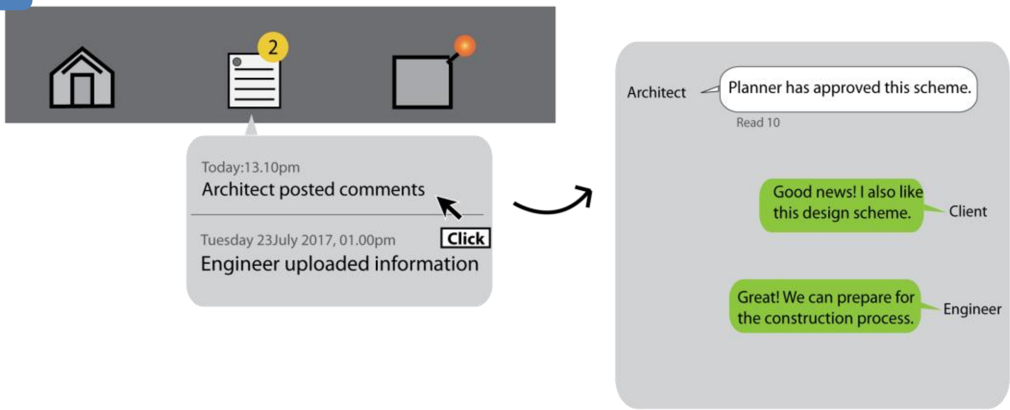
Key: Stakeholders can select view that they want to see.



Scenario: Planner approving height of the building.

Figure 5.29: **(continued)**

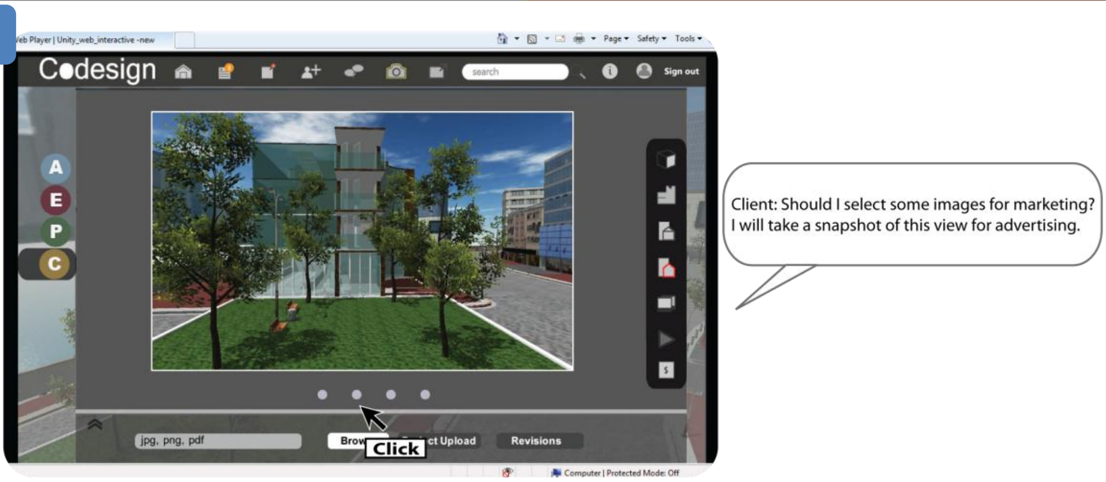
21



Scenario: Notification is sent to all stakeholders within the system.

Key: Notifications remind users of interaction.

22



Scenario: Client selects view to save and share.

Figure 5.29: **(continued)**

The storyboards demonstrate scenarios in which different stakeholders use the application for their work. In addition, these highlight significant features such as mitigating the gap of stakeholders' relationships and isolations; exploiting real-time communication to enable stakeholders to simultaneously respond; and presenting, viewing, archiving and sharing information in one system.

This section has introduced the mock-up that helps to demonstrate the IDCM system in the form of the storyboard in order to better understand how the system can be used to solve problems and improve communication between stakeholders in the design process.

5.4 Discussion on design of the IDCM system and the mock-up

The chapter discusses the efficiency of the IDCM system demonstrated through the mock-up and how both processes develop through a dynamic interplay. The development is not only for showing the design to stakeholders, but also enables the researcher to understand and produce both the system and the mock-up.

The IDCM system includes functions required in the design process as well as general information for architectural projects. It also highlights functions that facilitate real-time communication to improve the workflow. In addition, data management is included for storing, archiving and sharing information. This research finds these inclusive functions allow the stakeholders to interchange ideas, communication and information for the collaborative design, which are essential to dynamic communication systems today. The design of the mock-up was generated from background knowledge of the researcher along with enhanced aspects of interface design and HCI principles (described earlier in this chapter) based on the nature of a traditional communication system and the range of stakeholders in the design process. The design has considered the users to be central in order to enable them to use the mock-up as a trial and understand how the IDCM system works in reality.

The interface design was intended to enhance ease of use for a wide range of users. Stakeholders can see the architectural information displayed predominantly on the page. However, other functions such as ‘upload’ and ‘archived revisions’ can be enlarged. Icons were also designed upon users’ familiarity with the tools used in the built environment industry. The efficiency of this design is the organisation of data and functions that end users are familiar with. Furthermore, zoning management helps users seeking additional information.

The findings of this chapter include a suggestion that the IDCM system responds to the problems of communication and collaboration at stake in this research. The communication system is illustrated in the format of diagrams, and by demonstrating how it is used in the design process through storyboards.

This chapter has focussed on introducing the IDCM system and the demonstration of the system usage. The design employs the three guiding principles of ‘interaction’, ‘accessibility’ and ‘inclusivity’, to overcome problems that occur in traditional communication for stakeholders. The design process of the system, the mock-up and the storyboard adopt from various disciplines including information architecture (IA), interaction design (ID), and graphic design. This shows the significant areas for the architectural industry to take an advantage of the innovation. The interactive communication system is an alternative use of digital media in the design process for collaboration and communication, which operates on an Internet network.

Chapter 6 Evaluation of the interactive design and communication management (IDCM) system

Chapter 6 Evaluation of the interactive design and communication management (IDCM) system

This chapter describes the evaluation of the IDCM system being proposed. This evaluation was undertaken using a group of participants who were asked to use the mock-up and give their feedback on it. Participant feedback was used to inform the discussion on how the IDCM system works. The participants critically evaluated the system, identified the beneficial features as well as the issues that needed addressing. The feedback from the participants was used to make suggestions to resolve some of the issues in the current IDCM system and the mock-up.

In order to test the effectiveness of the IDCM system, a group of volunteers were asked to use the mock-up. This method of evaluation seems to be the norm in similar design situations. According to McDaniel (2011), the participants' feedback is significant for the design process in terms of vision, design, technology and people. Having a feedback process allows different opinions to reach common ground in the design. In the present research, user feedback is an important component. The collection of feedback was informed by the good practice of a number of relevant researchers. Other researchers who have used feedback for developing a design include Wahlstrom *et al*. (2010:197–211), who made use of a cave automatic virtual environment (CAVE) for end users to compare a real environment with virtual reality (VR). User perception and evaluation are studied through VR as a review tool. Others have used an experience-based virtual prototyping system (EVPS) to simulate scenarios that take place in healthcare facilities. The prototype was tested with users in healthcare to get feedback to develop the project (Kumar, 2013). These researchers gained important information from user feedback in order to improve design. Testing with end users enables designers to identify significant issues, and it reveals solutions that help to improve design or propose development. Hence, user feedback is integral to the present research, in order to outline relevant issues and propose solutions. It is crucial to receive evaluations after the design is finished.

The mock-up is important to the present research as it enables the researcher to gain insight as to how end users respond to the IDCM system and it identifies issues that could cause confusion to users. The user interface (UI) design is also important to the present research, in conveying messages to users. Therefore, feedback has been collected on the use of the mock-up, as well as on the system design. All comments and recommendations were summarised and interpreted.

6.1 Participant responses

Participants involved in this stage took part in the initial interviews described in Chapter 4. This section describes the participants' feedback process and the data obtained. The participants had time to reflect on what they had originally said at the initial interview, before having an opportunity to experience the mock-up. This enabled them to recall issues that were important to them in the design communication process. Their feedback was collected to reflect on how the system worked, addressing any inefficiencies in the design and suggesting solutions for the development of the system.

In the design process, architects and other stakeholders face difficulties in the communication of various aspects of the design, such as misunderstanding the plans or being unable to access the work due to incompatible software. The IDCM system is designed to improve communication between the various project parties involved in the design process. It works on a web browser and an Internet network. Users can upload, consider and share architectural information. The IDCM system puts traditional communication tools into application and uses attributes of social media in the design process. The mock-up web application for collaborative design, which is referred to here as 'Co-design' was built from the IDCM system. The system was created to enable collaborative design in architecture and is intended for use by architects, engineers, planners and clients. The following section describes the IDCM system's usability for each group of potential users.

Architects: This group uses the platform for uploading their work. They have to sign in/register with their personal information, which is then verified and saved. They can set up a package of instructions known as architectural instructions (AIs), including plans, elevations, sections, 3D models, images and videos. They can receive real-time feedback or comments from other stakeholders and at the same time, they can have real-time communication via online messaging. Architects tender a design package when they finish the design. However, as the design may need to be developed further, this web application enables the AIs to be archived as revisions. Stakeholders can track back through all of the information at any time, as Co-design is an online application.

Project Workflow Manager (PWM): This could be the project architect or someone appointed specifically for this task. This person can invite stakeholders to join the system, manage acceptances, issue AIs and back up information that is uploaded. When people first register, they need to be accepted by the PWM to become members of the system. Another important task of the PWM is to control the information/modifications that need to make their way to the master copy of the project file.

Engineers: This group uses Co-design to see design documents generated by the architect (drawings, specifications, etc.). Engineers can comment or work on the drawings or other architectural information themselves. Engineers as users are required to sign in/register. They can then upload their work to the Co-design for other stakeholders to interact with. Their work includes structural, technical, mechanical and electrical details.

Planners: This group uses the platform to view architectural information that the architect submits. Planners can look at 2D drawings together with interactive 3D models, which they can walk through, virtually; this is a useful feature of the IDCM system. Planners can explore specific viewpoints and view the building being designed within its surroundings, to check any planning issues that may arise. Planners can also track through revisions of previous designs in one place, which is very useful for comparing the current design to previous designs. The IDCM system encourages planners to upload any information, such as policies or acknowledgements, which they want to share with other stakeholders. The benefit of the IDCM system for planners is that it allows fast communication and archiving of documents in one location.

Clients: The clients use Co-design for viewing architectural information that the architect provides for them, including the budget. The client can explore the design and navigate through different functions. The application enables the client to view and comment on the design. Moreover, the client can save and share files or images. The client can see information from planners and engineers, such as relevant policies and the structure of the building. One benefit of using this web application for the client is being able to see the updating of the design process done by other stakeholders. Another benefit is having access to all information of the design that the professionals provide, in a single location and without having to chase different members of the design team, using time consuming traditional communication methods.

The IDCM system supports stakeholders' independence and inclusivity in the design process. Stakeholders see and acknowledge the design, which is done collaboratively by including them early in the process. Real-time participation helps to reduce inefficient use of time, misinterpretation of the design, confused communication and the effect of lack of specialist knowledge among stakeholders. The system enables communication to be straightforward and fluent during the workflow, applying a non-linear communication model, influenced by recent technologies. Hence, the IDCM system is more dynamic than traditional communication.

In the design process, it is important to communicate through architectural presentations and conversations between stakeholders. Different technical background knowledge enables stakeholders to understand and perceive the design differently. The IDCM system embraces architectural representation and information and effectively delivers it to other stakeholders. The system is designed with stakeholders' requirements in mind, which makes it intuitive. The interactive walk-through 3D model enables users to explore design and 'pull' the information that they need. It is easy to highlight points of concern and make comments that can be shared with other stakeholders. The system uses advantages of real-time communication, one of the attributes of social media technology, to help improve conventional communication in the design process.

6.2 Feedback

In the collection of feedback, the researcher was conscious of the ethical issues, as with the stage of data collection described in Section 4.3. Participants were asked for their willingness to participate and for the interviews to be recorded. Data from participants was kept securely as well as their identifications being anonymous. The feedback collection process started with introducing the mock-up to participants. Those who were involved in interview data collection at the beginning of this research were again asked for feedback. The eight participants in this process included three architects, two engineers, one planner and two clients. Showing a video was the method of choice for demonstrating Co-design and the IDCM system (see attached video in Appendix E). The video showed some detail of the functions, but not all, to avoid influencing the participants. In order to test how intuitive the IDCM system and Co-design were, the participants were not given an explanation or demonstrations of all functions before they tried them out. During the tests, participants could ask about the functions or any issues they experienced. The test took at least 15 minutes. Verbal feedback and audio recordings of the discussion were collected afterwards. Participants were also given a questionnaire to fill out (see Appendix D); the deadline for returning this was left to the participants. Some of them completed the questions immediately while others chose to take them away and think about them before returning their answers. As Someren *et al*. (1994) state, observations are unstructured techniques in the sense that they do not constrain subject behaviour. During the feedback process, the researcher applied a ‘think aloud’ method for collecting feedback, which has its roots in psychological research for problem solving and knowledge acquisition. This method helps to gain insight into what people think about problem solving. The method is important for gaining knowledge of a system based on human experience. The researcher could observe the participants while using the Co-design mock-up, which enabled them to reflect on the issues relating to the use of the mock-up.

Planner responses to the system are very useful for collaboration in the design process. The interactive 3D model helps planners to select viewpoints and capture the views they want. A planner agreed that having quick feedback and comments would also help speed up the design process. In addition, the archive function helps identify various revisions of planning submissions. This is useful when submissions contain a large number of documents. It was ideal to have all submissions in one package, as this was convenient to track through. The ‘share information’ function of the IDCM system was effectively responding to planners’ requirements. Planner feedback showed that acquiring a material schedule of the building is also essential for them to consider appropriate materials, such as textures and colours used for designing buildings and matching the environment. The main suggestion for improvement was to attach web links to suppliers’ websites for further information about which supplier could provide building materials.

The issue that the planner identified when he used the mock-up was that the icons of each function were not clear in what they represented. He suggested that adding text when the user rolls over the icon would clarify the meaning of each icon. In order to test the navigation ability of the system when participants asked questions, the researcher gave minimal answers. This was to avoid influencing the trial and the data. The planner said that he understood how the system worked, but he was not confident when using the functions. The full description was presented after the participants finished the trial to avoid bias of feedback.

The architects found the IDCM system very useful for archiving various revisions of the design document. This helped other stakeholders to access information by themselves without having to return to the architect, thereby allowing users to be more independent. One architect asked how a large amount of information could be chronologically organised. The mock-up did not seem to clarify this function in a visual way. The architect suggested adding a timeline to show the history of uploaded information. This would make it easier to store and retrieve documents on the basis of the time they were produced. In addition, a timeline would make it easier to see archived documents. The researcher agreed that a timeline function should be applied, as it is important to this research to make the information less complicated and to enable users to 'pull' the right information. Another architect wondered about archiving design revisions, as architects and engineers may have more revisions or have information, which is not ready for a client or a planner, so they do not want to show it. The researcher explained to the architect that this web application was created for the revisions that were ready for all stakeholders to review, so users should not need to upload raw information as all information is controlled by the architect/controller of the project.

One engineer was very good at using the IDCM system, but his concern was how the system would perform with a significant amount of data. As he works on large projects such as railway stations, there is a large amount of information, which requires specialists to look after it. The mock-up was produced to draw a concept for a collaborative web application. Therefore, it does not show much architectural information as there are some limitations of production and it might not give enough of an overview for a large project. The engineer also commented that the functions of the system should enable the architect to make quick changes, such as changing the cladding, texture, or perhaps adding a wall, windows or taking measurements. Another engineer suggested that the mock-up should include a clash detection function, which is issued to support overlay structure, electrics and mechanics. Clash detection finds where the models 'clash'. Models from different disciplines such as architectural, structural, mechanical and electrical areas, are checked against each other for interference (Guangbin *et al*., 2012). This function can be found in 4D building information modelling (BIM). Moreover, the engineer wondered about the same issue as other users, namely how the system organises data chronologically when stakeholders post information. The researcher explained that the information was shown as a timeline that presented information from oldest to most recent. However, the mock-up did not show timing clearly. In his words, the mock-up design was simple, which was good and straightforward, but the final system should take care of documents when larger data is uploaded. Large data sets may require highly efficient data management. Overall, he believed that the standard architectural information is good. This engineer also indicated that the mock-up had a good appearance and functionality, which made it easy to use. He encouraged the researcher to keep the system simple and direct. He recommended the integration of 3D modelling with data management for the final IDCM system, suggesting that the model could be used for a facilitative management system. For example, the system could offer a building specification search via clicking on a 3D model. Information could then be shown, related to the object that the user had selected. The system could also let the user click on a link to manufacturers to make orders or get quotes. This suggestion would provide a helpful tool and is taken into account in future development.

One of the clients reacted to the mock-up in the same way as the latter engineer, stating that the mock-up is easy to use and straightforward. This client found functionality to be helpful, especially the 3D modelling. He wanted to add links to information such as pricing, for example, of any change he wanted to make to the design. He recommended that it would be good for a client if the information could be used in the construction process. For example, if the client could see the specifications and cost changes when the design is changed, because the contractor has to replace a window, for instance. The client could then select the new windows and place an order. This recommendation is helpful to extend the researcher’s proposal to a facilitative management system for the client. The client explained that there are not many applications or systems for clients. Future research into this area is needed.

6.3 Results and findings

This section shows the results of feedback and presents the findings in a tabulated form. Table 6.1 shows the feedback from participants after watching the video and trialling the mock-up.

Table 6.1: **Participant responses**

Participants	Advantages	Issues	Recommendations
Architects	• Easy to use • Interactive 3D model • Open source • Accessible via web browser • Permits stakeholders to upload information • Good system for a small project • Permits switching from a 2D to 3D view	• No timeline to indicate when information has been posted • Unclear design revision management, not represented clearly • Unable to show who writes feedback / comments	• Show data as a timeline • Offer a larger display for architectural information on the web application • Use especially for small practices • Show interactive drawings, e.g. clicking on plan then links to the same position on 3D model
Engineers	• Easy to use • Direct and straightforward for organising and sharing information • Information uploaded has potential to be used as a database on other systems • Permits stakeholders to upload information • Interactive 3D model	• Unclear how system will organise large amounts of information • No indication of time and date of posting information	• Add specifications of buildings • Include a clash detection feature • Add an editable model for changing features like cladding or texture • Include links to supplier websites

Table 6.1: **Participant responses (Continued)**

Participants	Advantages	Issues	Recommendations
Planners	• Easy to use • Non-experts can use comfortably • Revisions can be archived • Open source • Interactive 3D model • Permits users to change 3D viewpoints	• Contains some unclear icons	• Add function to show materials and textures • Enable the 3D model to show day and night light selections
Clients	• Easy to use • Interactive 3D model • Information uploaded could provide database for management system • Enables user independence	• Does not show large data sets	• Allow uploaded information to be extended to support facility management • Include links to supplier websites

Table 6.1 presents the categories identified by feedback from different participants. Most participants agree that the use of the mock-up is easy. The IDCM system structures the functions that relate to information in a straightforward way. In addition, 3D interactive, archiving revisions and open source are very useful features for improving workflow and communication in the design process. Nevertheless, the main concern about the system is how it manages data when there is a lot of information. Another concern was the need for the icons on the mock-up to be developed for ease of use. These comments

from participants reflect the need to improve the design of the UI. The comments also demonstrate that the design of the mock-up and video must be developed continuously; they enable participants to perceive a clearer concept of the whole system.

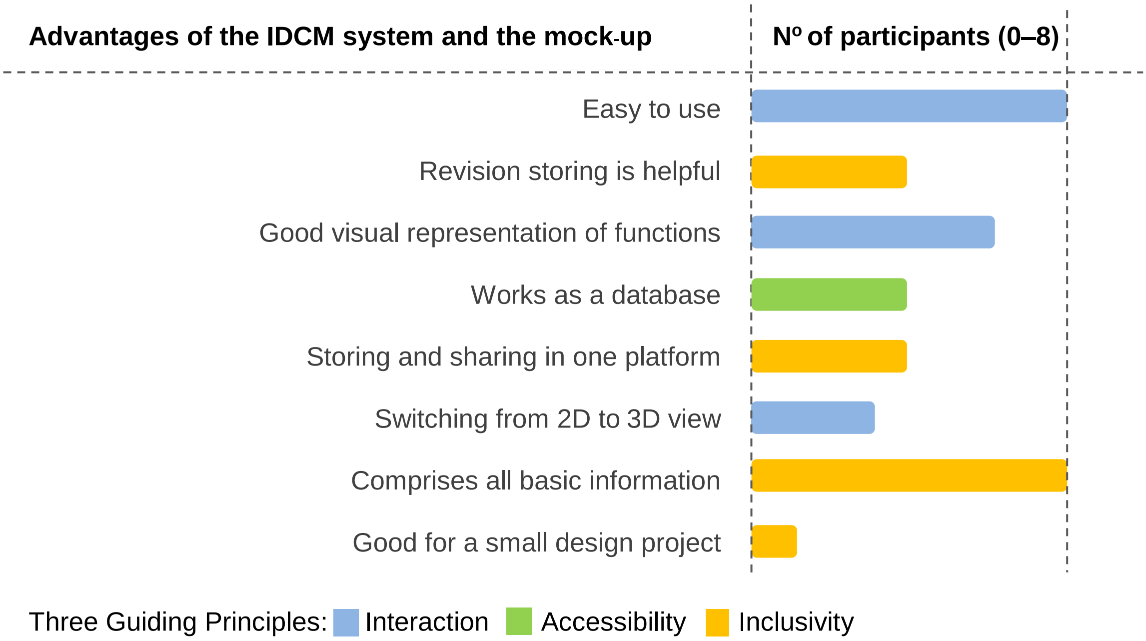


Figure 6.1: **Feedback on advantages of the IDCM system and the mock-up**

The analysis of the feedback (as illustrated in Figure 6.1) shows the number of participants that recognise the advantages of the IDCM system and the mock-up. The feedback was analysed according to the three guiding principles, suggested in Chapter 4. Every participant found that the system is easy to use and it covers all basic building information in the design process. The visual representation of functions is very good. Some participants identified significant features, such as storing and sharing information in one place, using information in the system for a database and archiving/storage of design revisions. These attributes are helpful, as are the switching between 2D and 3D views and the suitability of the system for small projects. Participants value most advantages of the system and the mock-up with regard to ‘inclusivity’ and can see its potential for becoming a web application that can significantly improve data management and collaborative design. The results show that participants who reflected on the IDCM system identify the most advantages under the area of ‘inclusivity’, followed by ‘interaction’ and then ‘accessibility’.

This result responds to the aim of this research, which is to enable stakeholders to collaborate in real time during the design process.

The mock-up test resulted in positive feedback relating to appearance and functionalities. However, there are some features that participants require for future developments, such as managing large data sets, editing documents in real time and linking between 2D drawings and 3D models on a specific focus. Table 6.2 shows some quotes from participants (code is explained in Chapter 4) after trialling the mock-up. It demonstrates that a great deal of the IDCM system applies to communication in an architectural project.

Table 6.2: **Selected feedback relating to the advantages of the IDCM system and the mock-up**

Participant code	Quotes
A03RA (architect)	*"The ability to combine all different specialists together in one database could definitely benefit the project."*
A03RA (architect)	*"It includes a whole range of information. It's a good sharing facility for design team members. The ability for information to interact with the model rather than stand alone when uploaded could help."* *"Good security with login features. Clear user interface ensuring each consultant knows where information is. Ability to see around the model is very good/useful."*
P02AR (planner)	*"Great appearance, functionality is very good. Easy-to-use platform; keep it simple, direct and easy."*
E01MT (engineer)	*"I kind of like having lots of experience with these kinds of functions so I have no problems using it, both visual functions and physical navigation."*
C02SK (client)	*"I like to see the budget and I want to see its changes compared to revisions because it helps me to decide whether I should go on or not."*

The findings from the feedback analysis show that dynamic communication is a significant attribute for an interactive communication system in architectural design. Communication systems require quick responses, along with the ability to store and share information. The models reviewed in Section 3.1 include elements such as receiver, sender, medium and noise, all of which have impacts on communication. This research has confirmed the importance of such elements. The data reveals new actions of dynamic communication to add on to communicating elements: digital technologies enable users to **input, pull, share** and **store** information in one place via interactive media which allows accessibility and inclusiveness.

In addition, data management has proven to be very useful for communication systems. Users want to keep the information in the design process so that they can easily look back at it, which means online information is required. This finding can also be extended to the idea that users can use information that is already uploaded, extending usability for further development of data management systems, applications or platforms for their organisations or specific projects.

6.4 Issues with the IDCM system and the mock-up

The IDCM system was tested with a sample of participants after they watched the video and trialled the mock-up. Subsequently, their feedback was collected and analysed. It reveals a number of issues and participant misunderstandings about the IDCM system. All of this data is used to inform the system development. For all participants, the main issue of the IDCM system is that it does not show clearly how the mock-up presents a large amount of information, and how sequences of information are organised. In the design process, a large amount of data is produced, especially in the case of complex projects, which include many drawings and images. Although participants agree that archiving the design revisions would assist workflow, they are concerned how it would look to the other stakeholders when they want to track back. This is especially important as data become larger. This issue has been taken into consideration.

Another issue is that sometimes people do not want others to know everything they change; they want to keep the information private. This issue was mentioned out of concern that it could interrupt communication. It was explained to participants that the IDCM system had been designed to account for this problem because only public documents would be uploaded and they are controlled by a PWM. However, the system endeavours to assist collaborative design in the stage of sharing information. It prompts straightforward communication by encouraging stakeholders to be participatory; it does not merely provide a system for individual design or internal communication within an organisation. The analysis of results for the system development is shown in Table 6.3, which identifies issues that the participants feel lack clarity, and provides explanations for the ways the system and the mock-up deal with these. Where necessary, recommendations are made to introduce changes that improve the experience of using the system.

Table 6.3: **Identifying problems and solutions for the IDCM system and the Co-design mock-up**

	Questions raised	Explanations	Recommendations
IDCM system	Will private information be revealed?	*The system encourages information to be public, but it is a closed system, accessible only to users who are members of the project.*	
	How will the system manage large amounts of information?	*A controller will be set up to manage information for each project.*	*Add a design timeline with specific dates and times.*
	How will the system ensure the privacy of the project?	*Stakeholders joining the system must obtain verification from the controller/project manager.*	

Table 6.3: **Identifying problems and solutions for the IDCM system and the Co-design mock-up (Continued)**

	Unclear issues	Explanations	Recommendations
Mock-up	The sequence in which information is posted is unclear.	*Information is shown from oldest to newest, from left to right.*	
	The meaning of some icons on the mock-up is unclear.		*Add a pop up description which shows when mouse rolls over an icon.*
	The feedback / comments are not visible.	*History of feedback and comments from stakeholders with notifications will be shown.*	
	The display area for the interactive 3D model is limited.		*Try to maximise the 3D model display area by hiding menu bar when not in use to add more space.*

The issues identified by the participants during the evaluation of the IDCM system and mock-up are acknowledged by the researcher who suggests a number of solutions for developing both the IDCM system and the mock-up of Co-design in the future. These are shown in the last column of Table 6.3, above. The table shows how the issues raised by the participants would be dealt with. Among these issues is that of insufficient display space. One young architect recommended gaining more display space in the interactive 3D model by using a ‘hidden menu’ bar and a ‘show menu’ bar when the mouse rolls over this area. This might be an efficient solution; however, the researcher argues that a hidden menu would only suit the younger generation who are familiar with technology. Older professionals want to see big icons and direct navigation. The Doro phone is an example of a phone popular among older users, as it has a limited number of functions, and the size and visibility of buttons make them easily seen. Even on a simple smartphone, not everyone uses all of the available functions. The extent to which these functions are employed depends on the users and their level of technological ability (Coates and Ellison, 2014:29). This research included participants from different generations. It acquired a wide range of stakeholder experience so that the system and mock-up could respond to a wide-ranging age group. Hence, the proposal of the hidden menu bar would be a good idea for the future. In the next five or ten years, user experience will change as new technologies become common and the older technological age gradually retires. Overall, the feedback has helped the researcher to acknowledge important elements that the system should carefully consider, such as how postings appear and how the mock-up displays the management of information.

On the whole, the system and mock-up have met users' expectations, nevertheless, some emphasis on functionality is lacking. The issues were raised because the lack of functions in the demonstration caused the participants some concern. The proposed solution to this issue is to show the posting of information, comments, feedback or other input as a timeline of posting, as well as showing the earliest date to the latest date, from left to right under the display area.

The mock-up does not provide a complete set of fully active functions, but instead presents the characteristics of the main features. It was validated using a limited number of participants, so further evaluation and feedback would be useful. As it is, it works sufficiently to deliver many common, necessary requirements for a small project. However, to fully meet stakeholders' needs, it should be further developed. More information from a wider range of participants would enhance the development of the system through feedback.

6.5 Conclusion

This chapter began with an outline of the approach used to collect feedback. The analysis of feedback has enabled the researcher to identify issues highlighted by the participants. Subsequently, these are clarified and some solutions have been proposed to refine the system and develop it further in the future. The research has demonstrated that the IDCM system and the mock-up are easy to use. The system is seen as straightforward, and the interactive 3D model is considered beneficial to architectural representation. In addition, archiving information on the system is seen as helpful for reference and for comparing design information. Therefore, the data reveals that participants agree that the system would help the communication of design and improve workflow. The evaluation of the IDCM system was undertaken using a mock-up with a number of participants. From this evaluation, the researcher has been able to identify ways to improve the system in the future.

The chapter finds that the IDCM system is satisfactory for a number of participants. Engineers would prefer the system to be extended to use in the construction phase. The client's perspective is that the system has an opportunity to develop a facility management system, which could be very helpful. The planner appreciates the inclusion of design revisions in one place. In addition, architects recommend the system to encourage other stakeholders to upload their information. Although the system is useful, the main concern is that the managment of large data sets has not yet been addressed. This research is at an early stage of design; it aims to demonstrate contributions to communication and collaboration, resloving issues that this researcher has uncovered.

The next chapter discusses the entire research, including theories, methodology, the IDCM and the mock-up development, in order to identify challenges and barriers to this study.

Chapter 7 General discussion

Chapter 7 General discussion

This chapter discusses the main findings of the research related to literature, theories, practices, methodologies and primary research undertaken in order to address the research questions, including those relating to the design of an enhanced interactive communication system, with a view to extending it to a fully functional web application. Having reflected on the process and the findings of the research, a possible development of the communication beyond its current status is outlined.

The review of the literature relating to architectural representations has revealed a number of researchers whose work is most relevant to this study. Bates-Brkljac (2012), identifies the types of presentations appropriate for helping people understand design. Unlike previous researchers who have focussed on static images only, Stikeman (cited in Carlson, 2007) argues that architectural representations need to closely resemble the way people see the real world, while Sevaldson (2005) claims that architecture is slower than other disciplines in transitioning to the use of advanced digital media. Koolhaas (2016) states: “Architecture has a serious problem today in that people who are not alike don't communicate”, and that the amount of time spent realising “the least architectural effort” was five or six years, which is “really too slow for the revolutions that are taking place”. This research is interested in the types of architectural representations that affect stakeholders’ perceptions and agrees with Koolhaas and Sevaldson that an investigation of digital interactive media is required for looking at interactive communication systems for newly emerging collaborative design approaches. The potential of interactive systems has been highlighted by a number of researchers (Fukuda *et al*., 2009; Kumar, 2013; Yeung and Harkins, 2011; Lan and Chiu, 2006; and Nakama *et al*., 2015), who have developed systems and used digital modelling techniques for collaboration and representation. Kim *et al*. (2015) created an interactive system using interactive 3D modelling for asset management. This PhD research has sets out to look into stakeholders’ requirements to improve the design process through an interactive media, providing a system to enable designers and other stakeholders to communicate and partake in the design process. Intended end users of this system are architects, engineers, planners and clients who are significantly involved in the design process. Other systems or applications, such as Invision and 4Projects, are created for collaborative design, but none employ 3D interactive modelling, which is widely used in the computer game industry.

Following the Building Information Modelling (BIM) 360 application, other BIM developers have investigated the potential of 3D modelling as a collaborative tool among professionals, which has been used for architectural, engineering and construction purposes. This research is interested in the design process rather than the construction phase.

Digital media facilitates effective communication in the design process, enabling not only the representation of design ideas but also conversations between stakeholders. To find an efficient form of communication, this research draws on several theories. Dynamic communication is underpinned by Schramm's (1954) model, in which the sender and receiver can be the same person. In addition, Barnlund (1970) finds that the sender and receiver can exchange messages simultaneously**.** This evidence has led the current research to adopt an omni-directional communication system that uses technologies to enable people to communicate dynamically. The sender should convey the right message to the receiver through the right channel (Berlo,1960). Most media used to present design work comes from the architects' point of view. This study is interested in hearing more about other stakeholders' perspectives. To further improve the design process, the investigation includes active participation by stakeholders with different professional backgrounds and with different levels of design and communication technology knowledge. The process establishes equal involvement and responds to participants' requirements. Identifying stakeholders' needs helps the research to advance the design process.

Currently, advanced functionalities of applications and software used in the built environment industry enable professionals to work efficiently. Nevertheless, some professionals are still limited by a lack of technological skills, and they are likely to work in the same way they always have, so that newly emerged features of applications and software are often disregarded. In addition, with the various software packages available, difficulties may be caused in accessing files when people use incompatible software. Hence, exploring existent technologies used for digital media in the design process enables the research to identify problems that emerge in the design and communication process. In this regard, this research starts by examining the potential of digital media to convey the design. Computer-aided architectural design (CAAD) tools are explored to identify attributes, functionalities and common file extensions that people can share. The researcher acknowledges the benefit and the development of technologies used in digital architecture.

7.1 The findings of the study

This research identifies the main communication challenges in the design process. First, using incompatible software packages is a barrier to sharing information between different parties. Stakeholders need to learn various programmes in order to work collaboratively with other professionals and non-specialist stakeholders; the learning process requires time and money. Second, stakeholders from different technical backgrounds have varying degrees of capability to understand conventional architectural representations.

Addressing the research questions

The first research question relates to the effect of digital media on the design process. The extent of this context reveals that digital media has been very useful and is important to the design process. It is used as a tool to create images for architects and to communicate their ideas to others. In recent years, digital media has influenced communication in the design process in contemporary architectural practices, especially in architectural representations, as a digitised form enabling the architect to visualise the design and to share design information across the Internet, supporting even global projects. However, some issues are identified such as an incompatible working system, giving inconsistent design information and miscommunication. As the most digital media types that are currently being used are inspired by the point of view of architects. There are often misunderstandings between the architects' intentions and stakeholder requirements in a design project. It is important to acknowledge stakeholders' points of view for straightforward communication, as that creates efficient workflow. Evidence is shown in the survey of software and the survey of participants using digital media in their practices, primarily for design and presentation. Architectural software has developed functionalities for design, analysis, documentation and visualisation of architectural projects of any size or complexity. In the light of useful software and applications, stakeholders still struggle with learning to use them and to communicate with people who use different software packages.

The second research question relates to perceiving the use and value of digital technology as they impact on stakeholders. Obviously, the evidence uncovered in the survey of participants shows that digital architecture accelerates the design process and is more convenient, saving time and money in terms of producing multiple copies of information and passing on information via the Internet network. CAAD tools are developed for many uses, e.g. modelling, presenting and collaborating. In the design process, perception is important for understanding what architects want to communicate. Technology empowers people to get close to reality by developing virtual reality (VR) gear or realistic renderings. Moreover, people have better access to online sources and platforms, which are provided for convenient workflow. However, a lack of technological skill is a barrier to the use of that software and such open sources. Users need to develop their capability to employ technologies. Some advanced functionalities are left behind as users are not confident in their use and refuse to learn new technologies; they stick to what they are good at. Although many new software programs and applications still emerge today, some of them are not popular, if they are used at all.

The last question investigates architectural design work and examines the potential for existing digital media and the Internet to provide effective communication tools that enable inclusivity in a user/stakeholder-oriented design process. Working across disciplines enables this research to develop the capability of digital media toward communication systems for collaboration. Digital media disciplines are used for architectural representations such as animation, graphic design and computer games. While revolutions are taking place, interactive media nowadays is used to communicate and present works as well as input information. The Internet empowers interactive media such as web and mobile applications, which are widely used for making design decisions or managing information. The practical aspect of this PhD research is an IDCM system to use in the design process. The IDCM system responds to the requirements of a new and more convenient tool for both communication and collaboration, encouraging stakeholders to participate in the early design process. The system includes necessary design information derived from user surveys and the literature. Moreover, the system allows stakeholders to compare the earliest to the latest designs for developing the project in one place. As the information is online, participants can access data, from anywhere and at any time.

The key findings of this research have become significantly refined as the research has progressed:

- The survey of software identified attributes of digital media that are required to improve collaboration and communication in the design process. The survey showed types of file extension, advantages and disadvantages of each software, and types of media that are necessary for architects.

- Issues obstructing communication and collaboration in the design process were identified, including an incompatible working system, misunderstand of design information as well as communication, giving inconsistent design information, costs of software and learning, and different technical skills causing variety in design interpretation, and using design tools. These stimulate an improvement to communication.

- Guiding principles – interaction, accessibility and inclusivity are suggested for attributes of IDCM system design.

- 3D interactive modelling is an efficient tool, especially for clients and planners. Architects and engineers agree that it is adequate for communication. However, architects and clients still require realistic images for marketing purposes.

- Unity is a piece of software used to create 2D and 3D games. It is also able to generate interactive 3D models, as well as produce web content, a feature which other 3D modelling software programmes do not offer.

- Data management enables users to track design revisions, which are saved and can be reviewed chronologically. Users can compare the previous design to the latest one. The IDCM system offers a single location/site for design information as well as real-time communication. Information and communication can be exchanged. This can all be done within one system. This attribute is a significant advantage to inclusiveness.

- The IDCM system includes architects, engineers, planners and clients as stakeholders in a project. The inclusion of the planner and client is an important innovation, as other communication methods focus on architecture, engineering and construction (AEC) only. Clients need to be persuaded because they own the project; the inclusion of the planner is also essential because the planning authority's consent significantly affects the design process.

The findings have enabled the researcher to design the IDCM system, which is intended for use in general design architecture projects with non-specialists. This research is limited by many aspects such as limited computer skills, budget and time. This PhD project has thus produced only a mock-up of the web application to evaluate the system's efficiencies, with participants who are representative of the end users of the research. The result of the evaluation is positive. Participants value the system as a convenient and efficient tool for presentation and collaboration. Furthermore, they expect that the system can be extended to use with other existing platforms. The use of the system is demonstrated through users' story has reflected on the issues in the design process (see in Chapter 5).

7.2 General discussion of the study

While the previous section dealt with the main findings of the study and how these addressed the questions that framed this research project right from the outset, this section will present the general approach adopted to conduct the research**.** The discussion covers both the theoretical approaches that underpin the research and the primary research in the form of the development of the proposed IDCM system and its evaluation through a mock**-**up**.**

7.2.1 Theoretical approach

This research has investigated how people experience architecture through representations. Human perception relates to imagining real space through 2D and 3D simulations. The simulations are explored along with digital media theory, such as ‘push’ and ‘pull’ media. Social media empowers users to interact with each other, and it offers a system that can help improve communication between users of architectural representations. It could also be useful for improving interactions between users.

Theories and models of communication help the researcher to formulate a framework for identifying issues and solutions. This research has studied communication models such as one-way, two-way and interactive communication, and applied these to new technologies through the development of the IDCM system. The communication models enable the researcher to focus on users and digital media. The system design starts with investigation of the use of current design communication methods in practice, to gain an insight into stakeholders’ experience within the architectural design project. It uses a qualitative method in the form of interviews, and each interview has been analysed. The following theories were used:

Experience / perception in architecture. Digital forms of architectural representations have informed this research from the outset. Technology is changing rapidly, and people’s experiences and behaviours change with technological innovation. Architectural practice adopts and develops technologies including hardware, software, digital media and facilitative systems for workflow. These developments impact human experience; therefore, it is necessary to study theories related to what humans perceive. This research finds that people perceive architecture depending on their experience. Although this experience may be broad and wide, this research has focussed on experience of architecture through digitised forms of representation.

Digital media theory / ‘push’ and ‘pull’ media. Architectural representation is a medium to convey design to stakeholders during the design process. Visualisation in architecture employs theories of art and design disciplines, such as film, digital photography, computer games and digital media. These theories are used to create the architectural representation. Ontology is employed to study what exists in this area of research. The researcher has considered digital media that are currently used, as well as those being developed for use in other disciplines, for potentially wider use in the future. Digital media has more capability when it is used through the Internet. Push and pull media are investigated to distinguish the attributes of the medium that would identify efficient tools for design communication in architecture. Subsequently, the research considers interactive digital media; currently, most architectural representations are ‘pushed’ from the architect’s point of view. The input of users is significant for this research because they can navigate, explore, manipulate and respond to the media by themselves. These actions are important for collaborative design.

Theories and models of communication. Conveying messages through verbal and visual means, or with text, is important for efficient communication. The design process requires effective communication between groups of people involved in the project. Models of communication are explored to understand sender, perceiver, message, medium and noise. These factors have a significant relationship with views of encoding and receiver’s interpretation. Theories of communication have helped the research to identify appropriate digital media for efficient communication and to distinguish the nature of problems that may cause miscommunication.

Qualitative research. It is necessary to identify end users’ backgrounds, as a wide range of users exists. A sample group was selected. Although each participant represents a single role and organisation, the professional experience of each participant is considered too. The participants' details enable the researcher to collect extensive information about stakeholders' experience in using digital media in design communication. It could be argued that this research would be more meaningful if it used a larger number of participants. However, once the researcher identified the stakeholders to work with (for example planners, clients, architects and engineers), a representative sample was selected. The researcher considered the trade-off between the size of the sample and the logistical difficulties involved in undertaking a large programme of data collection with professionals, who are busy with their everyday professional undertakings. Semi-structured interviews with participants enabled the researcher to explore issues relevant to a design process that could represent many people's points of view rather than numbers of repeatable answers. It is important that the communication system be based on good qualitative data. A quantitative approach to data collection may not have yielded the same result.

The above areas of theory have informed the design of the IDCM system. An exploration of the current technology means the research is responding to concerns about new technologies currently used in architecture. Current software and hardware used in architecture are reviewed alongside the common tools that make digital communication easy to use for all stakeholders. This review has also helped the researcher to identify an appropriate method to develop the mock-up, which required the integration of 3D modelling software with web design.

This research has explored theories and methods of developing communication tools through various approaches from different disciplines. These approaches include graphic design and web design used for designing user interface (UI). Game engine related knowledge was used to create a 3D environment with an interactive 3D model. This environment was enhanced through knowledge of user experience (UX). Digital media and communication theories have provided the background for this research, which argues that digital media in architecture could be improved by making it interactive. This argument comes at a time when advances in Internet and digital media technologies allow people to connect with each other and through the media at any time. People know what is happening within a society or a community via applications (apps) or websites. 2D apps such as Facebook, LinkedIn or Google are connecting people, but they do not create a real-world perception. They are different from 3D websites such as Second Life. Simulation in 3D helps users to perceive reality as closely as possible, and helps them to imagine and better understand real situations. Hence, this research investigates how interactive 3D models help people to consider design. It demonstrates the benefits of integrating architectural communication and social media.

7.2.2 Practical approach

The practical approach to this research begins with a review of the use of digital media in design communication. Digital technologies in architectural design and representation are also explored to identify methods to make a mock-up, which has helped to demonstrate the design concept of the IDCM system. The project studies have been categorised into three types: computer-generated (CG) realistic, virtual environment and 3D interactive information. These three types cover a range of digital media used for communication in architecture. This research endeavours to find the positive aspects of each type to use in the design of the system for collaborative architectural design communication.

At the beginning of the practical part of the work, information on users' requirements is collected to identify their needs and any issues in the design communication process. The practical part is categorised into two approaches. The first one consists of identifying existing technologies in digital architecture and new media that could be used to make contributions to communication systems in the design process. In the second, the task is to find the tools to develop a mock-up of a communication system.

In order to develop the IDCM system, the researcher had to gather data to identify attributes of digital media. The data was necessary to identify stakeholders' requirements and to determine how best to respond to these. In addition, recommendations on communication systems today require independent and flexible approaches. The system has been developed through exploration of other disciplines such as interaction design (ID) and information architecture (IA). The system was designed in parallel to the mock-up, which required knowledge of interface, web and graphic design.

Testing the design with end users is a practical process as it can reflect user experience. Observations on how end users use the mock-up leads to the development of the design work to respond to user experiences. Initially, the researcher received only a small amount of feedback, as few participants responded to the requests. This happened because of a lack of contact during the long period of the study. This research would have benefitted from finding a way to gather more responses and testing more people to receive wider feedback. This could have been achieved by uploading the mock-up and making it accessible to a larger number of people. However, the mock-up required participants to install the Unity Web Player to view the work. For non-specialists, installing and viewing this programme is difficult. Despite the small amount of feedback, the researcher was still able to gain insight into users' experience as the participants were observed during the mock-up test. The feedback, albeit limited, was therefore preferable to a larger volume of information and points of view collected remotely.

7.3 The IDCM system and the mock-up

This section outlines the significant developments of the IDCM system and the mock-up enhancement for further research.

7.3.1 IDCM system

The development of the IDCM system has come to address the issues raised by the analysis of data obtained using the interview process described previously. Requirements for architectural representations underpinned by data analysis, including employing 2D and 3D drawings and interactive 3D models, are identified. In addition, the mock-up includes basic necessary information such as planning policy and cost of the project. Types of stakeholder indication are also important for developing the system in order to divide information into the right users' categories.

The IDCM system has brought the characteristics of social media such as interaction, web-based system and real-time communication to improve communication and collaboration between stakeholders. Social media has impacted on the issues at stake in this research in many aspects; some of these issues are explored in Chapter 3 and more specific details are revealed in Chapter 4 in the section on data analysis and results. Social media attributes can be used to promote communication and collaboration, as agreed in the literature; this is increasingly relevant when participants identify similar issues, which have not yet been resolved. For instance, using incompatible file formats/software is still an issue, which causes difficulties in viewing architectural representation. Social media applications such as Facebook facilitates users to present and share various forms of media such as images, videos, online steaming video (Facebook Live[25]), and 360° photos[26]. Hence, this research suggests that using a web-based application to host a real-time operating system will overcome this barrier in viewing problems. Identifying compatible file formats used between stakeholders in the built environment is crucial, as discussed in Chapter 2. This notion is inspired by social media characteristics, as it results in the gathering together of information, enabling users to interact with the content at their convenience. In addition, working on the web-based application also supports the requirements for accessing information. This is impacted by the suggestion of storing and hosting information in a similar way to Dropbox or Microsoft OneDrive. Being able to store large amounts of information significantly supports the workflow; data can be stored online and people can access it from anywhere and at any time. This means that difficulties in accessing information are reduced. The IDCM system has considered the length of time that data can be kept securely. Project design information can be stored for as long as the users require it, and can be deleted when a user decides. The issues mentioned above concern collaboration, which is important to achieving an effective design process. However, the IDCM system has also been designed for improving communication.

[25] Facebook has functions for users to generate live broadcasts to share a moment with other audiences.
[26] Facebook enables users to upload and view 360° photos, sharing an immersive view without a third-party application or camera.

In connection with developing the system, real-time communication is the most significant attribute of social media that underpins the IDCM system. Stakeholders are encouraged, stimulated and requested to engage with the design process; the system will help them to avoid missing important updates to information when using the notification function. This function helps to speed up the process as well as to archive messages and activities for future reference. The research highlights significant characteristics that the online operating system should have and the IDCM system has been designed based on users' requirements. The demonstration of the users' story reflects idea of what the interactive communication system should offer. Nevertheless, the back-end design of the system is necessary for making real-time communication work efficiently; this matter is beyond the scope of this research

In addition, the research focuses on the improvement of architectural representation. This is undertaken for developing the communication system, as the system brings together architectural information and communication elements. An interactive 3D model plays an important role to improve the understanding of architectural designs for a wide range of audiences with different architectural background knowledge. The system shows 360° views and allows virtual walk-through, which enables users to have an immersive experience in architecture. The system also includes standard forms of architectural representation such as 2D drawings, animations and videos, as required by participants in this research. Such standard forms are necessary for stakeholders to have various forms of representation in order to explore a complex design project and make decisions.

Functionalities of the system are set according to the working nature of end users. Hierarchical system diagrams were drawn and reviewed several times. The system design and the diagrams reflect the researcher's point of view and experience. The researcher needed to investigate each communication system between architect and stakeholder and eventually combine the systems into a single one. It was beneficial to have representative participants from different roles giving feedback during the development of the system. However, during the data collection process, getting in touch with the participants took a long time, and this issue delayed the mock-up design process. Given the time limit of this project, the researcher decided to finalise the IDCM system and then disseminate the system by presenting it at conferences and through a paper. The researcher aimed to receive a wide range of feedback through peer reviews (see Appendix F). Although the feedback from peers is supportive, it was mainly from an architect's point of view. This researcher recommends further study to engage with a wider diversity of participants, including not only architects, but also engineers, planners and clients. Finding a real project to work with and identifying a specific communication system as a case study is one option.

The comments from participants of the present research were collected only after the mock-up emerged. The mock-up is designed to be used for role-play: stakeholders would pretend to work on the same design project and use some manufactured architectural information to complete the hypothetical project. Having participants involved in every stage of design is ideal. However, managing meetings with participants has proved difficult. Moreover, the mock-up took a long time to build and edit, as it combined 2D drawing and 3D modelling, which was time consuming particularly for rendering.

7.3.2 Mock-up enhancement

This research has created a front end design of a web application. To produce the fully working web application would require collaboration with a computer engineer to support the back-end design, including design of the system and server. This section summarises the requirements and recommendations for the back end of the system that are needed to complete the mock-up and create a fully working web application.

Sign in / sign up. This process requires a server and a security protocol. To avoid storing users' login details, the project suggests the use of the Google Identity Platform. This authentication system helps minimise risks associated with storing users' sensitive data and reduces the workload of designing and implementing the project's own login system. The login UI will capture the username and password of a user and send the information to the Google server for authentication. Depending on the message received, the application can either unlock to show all the features or prompt the user with an error message to try again.

Database. The main feature of this web application is to enable all stakeholders to store and retrieve a project's information. To support such functionality, the web application requires a database to store the information in an organised manner. The following table shows how the data may be stored for each project in a database.

Table 7.1: **Structure of data used in collaborative design**

	Project title		
Fields	Revision1	Revision2	Username
3D model	Data	Data	
Floor plan	Data	Data	
Building plan	Data	Data	
Outside plan	Data	Data	
Image	Data	Data	
Video	Data	Data	
Engineer print	Data	Data	
M&E	Data	Data	
Text documents	Data	Data	
Budget plan	Data	Data	

Every time a new project is created by a project workflow manager (PWM), a column labelled 'Revision', followed by the number corresponding to the revision, will be created under the project title. All relevant details for a particular revision will then be organised into designated fields, where each field represents the information that will be displayed in the side menu bar, as shown in Figure 7.1. The column for fields is only indicative and can contain more fields when choosing different stakeholders; fields will be different.

Figure 7.1: **Side menu bar showing the categories of architectural information**

The fields also support the storage of multiple files with the exception of the 3D model field, as there can be one model only per revision, which only authorised users can view. The revisions are approved and managed by the PWM.

Users with access rights to the project will have their names stored under the username column. In addition, the Revision column can be extended to accommodate as many versions of the design as are required. Another database will also be needed to store usernames, a list of projects to which each user has access and the online/offline status of each user. This database table will be organised as below:

Table 7.2: **Users' database table**

	Username
Project	Data
Status	Online/offline

Once the database is implemented, the application can use the username provided at the login stage to interrogate the table for a list of projects to which the user has access, and display them on the summary view after the login screen. At the same time, the user status is also updated. When the user selects a project to view, the system uses the project title to bring forward the right project table and show all the data to the user.

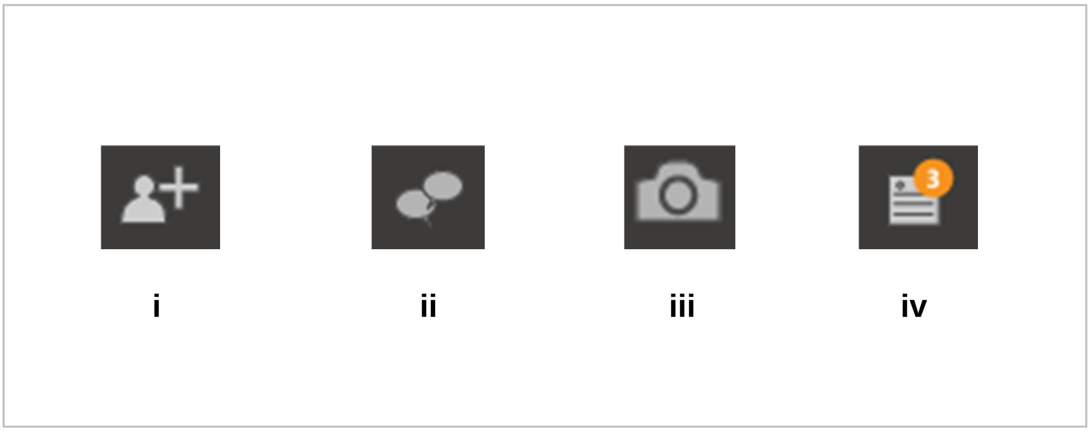


Figure 7.2: **Graphic icons of Utilities Bar on top head of the mock-up**

The utilities bar (top header) has a number of functions, which also require access to update information on the database. Below are brief descriptions of each interaction between the functions and the database:

i) Adding/inviting another user to the project can be done by clicking the 'Invite' button. Users can add colleagues into the system; however, they have to be approved by the PWM. The application sends a request to the database with the username and the current project title. The request then searches the user table for the appropriate user and adds the project title under the project field. The notification is sent by email to new users, telling them that they are accepted. The new user is then able to see the project the next time they log in.

ii) With user information in the database, the message function can be built using the Unity engine and Java. The function can make use of the project database table to obtain the list of usernames attached to the project, then search for users on the list and get their status.

iii) Images can be captured and saved to the database under the image field, or shared by sending an email. In addition to the project title, revised versions of the project are also included in the snapshot request, to ensure that the image is added to the right revision for further discussion and comparison of the design information.

iv) Notification of messages can be extracted from the database log file. Most database services produce a log file when a change to the database is detected. The log files contain details of the changes including the time those changes took place. The application can extract information from these log files and determine which ones the user has not seen. This can be done by comparing the times when the changes occurred and when the user was logged in to the application. If changes occur when the user is already logged in, then the time when the notification button was last clicked can be used instead of the last login time.

This section highlights the participants in the evaluation exercise suggested the communication system to be successful as the demonstration of the mock-up presents significant improvement in the workflow. Furthermore, issues identified in the survey can be overcome. However, there are additional suggestions to be developed in the future, such as dealing with large data sets, considering clash detections, and editing 3D models and drawings in place.

Both the theory and practice of this research demonstrate how interactive media can contribute to communication and collaboration in the design process. In terms of presentation, design work and interactive collaboration, tools have been sought to outline the IDCM system as a prototype for a web application to be used in collaboration with stakeholders during design. The decision was made to create a mock-up to test with end users, to achieve the result. The mock-up has enabled the researcher to acquire feedback to develop the web application. The next section describes the barriers that have limited the development of this research.

7.4 Reflections on the research

The main contribution made by this research is derived from the design, development, implementation and evaluation of the IDCM system, supporting communication and collaboration in the design process.

The research has used different theories to underpin the framework. The IDCM system concept is an example of a design that combines theory and practice to create a communication system for an improvement of the design process. The development of the system has utilised various theories from a range of disciplines, including:

- Psychology – identifying suitable architectural representations for audiences who are from different backgrounds, to optimise communication;
- Communication – exploring models to apply and develop traditional communication;
- Human interaction – designing a mock-up to test with participants; and
- Digital media – considering the impact of architectural representation and social media.

The IDCM system has been generated through the exploration of platforms, software, applications and digital media that were already in existence in a range of different contexts. The system emerged by combining theories from IA and ID. The development/making of the mock-up was also informed by practice from various disciplines, including graphic design, digital media and web design. The solutions proposed for the IDCM system and the mock-up development are based on methods and graphics used in web and computer game design. Therefore, the IDCM system is an example of combining theories and practice to create a new communication system.

The current state of architectural representations consists of one-way communication, where most of the information is presented by the architect. The researcher identifies the need for a tool that involves all stakeholders in a collaborative process within an architectural design project. More efficient ways of communication within the design process are explored to acknowledge all stakeholders’ points of view and their requirements, in order to improve the process using context design; user and environment context enable the identification and anticipation of actual users’ needs. Although many authors have previously investigated and developed systems for communication and collaborative design, these systems were related to particular projects only and were not widely applicable. Hence, this research endeavours to develop a system for general communication in the design process that works on open source applications. The system has been designed for multiple stakeholders including those who might lack technological skills. Furthermore, this research goes beyond linear communication by finding an interactive system that allows stakeholders to efficiently exchange architectural information in real time and on multiple levels.

The IDCM system’s strategy is designed for stakeholders to work collaboratively on communication throughout the process, as well as for collaborating on the design itself. Architectural presentations such as 2D drawings and 3D rendering images are uploaded and used to convey the design. In order to test and evaluate the IDCM system with the end users, a mock-up was developed. The result of the evaluation confirmed that participants valued the use of the IDCM system, finding it helpful, straightforward and easy to use. They also found the mock-up’s design understandable and useful. Participants valued the functions for data management and for archiving project information, within which they could review and compare designs at any time because the data is held online.

Additionally, the IDCM system can benefit from the application of emerging technology and advanced media such as VR. For example, Oculus is a VR headset that will potentially enjoy widespread use in the near future. If such a device is combined with the system, users can enhance their experience of the 3D interactive model and immerse themselves in realistic 3D views.

The researcher has endeavoured to gain insights into problems and needs of stakeholders in order to find adequate solutions. The proposed method was established by user-centred requirements necessary for improving design communication. The method of semi-structured interviews was used for the data collection part of this work. A huge volume of data was produced, but because the number of available participants was limited, the input may not include all possible points of view. In future research, a wider range of participants should be surveyed and asked to evaluate any improved versions of the current system.

Reflecting on the project as a whole, the research was carried out through a number of areas of work that include: the review of the current design and communication technologies; the identification of areas for improvement; the development of ideas, data collection and analysis; and the use of the findings to develop an IDCM system. This research is of an interdisciplinary nature in its conception. Initially, the researcher was interested in architectural communication that uses techniques and theories of digital media, including photography, animation and gaming. However, during the research process it became apparent that interactive media is important to presentations, particularly media used in ID and IA. In this context, the Internet has become an important tool for communication as it enables interactive architectural representation. The online platform offers users omni-directional communication. However, larger amounts of information require more organisation and tools that can support data management. Hence, the researcher has employed existing technologies in digital architecture to develop the IDCM system and the mock-up. Unity 3D was used to produce the mock-up as it creates web content alongside having the capability of 3D modelling. Consequently, evaluating the system to support end users' requirements form part of the data collection.

This research focusses particularly on the architect, engineer, planner and client as stakeholders in the design and communication process. All of these stakeholders have different professional backgrounds and levels of technical knowledge. It can be difficult for them to access the files that the architect sends to them. Hence, the IDCM system promotes a platform in which users can upload and share files. The system is a communication and management tool that presents design information. The design information can be kept in one location and can be pulled out by users anytime, anywhere. Archiving revisions offers users the ability to track the design information of previous revisions.

When a user selects a design revision, the relevant design file includes 2D drawings, 3D models and other information. The IDCM system automatically tracks the information uploaded and stored. However, of concern is that the mock-up lacks demonstration of how the system manages a large data set.

The collaborative focus of this research is one of its strengths. As technologies evolve, the capabilities to share and store data online would increase. The demand for systems that enable collaborative use of information is growing. Such systems must meet the needs of all key stakeholders involved in a project. Therefore, this researcher values the stakeholders' different points of view and has given them the opportunity to voice their dissatisfaction with the communication system they currently use. Consulting stakeholders for their ideas and seeking their views on how to solve communication difficulties has been essential in developing an effective and user-centred design communication system. The IDCM system has the potential to democratise the design process, making it a collaborative tool and assisting communication effectiveness.

7.5 Conclusion

This chapter has discussed the research as a whole and the relevant questions have been answered by serveral means. In the literature review, the research identified problems and gaps in communication and collaboration in the design process. Qualitative study has revealed unexpected information from stakeholders with experience of the architectural design process. Developing the IDCM stystem, which was demonstated through the interactive means of a web-based application, has enabled the research to generate useful feedback from the end users, in how they value the interactive media as a tool to promote workflow. In addition, implementation of a fully working platform has been suggested to application developers, so extending thoughts in this research area.

The findings of this chapter first suggest the need for an interactive communication tool to promote the design process. Issues and potential for such a tool are explored in the context of modern communication today. Second, general discussion on the theories and practice have brought contributions to the architectural design process, including real-time communication, a compatible software review, and an interactive 3D model embedded in a web interface for better understanding of architectural representations, created by Unity software. Thirdly, unlike in the AEC industry, planners are included in the system. Finally, the chapter has reflected on the development of the IDCM system, including strategies and limitations of the research.

The next chapter summarises the research as a whole, including outcomes, contributions to knowledge, effectiveness of the research method, challenges and limitations, as well as future research opportunities.

Chapter 8 Conclusions

Chapter 8 Conclusions

8.1 Summary

This research examines communication in the design process and the role of interactive media in facilitating workflow in such a process. In particular, it focuses on stakeholders' experience of the design process, to identify issues that may have created obstacles to effective communication and collaboration by all stakeholders. Computer-aided architectural design (CAAD) tools and digital media have been reviewed in order to identify the attributes of the tools used for design communication between specialist and non-specialist stakeholders working on the same project. The research has shown that there are often misunderstandings in the communication between architects (design information senders) and other stakeholders (design information receivers), significantly delaying the workflow. Architects often work independently; however, their decision-making affects others. The theoretical underpinning of this research is informed firstly by 'push' and 'pull' media theories, used to identify potential improvements in communication. Secondly, the analysis of models of communication and the exploration of interference in communication were used to find significant factors that affect communication in the design process.

At present, architects solely use one-way communication to 'push' design information and ideas to other stakeholders through architectural presentations. This can lead to information being missed or being too vague, due to the use of incompatible file formats, varying forms and styles of digital media, and inappropriate 3D representation tools. These issues delay the design process and lead to misunderstandings in communication. Alternatively, the utilisation of digital interactive media empowers all users to 'pull' and input information depending on their interest, thereby enabling stakeholders to actively review and make contributions that inform the decisions on the design project. In summary, many of the communication problems in the design process can be overcome by using digital web applications that enable people to interact more dynamically and with ease of access.

This research is situated within the wider context of the way people work and communicate in the modern era, which is very much shaped by digital technologies. Architectural practices use computer technology in order to design, present, and communicate their design proposals. In the light of the digital revolution, many software and applications offer useful technological functions that architecture should make use of, in order to facilitate an effective design process. This research sought to demonstrate that professionals in architetcure embrace the technological revolution by making use of what the digital technologies and the Internet can offer. The use of incompatible digital design tools, however, presents a barrier to collaborative working and efficient communication as stakeholders' varying technical background knowledge affects their understanding of the design on different levels. Developing technical skills in the use of specialist software is unappealing to many and can be cost-intensive. Therefore, appropriate architectural representation and design tools are required which support more efficient design communication and facilitate the involvement of a wider range of stakeholders. To address this, the research has considered the ways stakeholders can exploit existing digital media and Internet-based technologies to provide effective communication tools that encourage collaboration in the design process. Conventional methods of communicating the design work between various interested parties in any given design project, i.e., architects, engineers, planners and clients, have been revisited, with a view to proposing an improved communication system.

Stakeholders' needs and requirements in using digital media in the design process have been investigated to focus on the role of each stakeholder, in order to improve communication. Berlo's model of communication (1960) underpins the investigation of stakeholders' role in the communication process as the research explores many factors that affect the quality of communication such as stakeholder background, attitude and knowledge. As Berlo suggests, knowing audiences can make communication more efficient by sending the right message to the right receiver. Semi-structured interviews have been used to investigate stakeholders' requirements and seek their points of view in relation to the use of digital media for design communication with a view to identifying the potential for improvement.

From data analysis of the survey of participants' experiences of the design process, a number of issues were raised and these lead to putting forward the guiding principles which informed the design of an interactive design and communication management (IDCM) system. A mock-up of the IDCM has been developed in order to demonstrate the operation of the system and to enable the testing and evaluation of the IDCM regarding functionality, efficiency and usability. End user feedback produced positive results, showing the system to be easy to use, clear and straightforward; these attributes promote effective communication and collaboration. In addition, end users agree that storage, retrieval, and comparison of design information online are convenient, in terms of both access and use. Therefore, problems of inconsistent information and difficulty in access to information can be overcome.

This research offers an alternative approach to work in the future, although it has certain limitations. By identifying the problems, the research gains new knowledge and insight, suggesting new lines of research. During this project, the researcher's interest in the topic increased, especially as new technologies and improved hardware and software systems for collaborative design emerged. This motivated the researcher to ascertain the capabilities of embedding interactive digital media in the architectural design process. Currently, there are many channels by which design work can be communicated, and architects should engage with technology, especially the Internet and interactive digital media.

Although the main outcome of this PhD is the written thesis, an element of practice, consisting of the IDCM system was produced, which is demonstrated through the storyboard and the mock-up to simulate its operation.

8.2 Research outcomes and contributions to knowledge

The research makes a contribution to knowledge in the field of architectural design communication on several levels. This research set out to examine stakeholders' experience of the design process, focusing on the issues of communication in a collaborative design, including incompatible working systems, miscommunication between architects and other stakeholders, working with inconsistent information, and software-related skill development problems for stakeholders. To address some of these issues, the research has proposed a framework for an improved form of communication based on the use of interactive digital communication methods without the complications associated with conventional systems. The storyboard put forward as part of this research demonstrates how the system facilitates communication within the design process.

The proposed design communication system can be considered as the basis of what might become a new, more efficient form of architectural presentation, one which allows real-time collaboration between all stakeholders in the design process, supported by several key features:

- Compatibility supports common file extensions in order to overcome the issue of stakeholders using different software packages.

- Keeping consistent information by introducing an interactive 3D model linking all design material, which can be viewed, retrieved, archived, and tracked in a single online location.

- The system enables messages, conversations, and notifications of participatory design, promoting real-time communication.

- The perspective of the planner as a contributor to the design development process is considered, in contrast to other systems that focuses on architect, engineer and client perspectives only.

The proposed communication system, shown in Figure 8.1, makes suggestions that challenge both communication and collaboration within the conventional system in order to improve it. User feedback from the study participants confirmed that the IDCM system has the potential to facilitate a more efficient workflow in terms of communication and collaboration between stakeholders. Therefore, the aim of this research has been achieved.

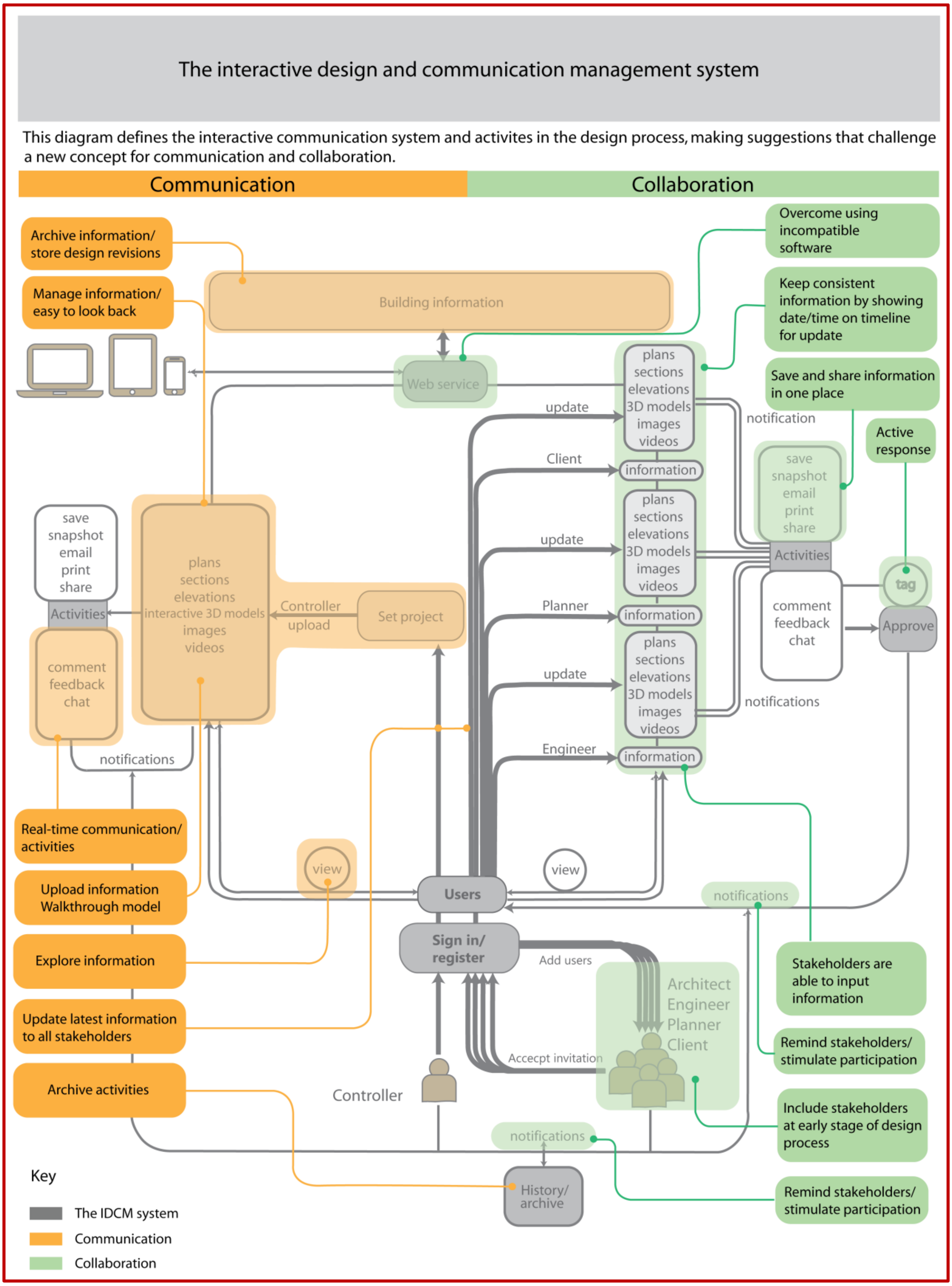


Figure 8.1 **The IDCM system in the design process (Meechao, 2017)**

While the work in this research did not lead to a working online platform for such a communication system, which was never the objective of the study, it has led to the identification of certain challenges relating to communication in design and offered a way forward to overcome these through an interactive communication system. At this current stage, the proposed system still requires continued development.

Further research should be undertaken to consider how instant messaging and real-time feedback would facilitate and speed up the design process, which includes both professionals in the built environment industry and laypeople. It is recommended to apply the guiding principles, developed through this doctoral research, of **interaction**, **accessibility**, and **inclusivity**, as they are required to assist the exploration and understanding of the design by various stakeholders.

Other outcomes of this research include:

- **A review of software** used in the design of the built environment. CAAD tools are identified along with their functions, file extensions, and capabilities with regard to Building Information Modelling (BIM).

- **A stakeholder survey** on the use of digital design tools, to elicit views and experiences. These include the 'benefits' of and 'problems' with using such media and 'suggestions' regarding the necessary attributes of these tools. The survey also identified three guiding principles that helped develop the IDCM system: interaction, accessibility, and inclusivity.

- **A number of visual outcomes** in the form of diagrams, a storyboard, and a mock-up of a web application have been produced to demonstrate the design of the IDCM system.

8.3 Effectiveness of the research method

A qualitative methodological approach was employed; methods used include data collection (semi-structured interviews, questionnaires); analysis (coding); practice (diagrams, mock-up, storyboard); and evaluation (feedback, observations). These methods enabled the researcher to gather important information leading to the identification of the requirements and needs of stakeholders to ensure effective design communication. As a result, new digital media has been developed to help with the establishment of guiding principles for a communication.

Although a survey of stakeholders using semi-structured interviews and data analysis allowed the researcher to efficiently identify their problems and requirements, some methods could be improved, due to the following:

- Finding time and places for interviews was difficult, and contacting each participant to arrange meetings was very time consuming. Timing was a particular challenge due to the nature of the participants' profession. Although the meetings were individual so that participants could speak freely and so that information shared could be kept private, it would have been beneficial to have conducted a group discussion between participants in order for them to exchange experiences and discuss significant issues.
- The data analysis to identify required attributes of the system was undertaken manually. This approach might be considered less rigorous than data analysis conducted using computer software. Nevertheless, the researcher's own experience and motivation enhanced the quality of analysis, and for this reason, a manual approach was used.

The interactive communication system was developed using the HCI, IA, and ID theories and through design practice methods. These included:

- A series of sketches for the IDCM, which were created in order to manage categories including the functions, users, and architectural design information required to create an efficient system. A detailed diagram of the system was developed based on a series of sketches. The sketches allowed quick drawing and editing of the relationships and hierarchy within the system.

- A series of mock-ups, which were sketched and illustrated for discussion and in order to obtain feedback from previous survey participants. The mock-up was produced using 2D and 3D software packages such as Adobe Photoshop, Adobe Illustrator, and Adobe Flash CS. Initial mock-ups were created with 2D software, which was less complicated than creating a 3D web application. However, it provided sufficient hierarchy of the system.

- The mock-up of the IDCM system, which was created and tested with end users in order to evaluate the system in terms of its usability and effectiveness. From the data analysis, it became apparent that a walk-through function would be required. Therefore, the software package Unity was used to enable the creation of interactive 3D models and a web application.

- A storyboard, which was created to represent users' stories of how the system could be used to facilitate the design process. This method highlighted the significant contributions of the interactive communication system to the design process by relating stories to current issues that obstruct communication and collaboration.

- Feedback from participants, which was collected by employing 'think aloud' methods to validate the effectiveness of the system and the mock-up. This method allowed the researcher to observe the participants both verbally and non-verbally as they responded to the design. The method also enabled the researcher to determine whether the participants were satisfied with the concept and the design.

The methods mentioned above revealed the strengths and weaknesses of the proposed system in its current state as well as opportunities for improvements, underlining the importance to advance its design.

8.4 Research limitations and challenges

Although this research was carefully undertaken, the technology involved is subject to constant and rapid change. This was the greatest challenge faced in this research. Rapid change in technology required the researcher to consistently review relevant advances, and this affected the identification of appropriate methods and resources to develop the interactive communication system. Further limitations and new challenges were revealed throughout the process of the research, such as:

- The small number of participants for this research (20), in relation to the vast number of professionals and clients involved in the architectural design process. This is a concern as a greater number of participants would have provided more diverse information and insight. However, this research was conducted within a limited period of time.

- Participants' feedback on the mock-up provided helpful reflection on practice and informed ideas for the future development of the system. Unfortunately, the researcher was unable to contact some participants to arrange a follow-up meeting. Despite this limitation, the researcher acknowledges that the data obtained from the participants covered their basic requirements and showed that they understood how the IDCM system works.

Some ongoing challenges of a more general nature came to light during the research, due to the complexity of problems that were being explored:

- Participants wanted to see editable 3D models in real time while communicating, which challenges the 'instant model' outcome. This would help the researcher to obtain the reactions of users in situations beyond the current problems or conflicts. However, transferring many ideas to the 3D model would make communication more complex, with omni-dimensional information. When many people are involved, finding an effective level of communication is challenging.

- Notification of activities, or the ability to see user status, encourages stakeholders to utilise the communication system. This would significantly impact on stakeholders' participation with regard to behaviour and communication culture in the built environment industry.

- Finding demonstration tools, as well as developing architectural presentation methods, is challenging. A system that is available through an open source would reduce the costs and difficulty associated with accessing information.

- Access to the system via a mobile device is presently limited due to licensing restrictions. The IDCM system is designed to work on desktop version only. This fact limited stakeholder participation during the feedback trials, in which users would have preferred to have run the system on tablets to better simulate their convenience of work.

A qualitative method enabled the researcher to ascertain the stakeholders' experiences and identify the problems they encountered with design communication. This helped to make the IDCM system design more straightforward as it took account of stakeholders' requirements for improving communication, deduced from their feedback. It would benefit future research to combine qualitative and quantitative research approaches. This would enable the collection of a wider range of participant information and the acquisition of a wider range of data to inform the system design.

8.5 Future work and applications

This section aims to elucidate the potential for further research development and application of knowledge within other disciplines, within either academia or practice. Although this research has clearly demonstrated the potential for improvement of effective communication in the design process by employing interactive communication means such as the IDCM system, there remain many opportunities to extend the research.

The researcher has identified the following potential future research areas:

- Application development – using the IDCM system as a basis to work collaboratively with software engineers to produce a fully working web application.

- Investigation into the enhancement of the IDCM system through a head-mounted display device – now available for use with a computer and a smartphone. A peripheral device, such as an Oculus or Samsung Gear VR, could be a standard tool for enhancing user experiences and has many applications. Visual perception and real-time communication can be developed concurrently to facilitate better communication.

It is anticipated that other disciplines will benefit from the methods, data, and results of this research. The developed communication system can clearly generate diverse concepts of communication, collaboration, and data management for other disciplines. There are thus opportunities for future development of these concepts in terms of their academic and professional use.

Academic implications

- Students working with other students or a tutor could apply the idea of interactive communication to their design project. Member categories would need to be adapted depending on the project.

- Research teams could apply the research methods to ascertain insightful information from participants and evaluate outcomes in their research. In addition, they could use an interactive communication system to share and store information online. Types of users and their requirements would need to change according to the nature of the research.

Professional implications

- Designers, including architects, graphic designers, product designers, and urban designers, acknowledge the communication problems that may occur in their practices. This research offers methods to take account of all stakeholders’ design project in terms of their requirements, background, and experience, in order to direct the right message and appropriate design information to them. In this research, interactive communication has been shown to impact on work and lifestyle, and both benefits and conflicts have been revealed. Other design disciplines can learn from the methods and findings of this research, the benefits of compatible working systems, ease of access, or real-time communication, to adopt in their practice in order to promote a collaborative design process.

- Planners could benefit from the ability to store and retrieve the data on each project in one place. With regard to extending the idea of archiving data, this could be developed as a web application on an intranet used within a planning organisation.

- Engineers could adopt real-time communication as well as present structural and technical information to other professionals and contractors involved in their projects. Moreover, the use of online data could be extended to construction mode.

- Clients may require a building maintenance management system that could become a significant database, through which they are empowered to maintain the system after the building is finished. The use of uploaded models could be extended to building maintenance. For example, clients would be able to recall specifications by clicking on windows to show the glass type and cleaning schedule. Clients could also establish links with suppliers.

8.6 Closing remarks

A number of problems with communication on architectural projects represent challenges to thoughts and activities in the design process, which highlights the complexity of design communication between architects and stakeholders at different levels. An understanding of stakeholders' requirements has provided a framework for designing more effective ways to communicate and work collaboratively. The proposed interactive communication system has been introduced to architectural practices and has stimulated a more efficient design process. The evaluation of the system by end users revealed positive results in terms of displaying architectural presentation and information, ease of use and access, and the gathering of design information in a single location. This research has attempted to reduce the identified challenges by suggesting the new term of communication and opportunities for inclusive collaboration. The future of collaborative design will require a system which enables users to communicate more interactively, more independently, and more effectively.

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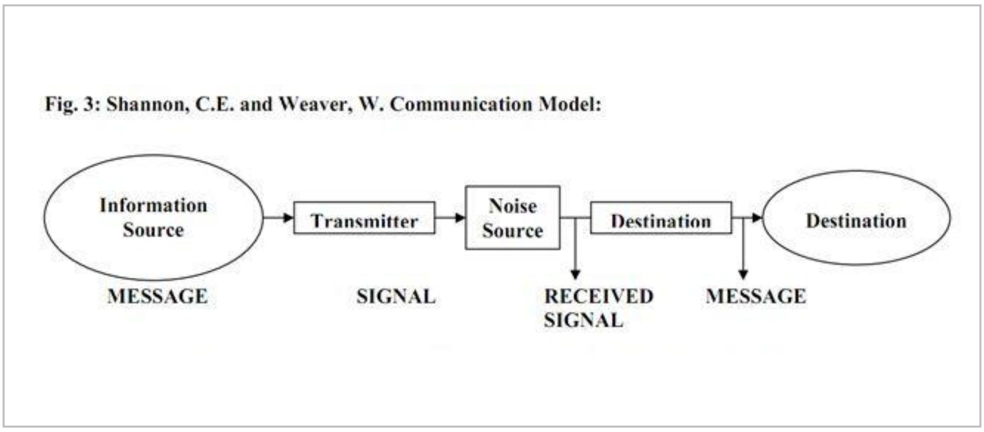
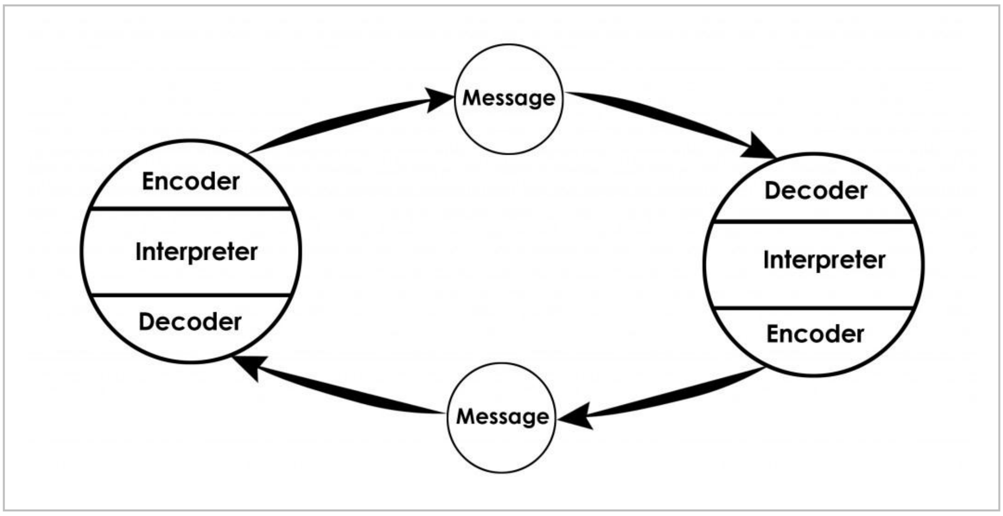
Appendices

Appendix A: Models of communication



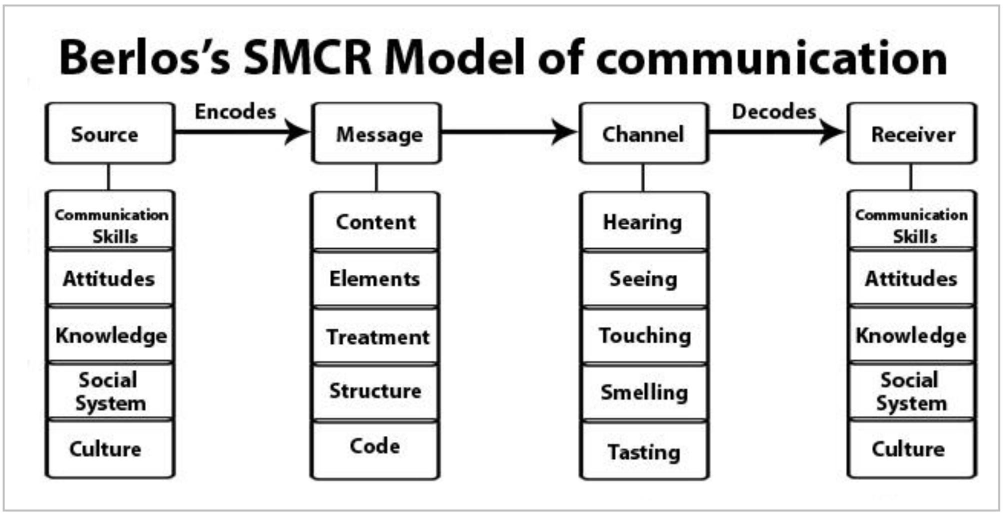
Shannon and Weaver's model of communication

Source: Salawu, I.O., Taiwo, S.A. and Aremu, G.B. (1994:19) *An Introduction to Educational Technology*. Ibadan, Afolabi Press Limited.



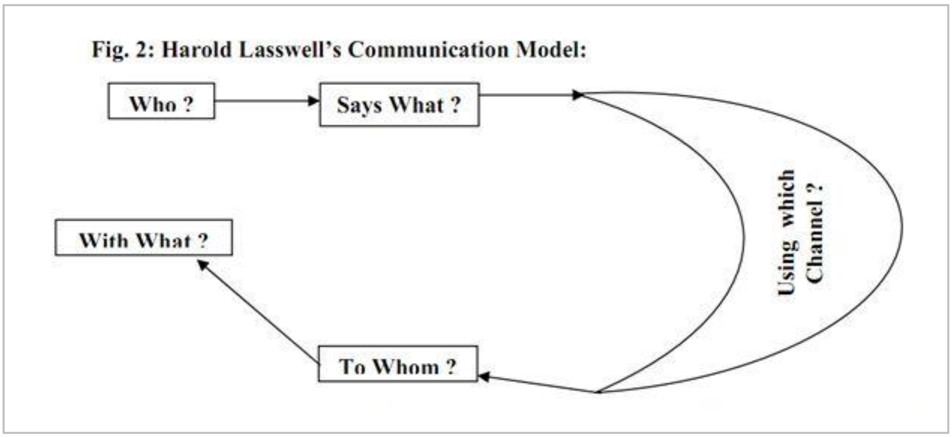
Osgood Schramm's model of communication

Source: Communication Theory (2010). Osgood Schramm's Model of Communication. At:http://communicationtheory.org/osgood-schramm-model-of-communication/ (Accessed on 10.06.15)



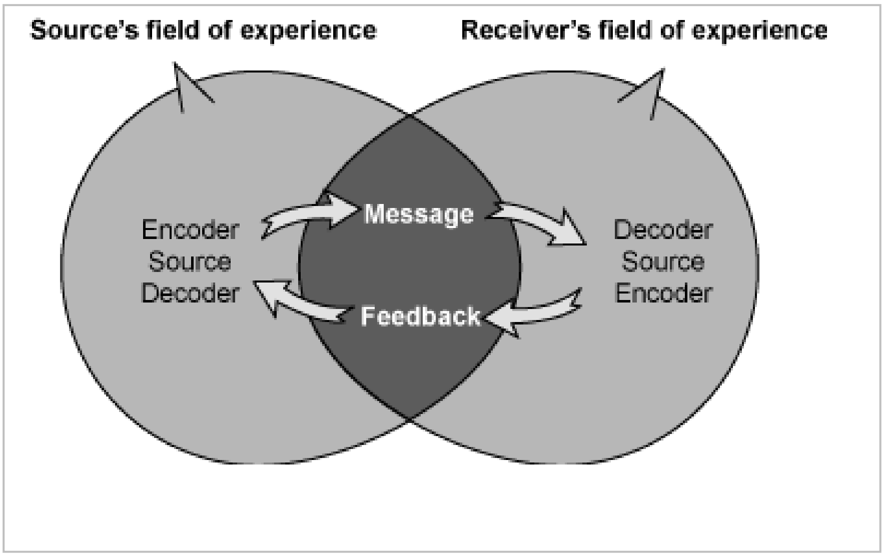
Berlo' s SMCR model of communication

Source: Communication Theory (2010). Berlo's SMCR Model of Communication. At:http://communicationtheory.org/berlos-smcr-model-of-communication/ (Accessed on 10.06.15)



Lasswell' s model of communication

Source: Aiyelagbe, G.O. (1999:121): *Basic Process in Education* (ed.) Ogunsanya, M.



An interactive model of communication

Source: Wood, J. T. (2009). *Communication in our lives* (4th ed.). Belmont, CA: Thomson-Wadsworth

Appendix B: Ethics consent form

Ethics Committee

Consent Form

Project title: Digital Presentation in Architectural Practice; from a presentation tool to digital media

Data Controller: Krisanee Meechao , MPhil/PhD researcher, University for the Creative Arts

Supervisors: Dr. Hocine Bougdah, Dr. Anke Jakob

Collaborators: (if applicable)

Participant Name:

Participant Location:

- I the undersigned voluntarily agree to take part in the study on (Title of the Research) a practice- based research project.

- I have read and understood the Information Sheet provided. I have been given a full explanation by the investigators of the nature, purpose, location and likely duration of the study, and of what I will be expected to do. I have been advised about any discomfort and possible ill-effects on my health and well-being which may result. I have been given the opportunity to ask questions on all aspects of the study and have understood the advice and information given as a result.

- I agree to comply with any instruction given to me during the study and to co-operate fully with the investigators. I shall inform them immediately if I suffer any deterioration of any kind in my health or well-being, or experience any unexpected or unusual symptoms.

- I agree to the investigators contacting my general practitioner about my participation in the study, and I authorise my GP to disclose details of my relevant medical or drug history, in confidence.

- I understand that all personal data relating to volunteers is held and processed in the strictest confidence, and in accordance with the Data Protection Act (1998). I agree that I will not seek to restrict the use of the results of the study on the understanding that my anonymity is preserved.

- I understand that I am free to withdraw from the study at any time without needing to justify my decision and without prejudice.

- I acknowledge that in consideration for completing the study I shall not receive any reimbursement, payment or rewards.

- I confirm that I have read and understood the above and freely consent to participating in this study. I have been given adequate time to consider my participation and agree to comply with the instructions and restrictions of the study.

Name of volunteer ………………………………………………

(BLOCK CAPITALS)

Signed ………………………………………………

Date ………………………………………………

Name of witness ………………………………………………

(BLOCK CAPITALS)

Signed ………………………………………………

Date ………………………………………………

Name of researcher/person taking consent…Krisanee..Meechao………………

(BLOCK CAPITALS)

Signed ………………………………………………

Date ………………………………………………

Appendix C: Question schedules for interviews and feedback procedures

Question schedules for interviews with architects

These questions aim to collect information about the use of digital media for architectural presentation and communication from an architect's point of view.

Q1. What size is your practice?

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Q2. What information do you deliver through architectural presentation? .

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Q3. Do you provide 3D presentation for your clients? If yes, what kind of 3D presentation do you normally use e.g., 3D rendering image, animation, VR, interactive media or else?

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Q4. Do you think the 3D presentation tools you are currently using are effective enough for communicating your designs? If not, please describe why.

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Q5. Do you experience any problems? What are they (e.g. miscommunication, too time consuming)?

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Q6. Do you think the introduction of interactive media, such as web-based application or virtual reality, for architectural presentation would be a helpful tool of communication with clients and project partners during the design process?

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....

Q7. Have you applied digital interactive media within your practice?

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....

Thank you for your contribution

Krisanee Meechao
Research student

Question schedules for interviews with engineers

These questions aim to collect information about the use of digital media for architectural presentation and communication from engineer's point of view.

Q1. What size is your practice?
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Q2. What information you do you seek in architectural presentation?
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Q3. Do you work with architectural 3D presentation tools? For what purpose?
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Q4. Which one do you use most? (If more than one)
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Q5. Do you think the 3D presentation tools you are currently using are easy to use and to understand? If not, please describe why.
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Q6. Do you experience any problems with the use of 3D presentation?
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Q7. Do you prefer to have a photorealistic 3D presentation? If so why?
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Q8. My research investigates the introduction of interactive media, such as web-based application or virtual reality, for architectural presentation would be a helpful tool of communication with clients and project partners during the design process. How is your opinion?
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Thank you for your contribution
Krisanee Meechao
Research student

Question schedules for interviews with planner

These questions aim to collect information about the use of digital media for architectural presentation and communication from planning officer's point of view.

Q1. What information do you seek in architectural presentation?
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Q2. What kind of architectural presentation, e.g. drawings, photorealistic images, animated sequences of buildings, work most efficiently for you?
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Q3. What kind of architectural presentation do you use most often for making design decision?
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Q4. What problems do you encounter with architectural presentations?
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Q5. Do you prefer to have a photorealistic 3D presentation? If so why?
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Q6. My research investigates 3D presentations through interactive media such as web-based application or virtual reality would help you to understand the architectural design better and make the communication process with architects and engineers more efficient. How is your opinion?
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Thank you for your contribution

Krisanee Meechao
Research student

Question schedules for interviews with clients

These questions aim to collect information about the use of digital media for architectural presentation and communication from client's point of view.

Q1. What kind of your project have you commissioned?
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Q2. What information do you seek in architectural presentation?
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Q3. How do you prefer an architect to present the project to you (i.e. drawing, physical model, digital 3D model)?
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Q4. Do you think the presentation tools that architects are currently using are easy to use and to understand? Please describe why/why not ?
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Q5. Do you experience any problems with the use of architectural presentation?Please describe how.
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Q6. Do you prefer to have a photorealistic 3D presentation or dynamic 3D model?Please describe why.
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Q7. What do you think about the introduction of interactive media, such as web-based applications on mobile divices for architectural presentation? Would that be a helpful tool of communication with architects and project partners during the design process? Please describe why.
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Thank you for your contribution
Krisanee Meechao
Research student

Feedback questions

Feedback Questions

1) What do you think about IDCM system? Do you find it easy to navigate?
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2) Is something missing? Do you want to add any other functions?
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3) Do you think IDCM includes enough standard architectural information? If not, what information, architectural presentations or data do you want to add?
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4) What do you think about the visual appearance functionality of IDCM system?
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5) Do you have any other comments?
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Thank you for your contribution
Krisanee Meechao
Research student

Appendix D: Examples of interview transcripts, data analysis and feedback transcripts

<u>Examples of interview Transcripts</u>

E01MT

These questions aim to collect information about the use of digital media for architectural presentation and communication from the engineer's point of view.

KM: What size is your practice?

MT: The practice has 8,000 staffs and 500 people for my branch. We work 15 people in my team. I am a manager wich covers both engineer and architect. We work on numbers of projects which are intenational projects in Middle East, Africa, HongKong and Europe.

KM: What information you do you seek in architectural presentation?

MT: The integration of structure, services, electronic and mechanic. Atkin also has our own architectural practice. They are very famous in Dubia, not in UK.

KM: Do you work with architectural 3D presentation tools? For what purpose?

M:Yes, everything make from 3D, we use BIM but it is too expensive that is why BIM is not use widely. BIM is very useful for Mega project, public project such as hospital.

KM: Do you use 3D for what purpose?

MT: We use 3D for construction propose to show how it buit. Using live model just for the client to avoid a mistake. Preparing 3D for planning structure/ microstructure including planning realm to see all affect to the environment.

KM: Which one do you use most? (If more than one)

MT: 3D rendering is the most important for the client. Animation is important for projects such as an airport, to show logistics, i.e. flowing of people or luggage. We do not use 3D for building regulations.

KM:Do you know VR?

MT: Yes, I knew that.

KM:Do you use VR?

MT: No, we do not use VR.

KM: Do you think the 3D presentation tools you are currently using are easy to use and to understand? If not, please describe why.

MT: Yes,SketchUp is especially good to use when we want somthing quick. However, mechanical formats are difficult to use.

KM: Do you experience any problems with the use of 3D presentation?

MT: Yes, the problems concern transferring files, time cosumming.

KM: Do you prefer to have a photorealistic 3D presentation? If so why?

MT: No, don't need to be realistic. We care more about how things integrate together: details, finishing and integration with the structure. Using 3D is crucial; we prefer isometric which shows better perception. We use it for details to include in the drawing, showing how it is built. Before having 3D, we have more problems on site, paying more labour, wasting money on cladding calculating.

KM: My research investigates the introduction of interactive media, such as web-based application or virtual reality, for architectural presentation would be a helpful tool of communication with clients and project partners during the design process. How is your opinion?

MT: Yes, it would be very helpful. Websites like Rightmove are interesting. It would be nice if we could see 3D and 2D on the web. It's good to see that the room is changed when we press a button.

KM: Thank you for your contribution

A02PN

KM: What size is your practice?

PN: My practice is medium size, around 80 people. At present our projects are office buildings, commercial and some residential.

KM: Where are most of your projects located?

PN: Most of our works are in central London but some projects are outside London. For instance, designing the library in Oxford.

KM: What information do you deliver through architectural presentation?

PN: The information is divided into two types. 1) For internal communication we use 3D programmes such as 3D Max and SketchUp, studying space and design to make a decision. In addition, InDesign and Photoshop are also used. 2) For external communication, material and design are visualised. We use physical and digital models. For 3D rendering we do both in-house and we out source.

KM: For what reason do you out source?

PN: The point is timing, definitely. Although it is more expensive, it is worth it because we can deliver work on time.

KM: Do you out source for other stakeholders?

PN: Yes, for internal or design teams I include architects and engineers. For planning, I call planning external communication – we submit 3D rendering, visualisation, elevations, sections and layout plans. For engineers, we do not deliver in very much detail; space and massing are necessary but not specific material.

KM: How do you send the presentation to stakeholders?

PN: If it is a big file, we use Dropbox. For a small file, we use BIM. For sending a 3D pdf, a 3D file is used for the engineer, which reduces the time because we can bind all information in a single file. However, the sender and receiver must have the same pdf version. For tender, we use the old style of creating sheets of design information.

KM: Do you provide 3D presentations for your clients? If yes, what kind of 3D presentations do you normally use, e.g., 3D rendering images, animation, VR, interactive media or anything else?

PN: Yes, most of our works are rendering images but we do not use VR, interactive media or animation. We use BIM and AutoCAD BIM.

KM: Do you think the 3D presentation tools you are currently using are effective enough for communicating your designs? If not, please describe why.

PN: Yes, they are good for complicated designs. However, using 3D for common projects becomes troublesome. For example, we have to submit in the old style by producing sheets, so we have to clean up 3D to 2D, which means doing double the work. I have to say; 3D presentation tools are good for study and internal communication. I have not heard anyone say that BIM is perfect. But they said finally we have to go back to the old style. This is my personal comment.

KM: Do you experience any problems? What are they (e.g. miscommunication, too time consuming)?

PN: Yes, too time consuming, especially using BIM in developing the design stage. We use Rhino for beautiful results, but this is not the answer for a practical purpose.

KM: Do you think the introduction of interactive media for architectural presentation, such as web-based applications or virtual reality, would be helpful tools for communication with clients and project partners during the design process?

PN: Yes, interactive media is very useful. In the future, websites will be a very important tool.

KM: Have you applied digital interactive media within your practice?

PN: No, not yet.

P02AR

These questions aim to collect information about the use of digital media for architectural presentation and communication from planning officer's point of view.

KM: What information do you seek in architectural presentation?

AR: Scale drawing, plans, elevations, sections got to be proper scale, 1:100, 1:50. Sometime 1:1 for molding and joinery. Image of proposed drawing is not essential but desirable and it usually help architect to convince us to accept their proposal. More important we expect it to be accurate.

KM: What kind of architectural presentation, e.g. drawings, photorealistic images, animated sequences of buildings, work most efficiently for you?

AR: We have to have drawings, and for a new building we might want to see photorealistic images. A kind of presentation that helps people (not professional) to understand the proposal; physical models with perspective, and now photorealistic images.

KM: What kind of architectural presentation do you use most often for making design decision?

AR: The drawing from the basis of the approval not the images and when the building has been built it must be according to the drawing.

KM: Do you have a background in architecture?

AR: I am urban designer-planning officer here come from a variety of background, several of them were architect.

KM: What problems do you encounter with architectural presentations?

AR: Sometimes they do not choose the right view point of the building. They are often too close to the building to allow you to see everything you want to see, particularly massing of it, the roof for example. We are very concerned about the height; sometimes it deliberately shows that the building is not as big as it actually is, so we often discuss where the view position should be taken from. We would sometimes agree with architect what views we want to see from a map, usually they (architects) try to make building lower than it is. The wide angle of image is often distorted so that is an issue. One project, architect dud a huge image of the building so that when we stood 1 metre away from image equalisation to the real one. We can see the impact of the building- very useful but expensive.

KM: Do you prefer to have a photorealistic 3D presentation? If so why?

AR: Images must be according to drawings. However, the drawing is the basis for us to use to make a decision.

KM: My research investigates 3D presentations through interactive media such as web-based application or virtual reality would help you to understand the architectural design better and make the communication process with architects and engineers more efficient. How is your opinion?

AR: Yes, it is very helpful, we often have only drawing and static image- never fly through 3D visual. There often the issue that we don't have the programme the same as architect have so we cannot view them. If they have programme that we can change and see building from different view point that could be helpful.

KM: Thank you for your contribution.

C01AD

These questions aim to collect information about the use of digital media for architectural presentation and communication from client's point of view.

KM: What kind of your project have you commissioned?

AD: Basically, my role here is store manager. I was asked by my line manager to directly as end user, engineer, people can use it. I dealt with the result, what is in the room, cost. What does it fit? What does it suit? To design what size of the room, one I agreed on, the concept of the building. How is it going to be feel? I was asked to rely on architect and contractor to make it happen. I had a meeting several 2-3 weeks, start with architect to the builder. With the builder all the way through.

KM: How do you select architect to work with on this project?

AD: I didn't do it personally, but I assume they went out with tender and the tender come with structure, the engineering company as well. This is my first big project, it was stressful. It's a lot to do and took a lot of time, but it's finished. One thing I would say to the architect, if they got any doubt, please come and ask me, otherwise you won't get anything build. But this project ran to delay anyway. For me, real-time communication will overcome the problem. It was quite challenging because the XXX would start to send you the money, let's say every month. If you don't spend the money, they could throw out the funding.

KM: Do you need to prepare the project plan before getting the money?

AD: Yes, there were concept, 3D walkthrough to show the project.

KM: Did you contact planner?

AD: There was the size and footprint of the building to submit first. There was a chunk building and interrupt the tree at the back. We were asked to reduce the size of the building so that might delay it a little bit. I wasn't involved in that bit.

KM: What information do you seek in architectural presentation?

AD: Definitely, 3D walkthrough. There was an animated project. They brought with them the real material fabric, stone, countertops. They had sick bound. They were a 2D what it would look like.

KM: How do you prefer an architect to present the project to you (i.e. drawing, physical model, digital 3D model)?

AD: Basically, all of it. The architectural drawings do not show the end user what it looks like. But you start with a physical model or 3D model. Yes, it actually demonstrates how the building feels. A digital walk-through would be recommended.

KM: Can you read 2D drawing?

AD: Yes, within reason. I am not an architect. I think if they don't have background knowledge, it will be difficult because you can't compare what the drawing is. So as soon as you go to 3D or other models, or walk-through, this will be good.

KM: Do you think 3D walkthrough is enough for communication or 2D drawing is still needed?

AD: I think for a big project the more representation of the project, the better.

KM: Are they show the presentation on the screen?

AD: Yes, but for the physical model, we kept it.

KM: Is it movie file?

AD: Yes

KM: Do you think the presentation tools that architects are currently using are easy to use and to understand? Please describe why/why not?

AD: Umm, yeah… I think the tool that they used were good. They talk about functions. How people get in and out and How is the use of the rooms. And it's good to have several meetings with architect.

KM: How many architects in this project?

AD: Just one.

KM: Do you experience any problems with the use of architectural presentation? Please describe how.

AD: I don't think so. I think if you have an electronic walk around that would be help. But what they had it's good.

KM: Did you contact with engineer?

AD: Yes, the meeting had university, me, the architect, the contactor and mechanical and electrical contractor.

KM: Do you have planner involved in the meeting?

AD: As the end user I wouldn't have thought that I need to speak to planner. The time we got involved was about the tree.

KM: Do you prefer using a photorealistic 3D presentation or dynamic 3D model? Please describe why.

AD: I think walking through can help to understand the design. It is quite difficult to imagine the size of the room and how people interact with it.

KM: What do you think about the introduction of interactive media, such as web-based applications on mobile devices for architectural presentation? Would that be a helpful tool of communication with architects and project partners during the design process? Please describe why.

AD: I would have say yes. Showing the presentations on the project is fine, but having an image on your phone is useful, that you can go back to and look at easily… 'I think the more chance people can talk on the construction and design process, the better you get what you want.'

<u>Data analysis</u> – benefits

Benefits	Engineers	Architects	Planners	Clients
Sharing information	For a very good project [sharing information] does happen and involves a lot of specialists; the bigger project, the more services you provide. There is an in-house knowledge share when needed. (E02MR)	We use Dropbox for large files. For a small file, we use BIM. 3D pdfs are sent to the engineer, which reduces time because we can bind all information in a single file. However, sender and receiver must have the same pdf version. For tender, we use the old style of creating sheets of design information. (A02PN) We use web-based open access. We update information such as images, including site images, all the time. Everyone can access and search; it is like a photo library for sharing. We use a blog to share information, such as problems that we experience or any competition. We can also answer if someone needs help. The supplier company that produces materials have a chat room where we can ask for information more quicklythan waiting for a face-to-face conversation. It's		

Benefits	Engineers	Architects	Planners	Clients
		convenient for asking for more information or addressing queries. (A04PA) We use Chatroom, email and telephone, like general offices. In my office, we also use GitHub for communication within the team. (A07DT)		
Marketing tools		3D is good when used for advertising is. (A06ED)		
Editing work		KM: 3D SketchUP is very popular at the moment. I can see that everyone uses it. ED: Yes, it is quite easy. (A06ED) By this time, is anyone going to say they want to change it, or don't like it? We are not using good 3D imaging as part of the design process, but more as a vehicle to deliver it. (A09CO)		
Portability		Standard design presentation document and marketing document (past and previous projects), starting with a presentation on an iPad bespoke book (A03RA)		

Benefits	Engineers	Architects	Planners	Clients
Better design communication	SketchUp is especially good to use when we want something quick. However, mechanical formats are difficult to use. (E01MT) What we often find is that the architect normally uses 3D much more than the structural engineer would do. We use 3D just to see the model of structure, so we use Revit; the architect would put their information around this model. 3D has become a very important way to communicate directly. We're also using 3D for structural analysis, when we are looking at a particular building. The mathematical side of it becomes quite complicated. We sometimes use tools to help us, like 3D analysis physical models where we model the entire building mathematically in full form, and use that to experiment load condition like storms, wind and earthquakes on the building. (E02MR)	They have done a lot of projects and seem to be going well. SketchUp has proved to be simple; used in complex designs, it seems to work well with AutoCAD. I think in some instances, a few people use Rhino to explore various designs of capability and potential. For example, doing curves for parametric design, or generating complex structures like patterns that cannot easily be carried out in SketchUp or AutoCAD. One or two projects have been applied to this in the office. Not everyone is fully capable; it works but is still a niche. There is still lots of potential to explore other tools. The more you make progress, the more detail, the better the design result. This is set aside for the client or planner; it is just for them to visualise. Not every client has a visual dimension. They look at the drawing and then they look at the model, then	I would rather have 2D or a drawing, as I have been trained to read this kind of information. However, when going to a committee meeting, I would rather have photorealistic and computer-generated images, as these are easy for people in the committee to understand. So for me, it depends when I need it for. If it was to present to a member of public, the more realistic the better. (P01SA) A kind of presentation helps people (not professional) to understand the proposal; physical models with perspective and now photorealistic images. (P02AR) When an application is discussed using a PowerPoint presentation with 3D walk around, this is usually good and useful. Although digital media is very important and helps in terms	I am not an architect. I think if they don't have background knowledge, it will be difficult because you can't compare what the drawing is. So as soon as you go to 3D or other models, or walk-through, this will be good. (C01AD) I think walking through can help to understand the design. It is quite difficult to imagine the size of the room and how people interact with it… I think the more chance people can talk on the construction and design process, the better you get what you want. (C01AD) Photorealistic 3D presentation, because the design intent of projects will be clearly conveyed to our purchasers. (C03NA)

Benefits	Engineers	Architects	Planners	Clients
	2D and 3D, they both have their play. I like the 2D to show where beam positions are and other details. But the 3D is very useful to see the relationship of the structure. Otherwise, we have not done many 3D so far. (E03DE)	they can understand what you are talking about. (A01PG) Using any kind of 3D reduces the time needed for clients to understand a design, and to communicate an idea. Although 3D takes time to do, the ultimate result is better. (A03RA) Yes, it is good for complicated design. (A02PN) However, for a new project, we need a 3D model to show clients that what they can expect from the design. (A05MS) DT: It is worth it. I use a 3D camera from Microsoft to capture images and transfer them to 3D virtual reality. Seeing these images helps the design. If I use other 3D software, I can't see that same effect that 3D virtual offers. (A07DT)	of reducing use of paper, as planners, we try to hold on to the important materials to have actual plans and use A1 sheets in the office, or A3 to go out on site. (P04DI)	

Benefits	Engineers	Architects	Planners	Clients
		Holograms need the right set up for viewing with a light source and a room. (A09CO) However, VR is not completely useful because clients like to touch the physical model. However, VR is helpful for project partners such as engineers and consultants. Perhaps they can understand graphics, but it is not helpful for clients. (A04PA)		
Solving logistical problems	3D rendering is the most important for the client. Animation is important for projects such as an airport, to show logistics, i.e. flowing of people or luggage. We do not use 3D for building regulations. (E01MT)			
Realistic simulation			The more realistic, the better. (P01SA) Yes, the perception that a councillor or politician, or a member of public, have. Unless it is photorealistic. (P01SA)	We are currently using the basic graphics programmes for working, i.e. AutoCAD, Photoshop, 3Ds Max, SketchUp; so far so good. We can clearly express our design intent to our management by using the

Benefits	Engineers	Architects	Planners	Clients
			We have to have drawings, and for a new building we might want to see photorealistic images. A kind of presentation that helps people (not professional) to understand the proposal; physical models with perspective, and now photorealistic images. (P02 AR) The best image is entirely dependent on what information is being conveyed. Photorealistic images are useful, providing they are accurate. (P03LJ)	programmes mentioned. (C03NA)
Good for urban purposes			It could be a useful tool for large scale masterplans, but may be too much work for the smaller scale applications. (P03LJ) We required various scale drawings of townscape, large-scale elevation, photographic images from different views on site and matching up with models (design proposal) to see what impact they have on the environment. (P01SA)	

Benefits	Engineers	Architects	Planners	Clients
Providing reference and enabling easy reviewing	We're also using 3D for structural analysis for when we are looking at a particular building. (E02MR)	GitHub enables us to share what we have done in each revision. (A07DT)	Quite often we are presented with such images and when compared with the actual proposals (on plans and elevations), they are not accurate, so can sometimes be counterproductive in that they are not representing the actual scheme. (P03LJ)	Showing the presentation on the project is fine, but having an image on your phone means you can go back and look easily at it. (C01AD)

<u>Data analysis</u> – problems

Problems	Engineers	Architects	Planners	Clients
Translated information from 3D to 2D	Yes, the problems concern transferring files. (E01MT)	Using 3D for common projects becomes troublesome. For example, we have to submit in the old style by producing sheets, so we have to clean up from 3D to 2D which means doing double the work. I have to say, 3D presentation tools are good for study and for internal communication. I have not heard anyone say that BIM is perfect. But they said finally we have to go back to the old style. This is my personal comment. (A02PN)		

Problems	Engineers	Architects	Planners	Clients
File transfer	Yes, the problems are about transferring files, which is time consuming. (E01MT)	Second, it is a problem when we work in a team; for instance, I work on 2D floor plans while someone else works on 3D floor plans. Ideally, there is a common tool set called work set that synchronises together. In reality, someone might be working on the lift core and another could make changes to that core. The software has asked for synchronisation; therefore, we have to categorise types of model all the time. It has to be planned quite a lot. Third, when we work on AutoCAD or MicroStation, we work on 2D and use it to produce 3D. It is different from Revit. (A04PA)	Also, the council does not always have the greatest IT equipment and there is disparity between the quality of the equipment that the design industries are working on, and the computer that we use. It is not capable and it is difficult to get some of the information from the same particular software (most CAD work needs to be transferred to .pdf). (P04DI)	
Inconsistency between images	Problems with expectations in resolving issues… when an architect presents rendering 3D images to the client to show what they should expect from the building, they would think [client] that the problem is already solved. However, as a designer, you know deep down inside that it is not		Inconsistency plus detailed elevation with shadow to show where the reveal and depth of the building. If the area of shadow is too big, detail will hardly be seen. (P04SA)	

Problems	Engineers	Architects	Planners	Clients
	finished yet and there are processes with a lot of work to do to achieve what has just been presented to the client. So, this is a challenge for both engineers and architects. (E02MR)		Inconsistency between images can be a problem. (P03LJ)	
Misunderstanding due to shadow on flat elevation			Inconsistency plus detailed elevation with shadow to show where the reveal and depth of the building. If the area of shadow is too big, detail will hardly be seen. (P01SA)	Sometimes architects can put too much information on the drawings that, from my point of view, can cluster and the client can find it hard to understand. (C02SK)
Inaccuracy		When we change to 3D, we don't always know what has been changed on the 2D drawings. (A04PA)	You might not get an actual building of what you are looking at; it might be more of an artist's impression than an accurate drawing. (P01SA) To make the building lower than it is. (P02AR) The wide angle of the image is often distorted so that is an issue. (P02AR) Quite often we are presented with such images and when compared with the actual proposals (on plans and elevations), they are not accurate, so can sometimes	When they show it will fit in the drawing, but it is not working in reality; it is important to be clear that the plans are workable. (C02SK)

Problems	Engineers	Architects	Planners	Clients
			be counterproductive in that they are not representing the actual scheme. (P03LJ) What can be a problem is accuracy as there is too much artistic licence. This is not a serious problem, but it is something that planning officers need to be aware of when they are making a decision. (P04DI)	
Time consuming		Time consuming, yes. (A09CO) Although 3D takes time to do, the ultimate result is better. (A03RA) Yes, much too time consuming, especially using BIM in developing the design stage. We use Rhino for beautiful results, but this is not the answer for a practical purpose. (A02PN) Too time consuming (A05MS) Yeah, talking about my experience in the past, the problem is having the right		

Problems	Engineers	Architects	Planners	Clients
		materials; presentation was not clear and it's time consuming. (A06ED) Model review can be slow and laborious but do provide flexibility in what to view. (A09CO)		
Client could not understand 2D drawings		In my case, the important issue is that the client can't understand, as it is a tool for design rather than presentation. Rhino is a tool that we use for working and presenting. Clients see different views from us as we print views from the presentation view, which is a different view from the working file. (A07DT)		
Difficulties in accessibility			There is often the issue that we don't have the same programme the same as architect, so we cannot view them. If they have programmes that we can change and allow us to see buildings from different view points, that could be helpful. (P02AR) Also, the council does not always have the greatest IT	

Problems	Engineers	Architects	Planners	Clients
			equipment and there is disparity between the quality of the equipment that the design industry is working on, and the computer that we use. It is not capable and it is difficult to get some of the information from the same particular software (most CAD work needs to be transferred to .pdf). (P04DI)	
Too much detail and information			If the area of shadow is too big, detail will hardly be seen. (P01SA)	Sometimes architects can put too much information on the drawings that, from my point of view, it can cluster and the client can find it hard to understand. (C02SK)
Expensive to source		It is more than enough. In terms of tools it is fine but it is expensive. We have limited software. (A04PA) Mock-ups are good but time consuming and provided too late in design process. Cost is a factor in all, as the client can generally see these as an extra rather than part of the design process. (A09CO)		

Problems	Engineers	Architects	Planners	Clients
Opening media files	CAD is not user friendly and it takes a lot of time to understand what it can do. (E03DE)	Yes, we do sometimes use different versions Problems depends on programmes". (A10DO) With rendered images, the issues are with the file size file and reproduction quality. With animations, the problem is the viewing method, and the extensive time taken to agree the animation route and what needs to be shown. (A09CO) A lot of the time, clients don't have a licence. They don't have programmes installed in their offices. So, there is a bit of introduction to Adobe pdf format, like the 3D version so you can export a 3D model to .pdf format. And I think anyone can open Acrobat Pro using the web browser. An alternative, would be if there was a format that helps the client to be able to have power to navigate the model interactively. That would help them immersively. They are not only interested to see	The planner cannot afford to have an iPad, etc. It is not only an issue of cost, but it is also a risk to have such an expensive device when working out and about. (P04DI)	They will prefer it in pdf. I do not think they have the software to view 2D CAD drawing on their system. (C02SK)

Problems	Engineers	Architects	Planners	Clients
		how the building will look at the final rendering but they would also be able to interact with the model, which will help them to understand the design, make quicker decisions quicker and have greater control over the design process. A lot of time, clients can't make a decision as there are usually too many options, or they can't understand and further development is required. If they had a 3D model to interact with, I think that would do. (A01PG)		
Over budget for 3D rendering				Sometimes the client can be steered toward a higher cost as long as there is a good reason in doing it. Sometimes the architect charges too much for 3D rendering, when we don't need it. (C02SK)
Disappointment with CG images		The biggest problem we encounter is clients actually having the same visual appreciation of what we envisage in our 3D and 3D CAD models. (A09CO)		

Problems	Engineers	Architects	Planners	Clients
Misunderstanding 2D drawing			The main problem we encounter within architectural presentation is our lack of understanding in flat elevation. It is difficult for planners to appreciate that you never view the building that way. So, although you can access the information of that building from the flat elevation, planners must be informed that in real life it would never be seen in those terms. So, I find it is a very difficult mind switch to make! (P01SA)	Sometimes architects can put too much information on the drawings that, from my point of view, it can cluster and the client can find it hard to understand. (C02SK)
Misunderstanding bird's eye views		If we present the view that is not the human eye view, most of the clients would not understand. However, it still enables them to understand the concept and colour scheme. I would say human eye view is the most understandable. (A08AW)		
Different view points			Sometimes they do not choose the right view point of the building. They are often too close to the building to allow you to see everything you want to see, particularly massing of it, the roof for example. We are very	

Problems	Engineers	Architects	Planners	Clients
			concerned about the height; sometimes it deliberately shows that the building is not as big as it actually is, so we often discuss where the view position should be taken from. We would sometimes agree with architect what views we want to see from a map. (P02AR)	

<u>Data analysis</u> – suggestions

Suggestions	Engineers	Architects	Planners	Clients
Sharing information	It is very rare that you find that people come to see us to see calculations, for example. However, for a very good project [sharing information] does happen and involves a lot of specialists; the bigger project, the more services you provide. There is an in-house knowledge share when needed. (E02MR)	Sometimes, I can remember, we took a laptop and SketchUp file for a client meeting to do a navigation. So, if we have a project meeting far from the office... You have to allow for time travelled and the cost of the ticket (A01PG) There are systems, both manual and applications such	Subject to all the things that I already said, I can see the benefit of all that but in reality, it's not going to happen if the council have to pay for it. If the services provided by the applicants or architects are additional to what we already have, something that has set up in the architectural office, the planner can go and see this. This is potentially something	I think the more chance people have to talk about the construction and design process, the more likely you will get what you want. (C01AD) We currently use interactive media in our own corporation, i.e. between our business unit and other units, and found that it is useful and

Suggestions	Engineers	Architects	Planners	Clients
		as Newforma, used for sending files. (A10DO) I code on my own. Each person is an expert in different computer languages, and one is an expert on front end design, one is an expert on back-end design. If the project involves many people, communication is important. (A10DO)	that can be very helpful. (P04DI)	makes communication more efficient. (C03NA)
Interactive viewpoint changing	It would be very helpful. Websites like Rightmove are interesting. It would be nice if we could see 3D and 2D on the web. It's good to see that the room is changed when we press a button. (E01MT)	Walk-through has been developed and we can produce this more easily than before. (A10DO)	Yes, it is very helpful; we often have only a drawing and a static image – we never have fly-through 3D visual. (P02AR) If they have programme that we can change and see building from different view point that could be helpful. (P02AR)	Basically, all of it. The architectural drawings do not show the end user what it looks like. But you start with a physical model or 3D model. Yes, it actually demonstrates how the building feels. A digital walk-through would be recommended. (C01AD)
Carrying digital tools to replace physical tools		Using an iPad remotely is good, when it can hold a lot of information within one device (A03RA)		
Digital media can connect to drawing		Yes, for internal or design team, I include architects and engineers. For planning, I call planning external	I still think it is best to see the overall composition through drawings. 3D fly-through virtual reality is only used for	

Suggestions	Engineers	Architects	Planners	Clients
		communication – we submit 3D rendering, visualisation, elevations, sections and layout plans. For the engineer, we do not deliver in much detail; space and massing are necessary but we do not specify material. (A02PN) Ok, before we send out to tender, it is a presentation process, starting with a concept of the design. We use SketchUp and render by V-Ray in SketchUp. We work on SketchUp and then transfer to AutoCAD. (A08AW)	selling points, but there are still reservations about relying on that. When you come to the details of the drawing, you are still more traditional. At the moment, there is not a big appetite for it [3D video]. (P01SA) KM: Do you prefer to have a photorealistic 3D presentation? If so, why? DI: I like it as a part of a package but not on its own. (P04DI) Plans and elevation images are more important for the final decision, but often these will not give an accurate representation of a scheme in reality, so massing images and perspectives are an important part of an overall package. (P03LJ) The drawing forms the basis of the approval, not the images. When the building has been built, it must be according to the drawing. (P02AR)	

Suggestions	Engineers	Architects	Planners	Clients
			Images must be according to drawings. However, the drawing is the basis for us to use to make a decision. (P02AR)	
Showing isometric projection	We care more about how things integrate together: details, finishing and integration with the structure. Using 3D is crucial; we prefer isometric which shows better perception. We use it for details to include in the drawing, showing how it is built. (E01MT)			
Real-time communication	It would be nice if we could see 3D and 2D on the web. It's good to see that the room is changed when we press a button. (E01MT)			For me, real-time communication will overcome the problem. It was quite challenging because the XXX would start to send you the money, let's say every month. If you don't spend the money, they could throw out the funding. (C01AD)
Faster accessibility		If you can get the client to be able to navigate the model, then you can also have web-based meetings from your office, which would save time. And the main thing is to make the decision quicker. (A01PG) Standard design presentation documents and	I think we would need to do a lot to upgrade all the IT we have, in order to get any other kind of software and to install it. It is the infrastructure that needs to be improved (even Internet access is very slow). (P04DI)	

Suggestions	Engineers	Architects	Planners	Clients
		marketing documents (for past and previous projects) and starting with a presentation on an iPad bespoke book, etc. (A03RA) We present on a computer or by printing on paper, but at XXX we present a lot of models and show these on an iPad. Recently we have been using VR. We often use 3D printing. We also use animation. A web browser is very useful for client partners. For example, we can sketch on the iPad and show client. It is great if we move the mouse to reveal pop-ups to show design information. It is good for the client to help them understand better than explaining a drawing. (A04PA)		

Suggestions	Engineers	Architects	Planners	Clients
Easy to use and produce	Revit is something that we employ for people who know how to use it. It's not easy for everyone to use it. So for us, Revit is a tool for specialists. SketchUp helps us understand a little bit about the model. Some of us will have our own preference for software; for example, I use Bentley Structural to understand some complicated structures and how they come together. (E02MR)	There is an exponential scale regarding image quality to photorealistic images. We tend to stick with a basic format, which is quick. (A09CO) Yes, interactive media is very useful. In the future, websites will be a very important tool. (A02PN) No, it is a programme that anyone can use. It keeps emails, files and archives. However, it does not keep everything. It is similar to an email system. (A10DO)		
Friendly interface	CAD is not user friendly and it takes a lot of time to understand what it can do. (E03DE)	We use an easy animation, and no rendering. We set views and use moving views instead. It is not too complicated. (A08AW) Animation – they do a kind of basic form of SketchUp. Showing how they set up the scenes and move between the scenes, getting that transition, basically. It so much likes animation that		I am not an architect. I think if they do not have background, it will be difficult because they cannot compare what the drawing is. So as soon as you go to 3D or other models, walk-through will be good. (C01AD)

Suggestions	Engineers	Architects	Planners	Clients
		setting up to displays those views. (A01PG)		
Faster turnaround of design alteration		I am interested in communication, both inside and outside the office. GitHub enables us to share what we have done in each revision and it is helpful for users who are writing the same code. It also helps me develop the design. I can see what has been done chronologically. So, it can be used by the team and me. (A07DT)		
File converter	We often do it through the web and we often run them through to show the client the model. When everybody is using 3D, you can combine them all together and show them live in front of the client, demonstrating how everything fits together. (E02MR)	We use programmes that can be opened on the iPad, but we need to convert files for the iPad. It is not very handy; better to use a mouse to navigate. (A08AW) Sometimes we use different versions. (A10DO)		
Ease of progress tracking through a reference/archive		It is about files have not been updated. (A10DO) GitHub enables us to share what we have done in each revision. (A07DT)	Quite often we are presented with such images and when compared with the actual proposal (plans and elevations), they are not accurate, so it can sometimes be counter productive, in that they are	Showing the presentations on the project is fine, but having an image on your phone is useful, that you can go back to and look at easily. (C01AD)

Suggestions	Engineers	Architects	Planners	Clients
			not representing the actual scheme. (P03LJ)	
Combining physical and digital tools		We use 3D models. What we provide is a mock-up of thedesign; our work is not only to design the space, but also to experience it. So, it needs a physical mock-up as well as the real effect of users' interactions. The 3D model enables us to design but is not for selling a project. (A07DT) We use animations, rendered images, walk-through model reviews, rendered drawings, and we have also used printed holograms. We do still use physical models as well when required. We also undertake full-size mock-ups of offshore cabin accommodation. (A09CO)		There was an animated project. They brought with them the real material fabric, stone, countertops.… There was a 2D drawing of what it would look like. We liked all of it. The architect drawing does not show the end user what it looks like, but once you start seeing the physical model or 3D modelling… I think for a big project, the more representation of the project, the better. (C01AD)
Deliver real-time cost information				Cost is always a consideration; I would say as often as 99.9% of the time, the client would say it is money!! (C02SK)
Produce more images from human eye view				I think if you have an electronic walk around that

Suggestions	Engineers	Architects	Planners	Clients
				would be helpful. But what they had was good. (C01AD) Drawing is definitely what I am used to. I think for impact, certainly 3D graphics that I have seen are great for me, perhaps because I am a little bit more technological. In the view of the building surveyor or architect, it is important to be able to see the building in 3D view. (C02SK)

Examples of feedback after participants trials of the mock-up

E01MT

Feedback questions

1) What do you think about the IDCM system? Do you find it easy to navigate?
…It seems easy to use, but my concern is that, being a web-based platform, how it would perform with large data sets.
……

2) Is something missing? Do you want to add any other functions?
   - Maybe enabling the architect to make quick changes such as change of cladding, texture or perhaps adding a wall, window, door etc.
   - Taking measurements.

……..

3) Do you think the IDCM includes enough standard architectural information? If not, what information, architectural presentations or data do you want to add?
   - Not sure about the benefit of this to the contractor or the engineer; other visual representation.
   - Could capture walk-through or a video clip.
   - Could change the lighting effect from day time to night time.
   - Site plan.

……

4) What do you think about the visual appearance/functionality of IDCM system?
……Appearance is good because it is simple, uses familiar icons and functions as other software.
……

5) Do you have any other comments?
   - Not clear about what distinguishes this platform from other widely available platforms such as Adobe 3D, Navisworks.
   - Control of the data might be tricky as it is not linked to a BIM model, or is it?
   - Instead of just adding comments, it would be useful to make changes on the spot.

- Is this mainly as a communication tool based on visual representation or more?
- Is it being used as a data gathering platform or more?
- Who controls the data and how is it kept up to date? It will need stick control. Who from the design team will perform this task? It may need a dedicated resource on a large project.
- Can you use extracts to attach to PowerPoint presentations, documents etc.

Thank you for your contribution
Krisanee Meechao
Research student
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A03RA

Feedback questions

1) What do you think about the IDCM system? Do you find it easy to navigate?

   …*Very clear and easy to navigate. Easy to use interface with interactive and useful video shown beforehand.*
   The ability to combine all different specialists together in one database could definitely benefit project.

2) Is something missing? Do you want to add any other functions?

   …*Ability to move inside the building could be easier; could use a shortcut on the 2D plan for example. Ability to manipulate/use the 3D model more to present the building, taking section cuts, etc., to present the building more could help.*

3) Do you think the IDCM includes enough standard architectural information? If not, what information, architectural presentations or data do you want to add?

   …*It includes a whole range of information; is a good sharing facility for design team members.*
   The ability for information to interact with the model rather than stand alone when uploaded could help.

4) What do you think about the visual appearance functionality of IDCM system?
   … *Good security with log in features. Clear user interface ensuring each consultant knows where information is. Ability to see around the model is very good/useful.*

5) Do you have any other comments?

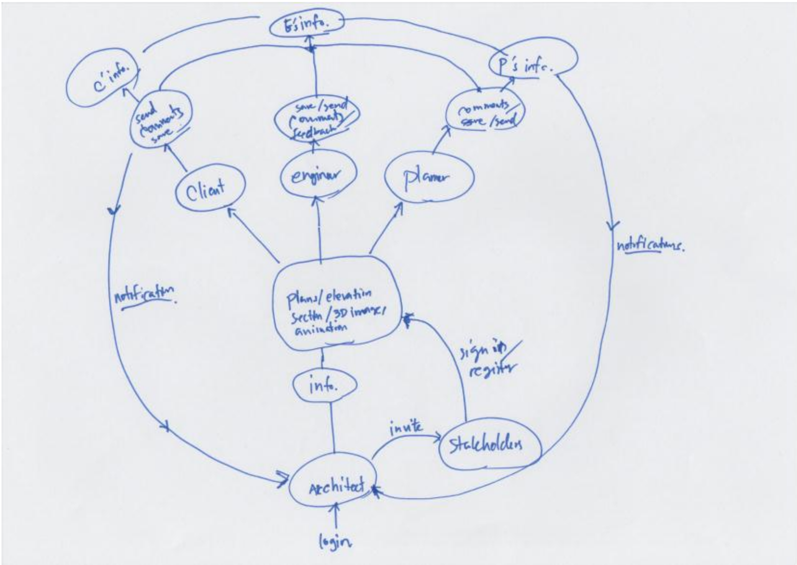
   … *Programme can save time/errors with the design process by planning and client and concise manner of communication by the design team.*
   The programme will mean less <u>reliable</u> on email to issue information which is unreliable/writing. The programme is a cross between BIM and 4Projects……………………………………………………………………………………………………

Thank you for your contribution
Krisanee Meechao
Research student

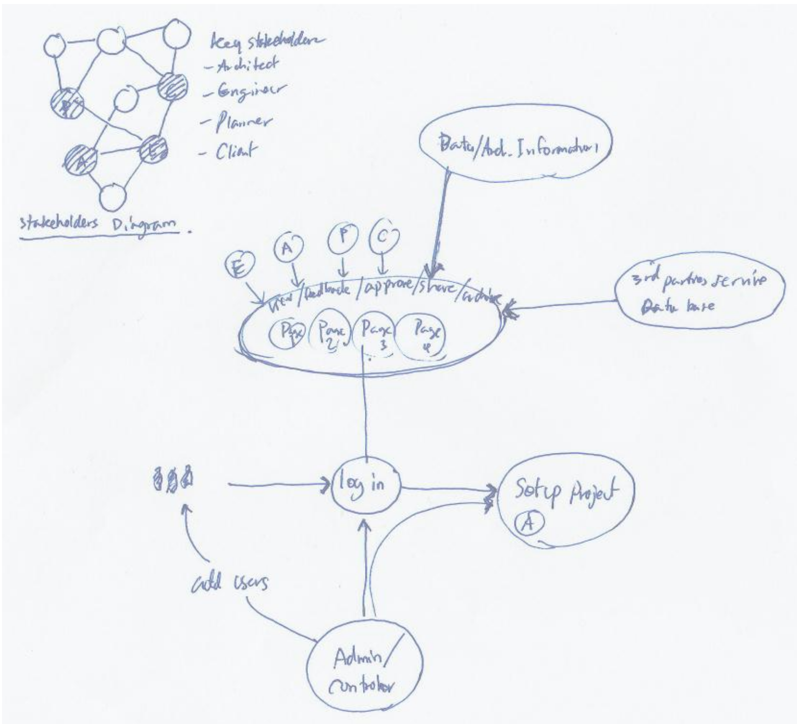
Appendix E: The IDCM system and the mock-up design

(additional images)

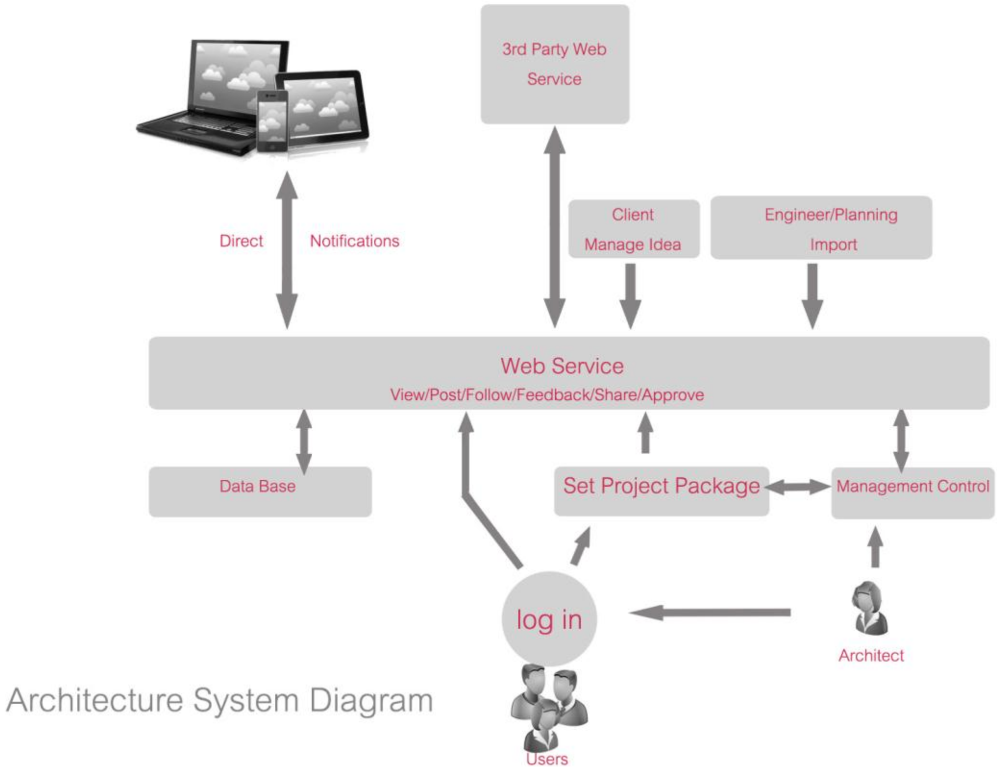
The IDCM system design (additional and enlarged images from Chapter 5)



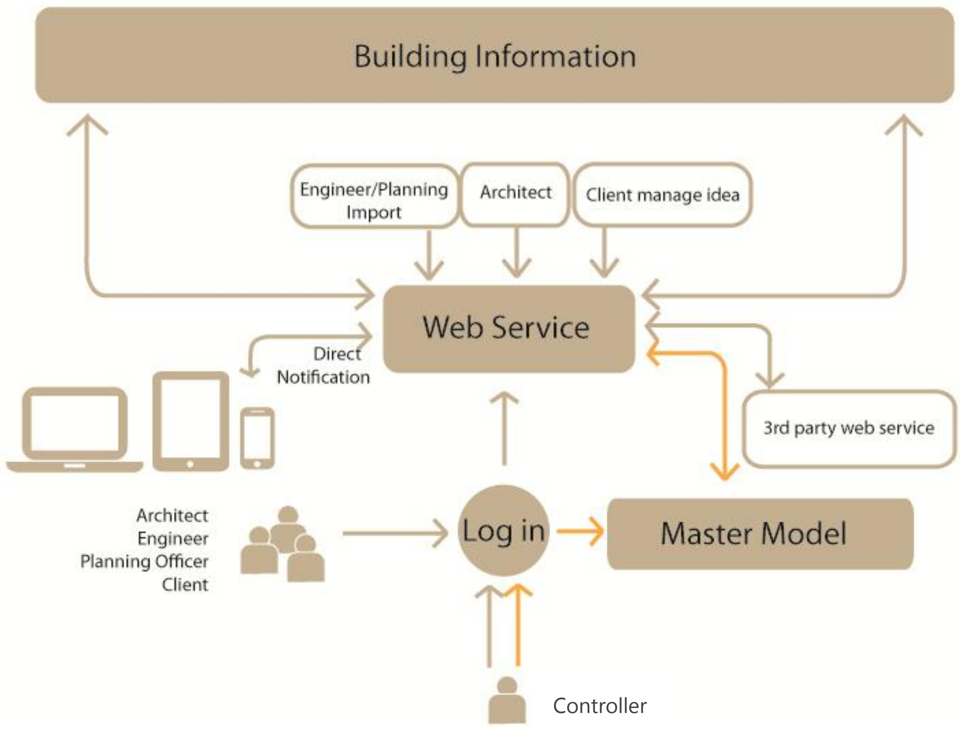
The sketch enlarged from Figure 5.3



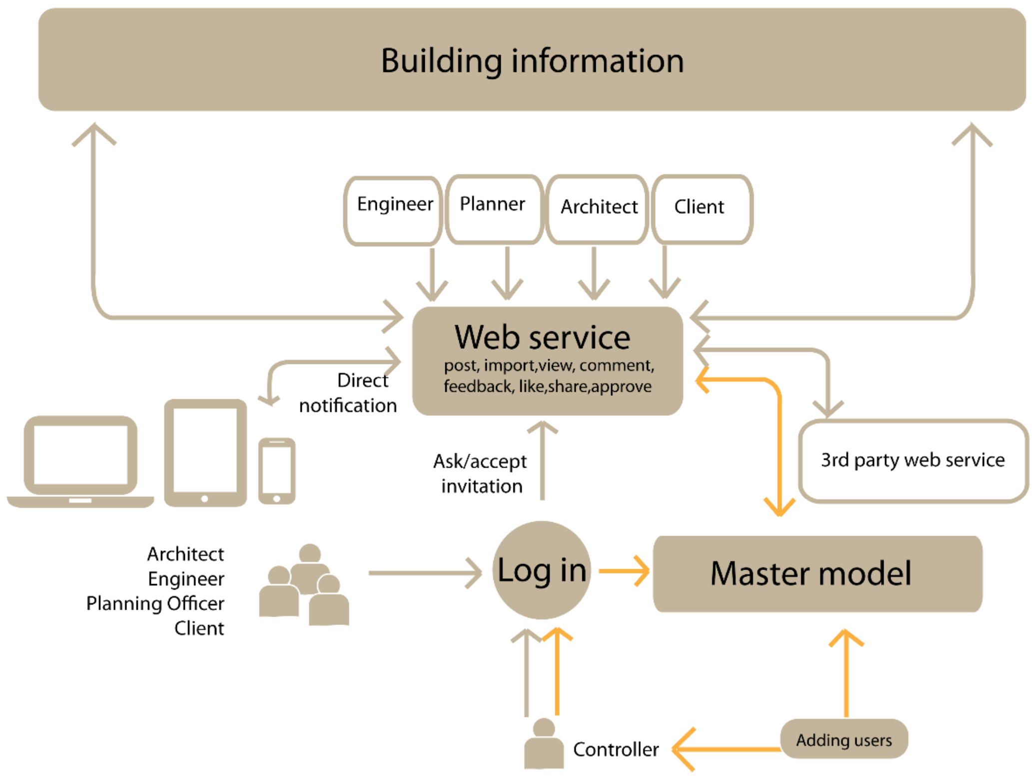
The sketch enlarged from Figure 5.3



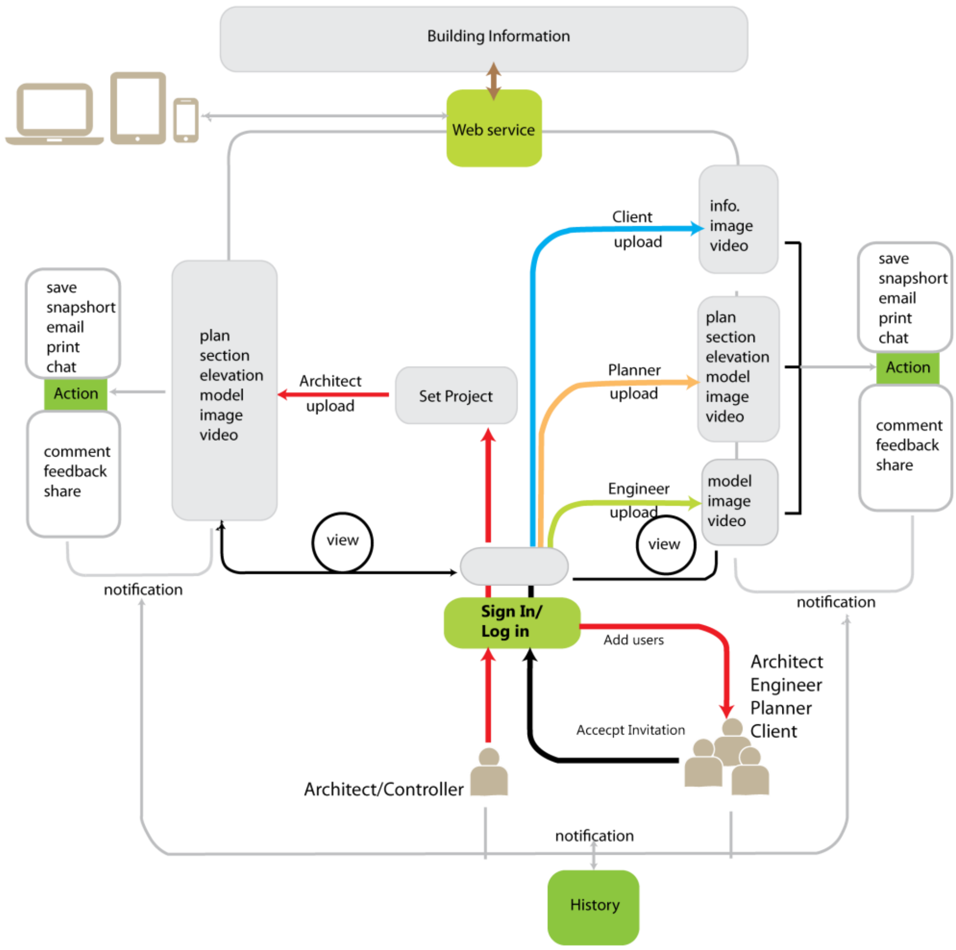
Initial representation of the system diagram



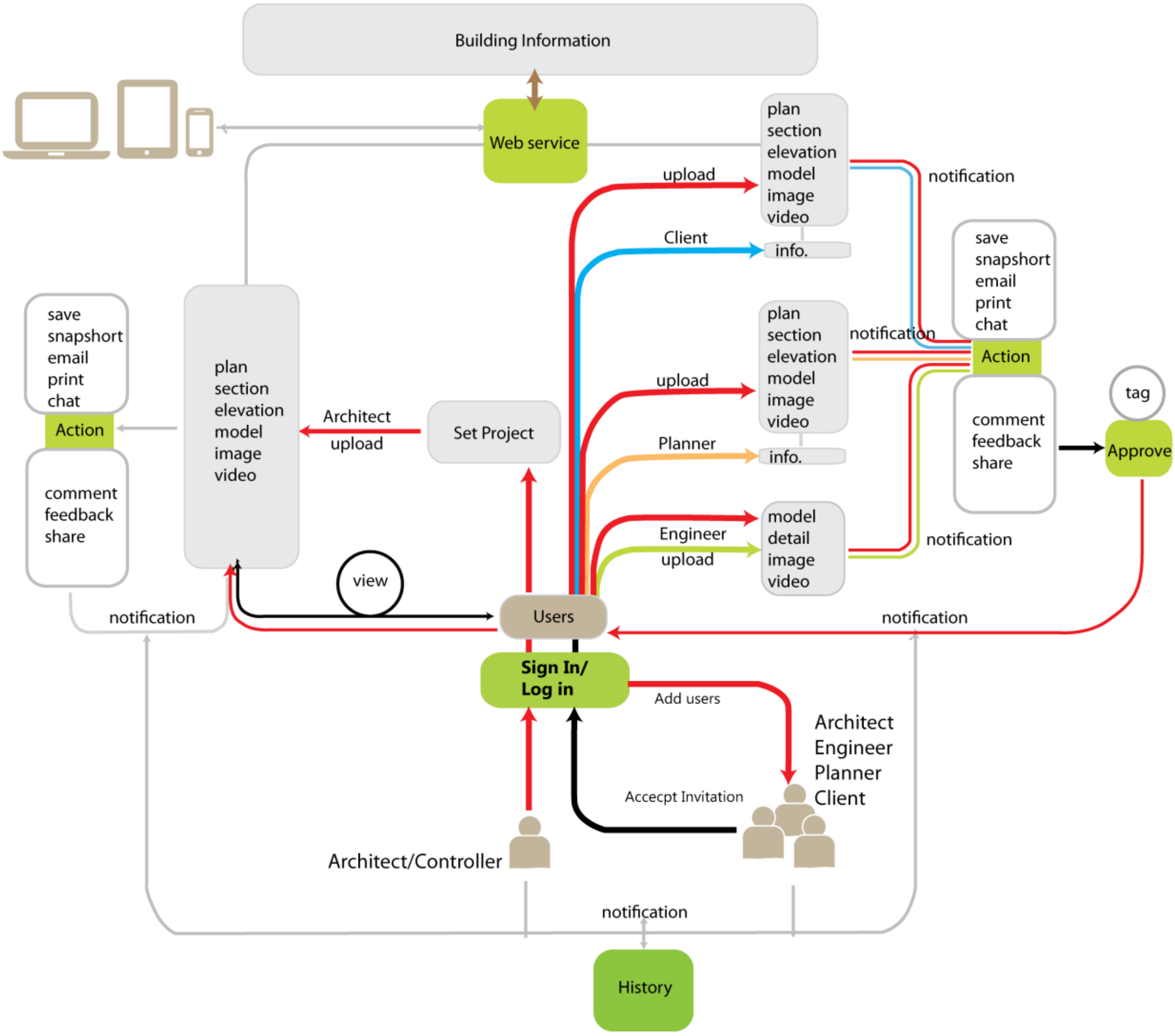
Schematic design of the system diagram, enlarged from Figure 5.3



Schematic design of the system diagram, enlarged from Figure 5.3

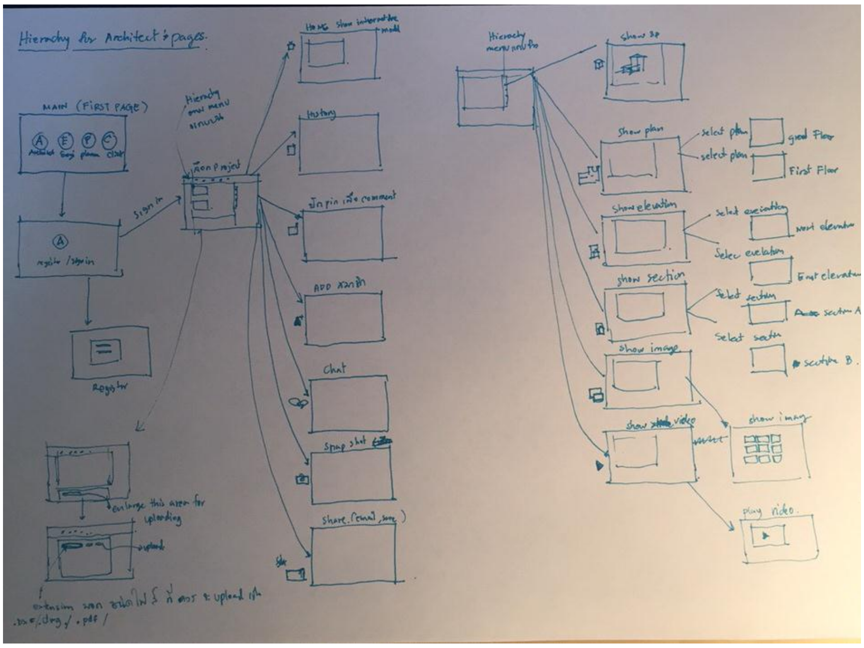


Schematic design of the system diagram, enlarged from Figure 5.3

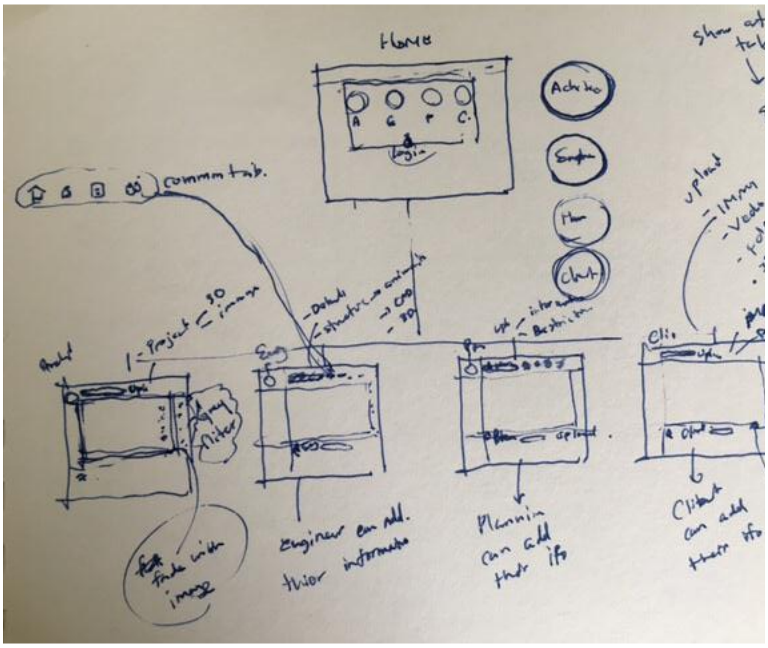


Schematic design of the system diagram, enlarged from Figure 5.3

The mock-up design (additional and enlarged images from Chapter 5)



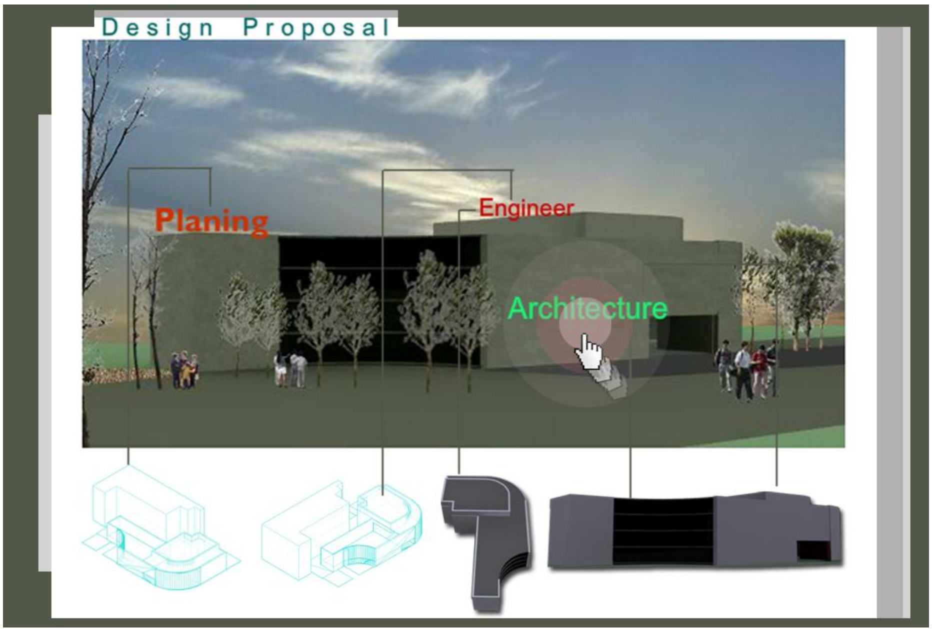
The sketch of hierarchical pages



The sketch of information on each page, together with functions

Schematic design 01

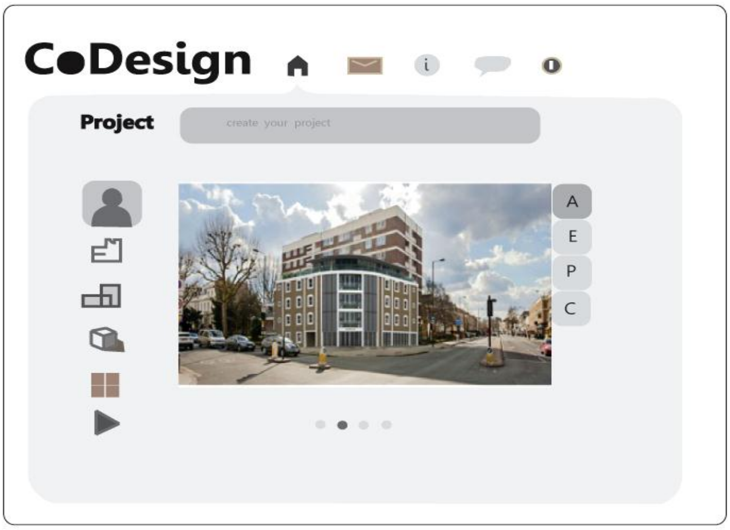
For the trial of the interactive media of this initial design (files available on DVD).



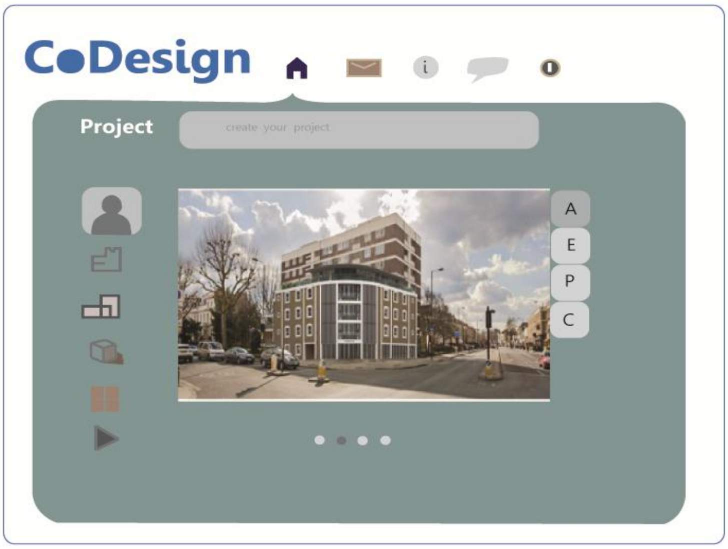
Early stage of interactive media design, enlarged from Figure 5.5

Early stage of interactive media design

Schematic design 02



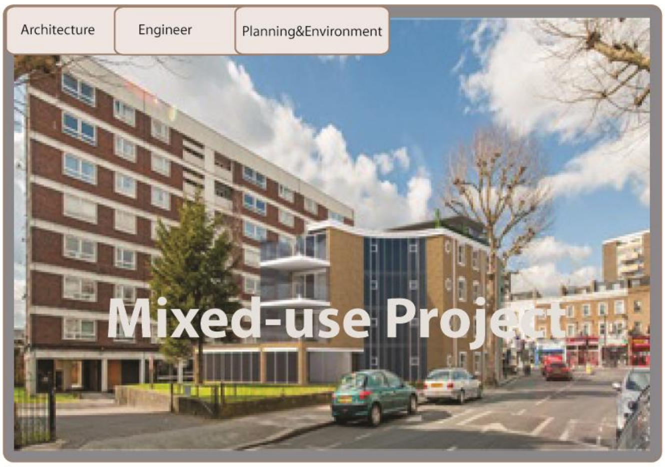
Early stage of user interface design, enlarged from Figure 5.3



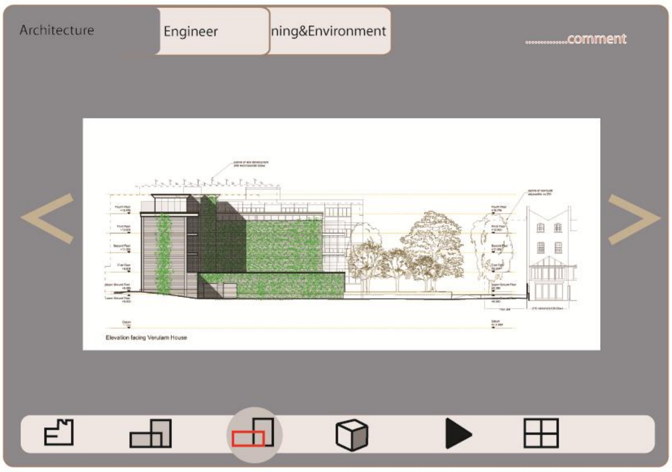
Early stage of user interface design (colour selection), enlarged from Figure 5.3

Schematic design 03

Design stage of user interface design (information management), enlarged from Figure 5.3



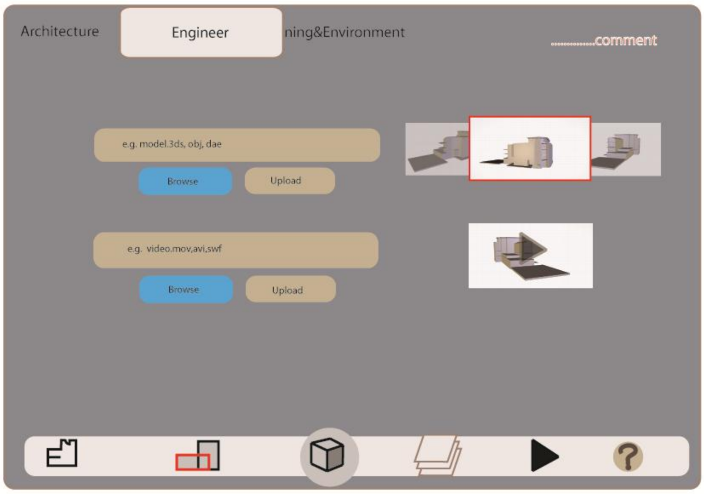
The design of the home page



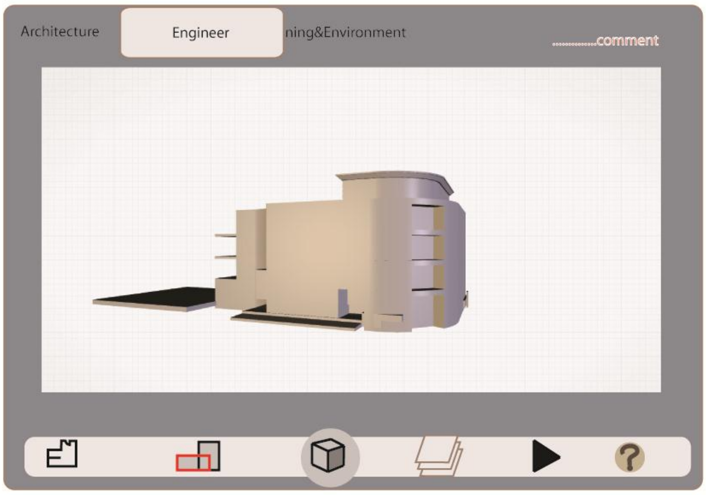
Design stage of display of design information

Design stage of user interface design (information management)

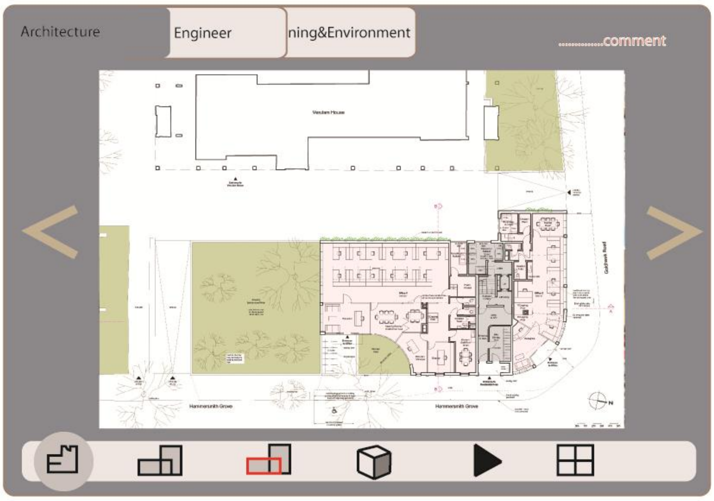
Schematic design 03



Uploaded file function design



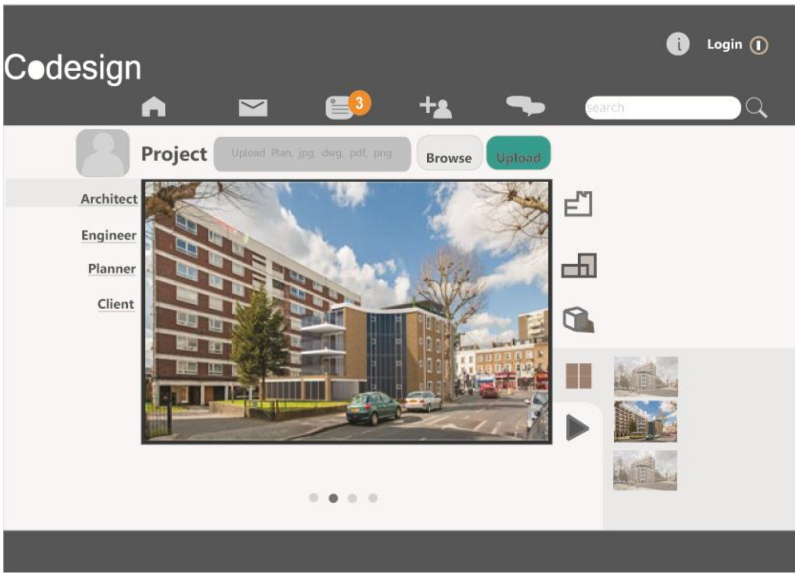
Design stage of user interface design with 3D model display



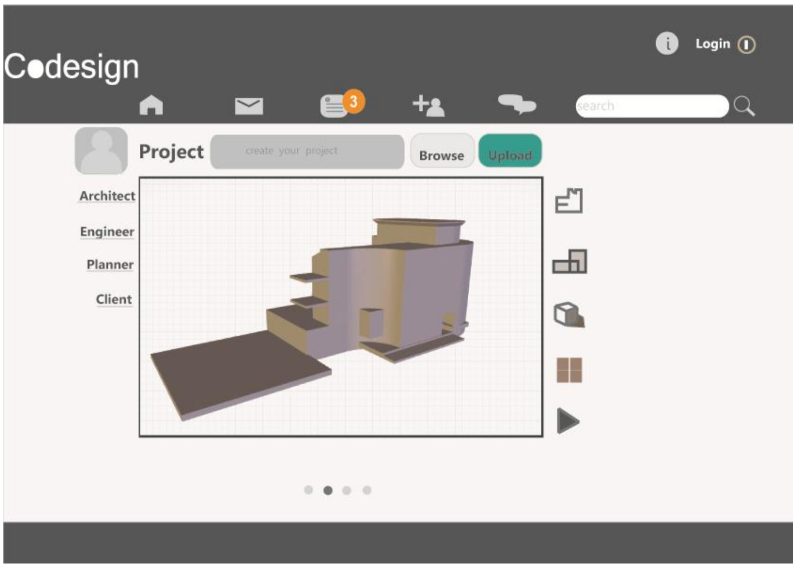
Design stage of display of architectural presentation

Schematic design 04

Interface design development – this design was used to test the interactive system (trial available on DVD).

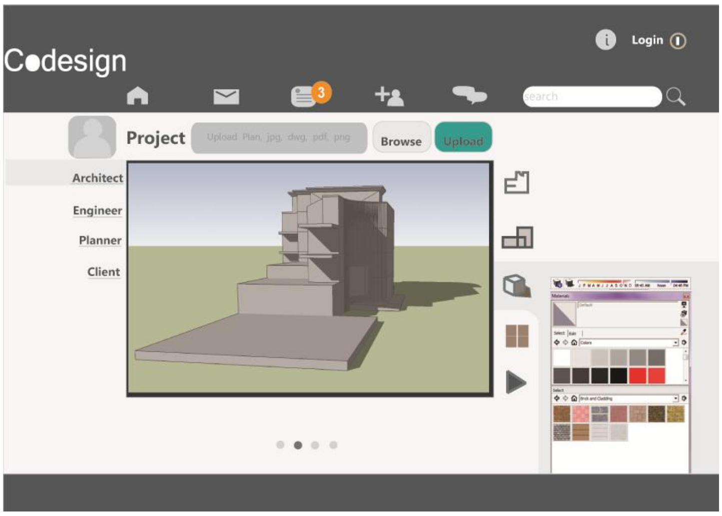


Design of architectural presentation selection

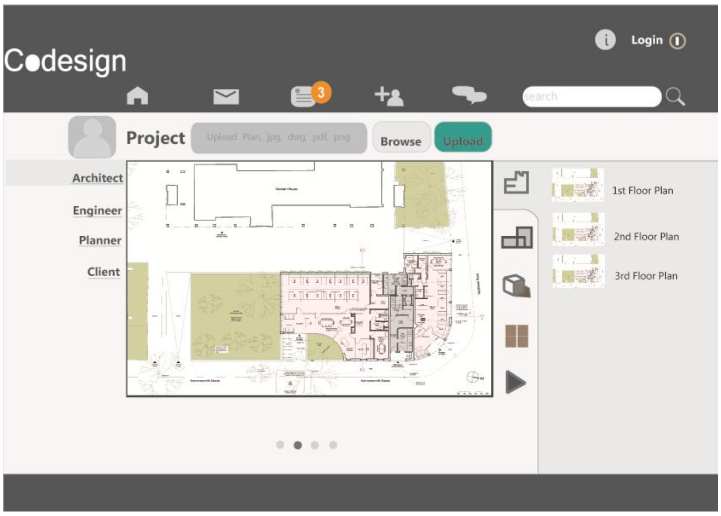


User interface design and icon design

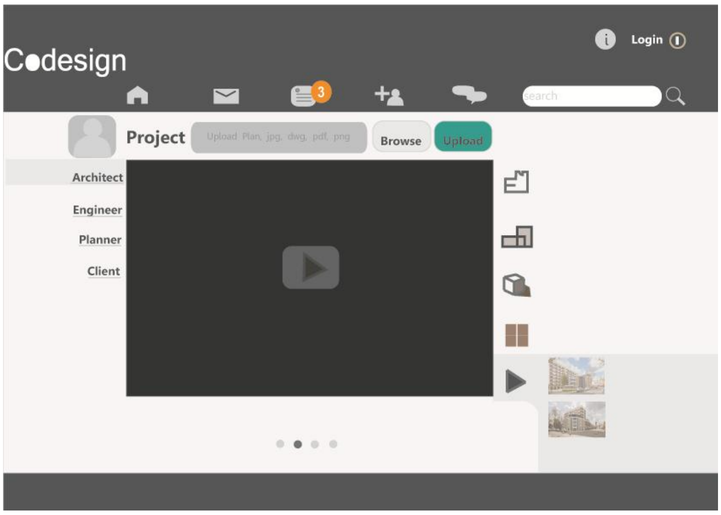
Schematic design 04



Presentation of the mock-up usability

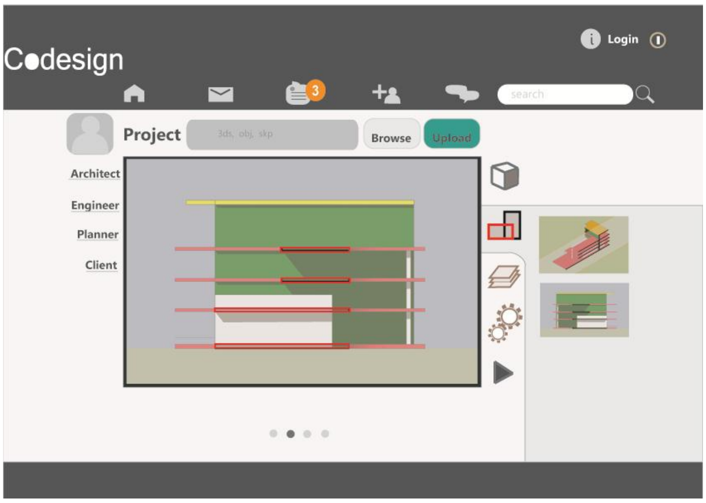


Design of data management

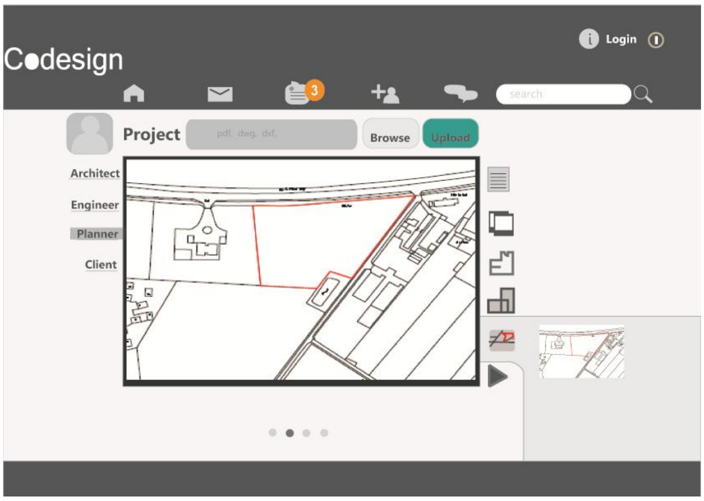


Multimedia included

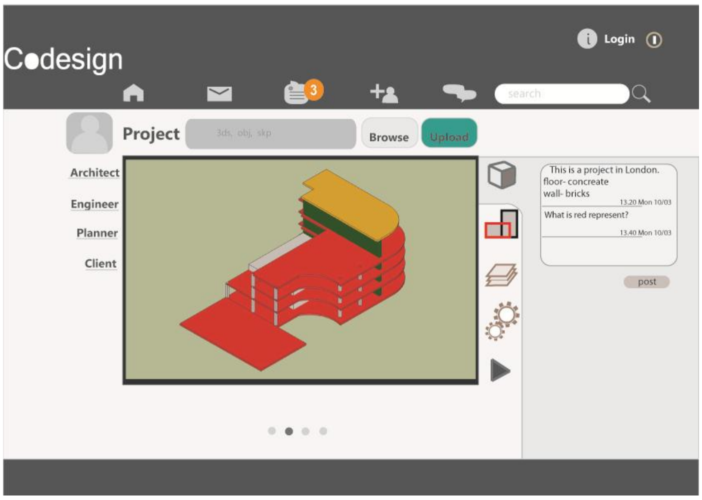
Schematic design 04



Data management, presentation of sections included



Data management, presentation of layout plan included



Data management, presentation of structured model included

Schematic design 05

Interface design development – this design was used to test the interactive system (trial available on DVD).

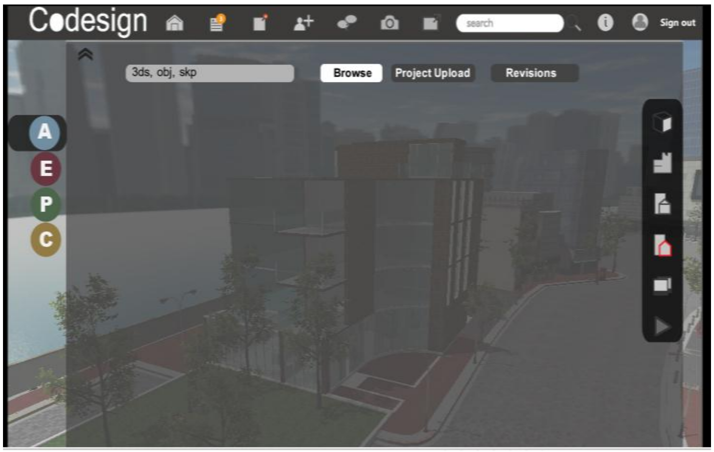
Home page design

User registration system design

User details required

Schematic design 05

Project selection, showing projects that each stakeholder is involved in

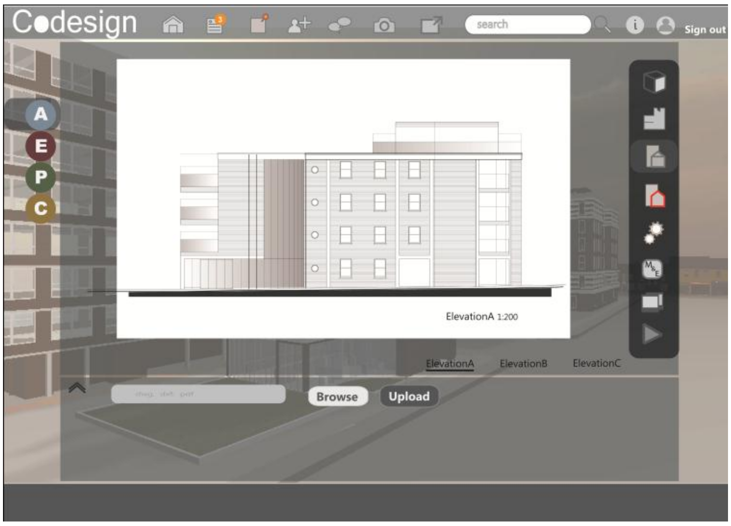


Upload function – users can upload their information by browsing files in the provided area

Showing plans on the architect's page

Schematic design 05

Showing sections on the architect's page



Showing elevations on the architect's page

Client 'sign in' page

Schematic design 05

'Invitation' function – people can be invited via third parties or email

'Notifications' function archives actions – stakeholders are invited, give feedback on the system

'Feedback' function is designed for stakeholders to give feedback

Schematic design 05

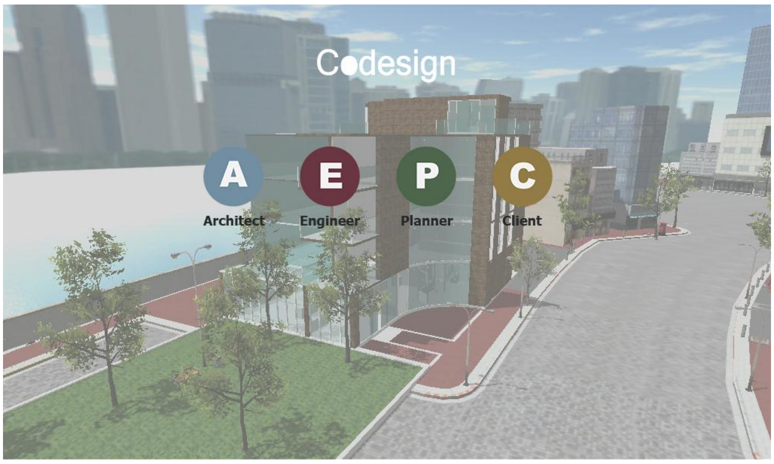
The function shows which online stakeholders online and available to chat

Revisions can be selected to track through previous designs

Stakeholders can upload their information by browsing from their computer

The mock-up of Co-design

Example images from the mock-up. The trial mock-up is available on DVD (Co-design mock-up).



The first page of the mock-up

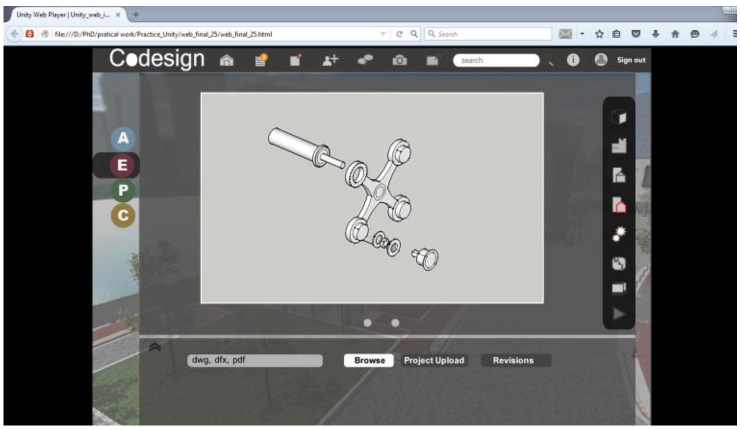
Registration page of the mock-up

Function to give feedback is displayed

The mock-up of Co-Design

Function to give feedback is displayed

Previous design revisions can be tracked



Engineers (stakeholders) can input their information

Appendix F: Instructions for opening the digital media

To open the video demo

i) The video can open on normal video display applications, for example Windows Media Player, QuickTime, etc.
The link below includes the video demo file that can be downloaded at:
https://www.dropbox.com/s/4aj9bz8recf4fbq/Video%20demo.avi?dl=0
The link will bring you to the Dropbox site. You can sign in or register to go to the page. If you do not want to sign in or sign up just click on 'no thanks, I do not want to register' at the bottom of the small window pop up.

To open the mock-up

i) Opening the mock-up requires Unity Web Player to be installed. Click on the link to install: https://unity3d.com/webplayer

ii) Install Unity Web Player for **Windows**. This will play on Internet Explorer, Firefox, Safari, Opera (Firefox is recommended).

Requirements
Windows XP/Vista/7/8/10

iii) Install Unity Web Player for **Mac OS X** to play on Safari, Firefox.

Requirements
Mac OS X 10.7 or newer

iv) Internet link required for viewing the mock-up.

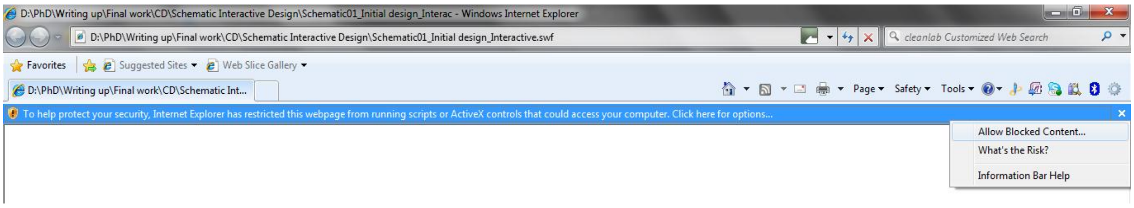
The link below includes the mock-up file that can be downloaded at:
https://www.dropbox.com/s/3041buux08u9u8z/Co-designMockup.html?dl=0

The link will bring you to the Dropbox site. You can sign in or register to go to the page. If you do not want to sign in or sign up just click on 'no thanks, I do not want to register' at the bottom of the small window pop up.

Alternatively, use the files in the DVD attached to this research

To open interactive media files

Internet Explorer is recommended. The pop up message will be shown. Please click to allow blocked content.



Appendix G: Copy of publication

Emerging Experiences in the past, present and future of digital architecture

Proceedings of the 20th International Conference on Computer-Aided Architectural Design Research in Asia (CAADRIA) 2015, May20–23, Kyungpook National University, Daegu, Republic of Korea