Digital Re-analysis of Lost or Unbuilt Architecture

Thesis submitted in accordance with the requirements of the University of Liverpool for the degree of Doctor in Philosophy by:

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To my Grandparents

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Abstract

Digital Re-analysis of Lost or Unbuilt Works of Architecture

Nicholas James Webb

The research presented here utilises contemporary digital techniques enabling a consistent analytical technique to systematically study significant works of unbuilt, damaged and destroyed architecture. The analytical technique provides a methodology that can be utilised for future research employing digital tools in the context of investigating historic works of architecture.

Digital representation tools are therefore used to re-analyse and re-interpret unbuilt, damaged and destroyed works of architecture. This augments research already undertaken by architectural historians, who provide traditional critique and analysis, by testing such studies further using a range of contemporary digital techniques.

The research is significant as it demonstrates how contemporary representation techniques can advance knowledge and understanding of significant architectural designs that once existed, or could have once existed. Consequently, this enhanced understanding can then be used to add to knowledge already attained about a particular architect and buildings they designed.

Three case studies by important twentieth century architects were used to demonstrate and advance the methodological process provided. These were an unbuilt student project by Sir James Stirling, a pair of unbuilt museum projects by Auguste Perret, and a partially built cathedral design by Sir Edwin Lutyens. Each case offered its own benefits in researching the analytical technique.

The Stirling case study enabled the techniques and principles of the methodological process to be established and demonstrated that it could provide enhanced understanding of an architect's work. The Perret case study was important in finding unexpected results as part of the digital representation construction process, which enabled the methodology to be revised to take into account the significance of serendipity in the research. The Lutyens case study was particularly successful in developing lines of enquiry through looking at primary and secondary source data available for a design, which could then be used to re-analyse and enhance understanding of the design using digitally augmented techniques.

The findings offer enhanced understanding of using digital tools as a technique to study unbuilt, damaged and destroyed works of architecture. In the first instance they demonstrate the significance of the process of constructing digital representations of such architectural artefacts. During this process inferences have to be made as representational source data such as architectural drawings are almost always incomplete, therefore parallel study into the architect, their architecture and the contemporary context they worked within has to be investigated in order to fill in gaps in an informed way. It is during this investigative process that enhanced critical understanding of an architect and their architecture is achieved.

The findings also illustrate how contemporary digital tools can be used to augment and enhance knowledge of unbuilt, damaged or destroyed works of architecture by following particular lines of enquiry generated through the study of primary and secondary source data. The key here is the advanced knowledge that digital techniques bring when compared against critique of a work of architecture that was established in a pre-digital context.

1 Introduction

In architecture, mediating devices are an essential tool for describing a design, enabling ideas to be translated into a finished building. Unlike other disciplines in the arts, the use of representation techniques such as scale drawings, three-dimensional models and perspective images, are crucial. This is because, in the vast majority of cases, it is unfeasible to make full-scale physical prototypes of works of architecture.

Such mediating devices have developed into the digital realm with the widespread introduction of computer aided architectural drafting and design from the 1980s onwards. Since this, the process of constructing digital representations of architectural designs has become increasingly complex, offering the potential to be exploited as analysis tools in a research context (Brown and Knight 1995).

In many situations, works of architecture remain unbuilt, or were never intended to be built. Also, they may have been constructed and subsequently damaged or destroyed. In such cases representation documents may still remain, offering an insight into what once was, or what could have been.

Beyond their use as a tool for architects to construct predictions of schemes that are yet to be built, digital representation techniques began to be used to visualise damaged, destroyed or unbuilt works of architecture as well as remote archaeological remains (Mitchell 1992a, Forte and Siliotti 1997, Novitski 1998, Maver and Petric 1999). Such investigation has enabled the findings of archaeologists and architectural historians access to a much wider audience, producing enhanced spatial understanding of what these buildings and objects would have looked like.

As a visualisation tool, digital modelling has become invaluable as part of this process. However, the use of such techniques in the context of damaged, destroyed or unbuilt architecture is underexploited as an analysis tool. The research presented here addresses how methods can be introduced to enhance critique of such works of architecture.

1.1 Research value

In the last thirty five years a growing interest in lost designs has become prevalent in architecture, whether they be built and destroyed or not built at all (Sky and Stone 1983, Stamp 2007). This timing coincides with the profession moving away from the Modernist agenda looking more towards ‘what we formerly destroyed or ignored for what it can contribute to the future’ (Sowa 2005). The representation material left behind to study such designs vary from archaeological remains, remnants of buildings that have been altered or added to, photographs and other images of destroyed buildings, as well as architectural drawings and models. Digital techniques can be used to re-analyse and re-interpret surviving mediating documents of such architectural artefacts; previous research has shown that this process can uncover new information and enhanced understanding in relation to particular architects and buildings that they designed (Richens and Herdt 2009, Mark 2011).

When investigating unbuilt, damaged or destroyed works of architecture, the information available to construct digital representations of them is almost always incomplete. Therefore interpretation of material requires parallel study into the architect or designer, their influences and the contemporary context they operated within. This research can then be used to make inferences in order to fill gaps in an informed way.

Additionally, the construction of the digital models enables a forensic analysis of the designs. An analogy for this can be seen in elements of police crime forensics; the reconstruction or simulation of events produces an investigation into what may have occurred (Harfmann and Akins 2000). The process of constructing a digital model of an unbuilt, damaged or destroyed architectural artefact is used to augment our understanding of them. For example, if current knowledge of a design is based on surviving literature or fragmented images, the new arrangement introduced using digitally augmented techniques allows a clearer reading of the original sources, therefore the research is valuable as it enables more information to be divulged about a given model in a more precise way (Sabater and Gassull 1992).

As already stated, the use of digitally created models to enhance our understanding of unbuilt, damaged or destroyed works of architecture has already proved a rich area of research within the academic community. However, the focus of the research presented here differs in two ways; firstly emphasis is placed on the *process* of constructing the digital representations and what can be learned from this; for example, how to deal with inconsistencies across drawings. Secondly, the study of source data is utilised to pose specific questions about architectural designs in which knowledge can be enhanced using digital techniques; the kind of techniques that would not have been available for the designers to make use of at the time.

1.2 Aims and objectives

The main aim, or research question, is:

To investigate how digitally mediated techniques can be utilised to augment and enhance critique of damaged, destroyed, or unbuilt significant works of architecture and the architects that designed them.

So, to summarise, the context for this research is:

The use of digital techniques has progressed rapidly in architectural design and is increasingly beneficial as a representation and analysis tool. This technology has primarily been used to construct models of designs that are yet to be built. These techniques have also been used less commonly to visualise lost, damaged and destroyed works of architecture, however, analysis techniques of such designs are yet to be fully exploited in a research context.

In order to fulfil the research question, the following objectives have been set:

1.2.1 Research objectives

Objective 1: To investigate the relationship between significant unbuilt and built architecture, by a particular architect or in a particular context.

Rationale: *In order to understand why investigation into unbuilt works of architecture is important, its relationship to built architecture must first be understood. Particular focus is placed on architectural works that challenge notions of reality, specifically the blurred boundaries between the built and unbuilt which consequently blurs the boundaries between reality and virtual reality.*

Objective 2: Review previous research that incorporates the use of digital techniques to enhance understanding of works of architecture.

Rationale: The use of digital techniques as an analysis technique needs to be fully reviewed in relation to existing, proposed, damaged, destroyed and unbuilt architecture. Particular focus will be placed on damaged, destroyed and unbuilt architecture in order to understand what has already been achieved in terms of research, what is missing and what could be expanded on in the research presented here.

Objective 3: To examine traditional methods of critique and representation as well as a comprehensive range of contemporary digital techniques in architecture.

Rationale: Traditional text and image based analysis of historic buildings needs to be understood in order to demonstrate how critique of architecture has been enhanced using representation techniques historically. A comprehensive toolbox of contemporary digital techniques will then be discussed in the context of how they can be used to augment our understanding of unbuilt, damaged or destroyed architecture.

Objective 4: To develop a consistent analytical technique, incorporating current digital representation tools that can be used to systematically study significant cases.

Rationale: The use of case studies to formulate a methodology enables a consistent analytical technique to be developed. It is predicted that using three different cases will result in different aspects of the research being explored, for example one study may produce substantial results linked to the process of constructing digital representations of a scheme, whereas another may reveal more results based on lines of enquiries investigated as part of the background information studied.

Objective 5: To analyse and review the case study research carried out and give key conclusions in terms of refining the methodology for further research.

Rationale: *Reviewing the case study research will enable the implications and limitations of the research to be understood fully. From this, the methodology proposed can be further refined in order to present it as a system for further research to be carried out in the area of digital simulation and reconstruction.*

1.3 Research methodology

The methodology proposed for the research utilises three different case studies which will be outlined in the following section. The flow diagram in Figure 1.1, which establishes principles and techniques to define the initial methodology, was produced based on a pilot study that became a Masters dissertation (Webb 2009). This will be explored and tested extensively using further research into the initial pilot study, as well as additional case studies forming the later chapters of the thesis.

1.3.1 Case study methodology

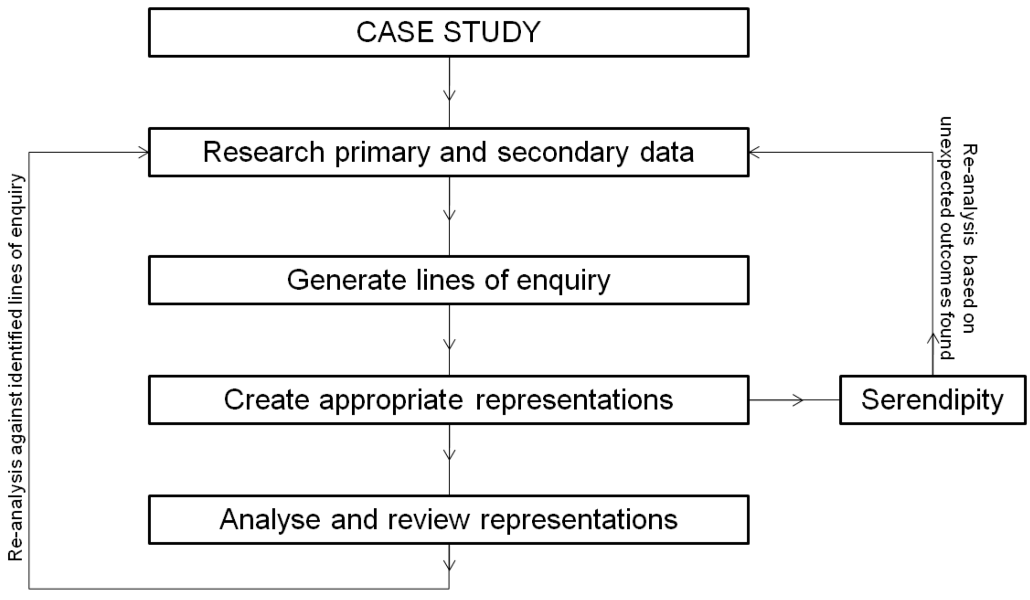


Figure 1.1: Flow diagram demonstrating the research methodology proposed based on initial investigation into the subject.

The methodological process displayed in Figure 1.1 demonstrates the process of selecting a case study, researching it, generating consequent lines of enquiry, creating an appropriate set of digital representations to support the enquiry lines and finally analysing and reviewing the representations created against identified gaps in knowledge and questions posed in the lines of enquiry.

The case studies are selected based on a combination of factors; firstly the amount of primary and secondary information available has to be investigated. This is crucial in defining the scope of each case study, for example an unbuilt, damaged or destroyed work of architecture with less information available is likely to rely further on inferences to fill in unknown elements. This consequently shifts the focus to the process of constructing the digital representations, whereas a case study with substantial source data is likely to have more focus on results derived from lines of enquiry generated. The logistics of locating the source data available for each case study also affects their choice; preference has been given to cases in which material is easily accessible whilst still having potential to provide enhanced critique of them.

The next phase of the methodology is to research all of the primary and secondary information available for the case study in question. Primary sources consist mainly of archive material such as letters, newspaper and magazine articles, meeting records, architectural drawings, sketches, models and photographs. The purpose of these sources is to provide material to construct digital representations as well as to generate lines of enquiry; for example correspondence between the architect and client could reveal contentious issues that can be investigated further using digital techniques. Secondary sources such as monographs and biographies of an architect and their work are also valuable at providing additional material to construct representations. They are also central to the research as architectural biographers and historians often pose questions or statements that could be enhanced using digitally augmented critique. For example, a historian may suggest an architect designed in a certain way and with certain influences. Digital techniques could be used to investigate our understanding of this.

Once the source data has been fully researched, the next stage of the methodology is to suggest questions, or lines of enquiry, based on issues raised from dissecting the primary and secondary data discussed above. Decisions can then be made into which digital techniques are most appropriate to answer the questions posed in the lines of enquiry.

The pilot study for the research established that the creation of digital representations can sometimes reveal unexpected information and understanding;

in this sense the new knowledge is derived serendipitously. This is an important potential in the research methodology due to the increased understanding of unbuilt, damaged or destroyed architecture that this re-analysis based on unexpected outcomes can provide.

Once the digital representations are constructed and lines of enquiry are proposed based on these, the case study in question can be re-analysed and reviewed. This re-analysis then forms enhanced critique of the primary and secondary information that was available at the beginning of each case study. Therefore the research aims to add to the information already available for a particular architectural design and augment understanding of it using digital techniques.

A key aspect of the research methodology is to constantly question and reappraise the methodology itself. The primary goal is to create a refined and robust approach that can be applied to future cases.

1.3.2 Research strategy

The strategy is established in order to understand best how the case study methodology can be implemented. Initially a critical review of qualitative sources will be undertaken in the form of a literature review evaluating projects that have also used digital techniques in the context of unbuilt, damaged or destroyed works of architecture. This will be carried out in order to gain a breadth of understanding into the subject area and consequently give the research focus and originality. This will be formulated by reviewing literature such as books, journals, conference proceedings and other online sources. Once focus has been achieved by reviewing these sources, appropriate methods can be analysed in terms of which digital tools could be utilised. This is because of the nature of the research revolving around case studies which utilise digital modelling extensively.

1.4 Three case studies

The case studies are chosen for their merit in aiding understanding of digital techniques in the context of augmenting knowledge of unbuilt, damaged or destroyed works of architecture. Rather than choosing a series of projects linked by a particular theme, the cases are chosen because they each offered different scenarios to test and research the process. The case studies all happen to be unbuilt designs, rather than damaged or destroyed works of architecture. Again, whether or not the designs are unbuilt, damaged or destroyed is unimportant in comparison to the benefits that each case study can bring in terms of aiding understanding of the process. Crucially, the methodological process is still the same; the main difference between them is that damaged or destroyed buildings may also leave behind physical archaeological remains in terms of primary information. The case studies represent the work of three significant architects from the twentieth century:

1.4.1 Stirling's Newton Aycliffe Community Centre thesis

The initial case study investigates Sir James Stirling's unbuilt Newton Aycliffe Community Centre thesis project from his final year as a student at the Liverpool School of Architecture in 1950 (see Figure 5.1). A physical model of the design was built by Stirling but has since been lost; all that remains locally was a set of fragmented drawings and images. The model was reconstructed physically and digitally in order to enhance understanding of the architect in his formative years. This research produced the pilot study enabling the initial methodology to be formulated. Further research could then be generated based on lines of enquiry pursued. Stirling became one of the key figures in twentieth century British architecture and the International Movement. This scheme was likely to embody some of the early ideas that Stirling was to go on to develop in his subsequent career.

1.4.2 Perret's Musée Moderne and Musée Bourdelle

The second study investigates the work of the French architect Auguste Perret. Two of Perret's unbuilt museum projects were chosen for the case study as they share a common typology allowing investigation to be carried out into the similarities between the two schemes. This is of particular significance as one of the schemes was a theoretical narrative describing his ideal museum; the Musée Moderne. Perret describes his ideal museum design primarily using text, which was published in 1929, and two years later he put forward proposals for a museum to hold the works of the late Antoine Bourdelle; his friend and collaborator (see Figure 6.1). This was Perret's first opportunity to put his theoretical ideal into practice; therefore digital representations have been created to directly compare the two design schemes. This line of enquiry offers an opportunity to visualise Perret's theoretical ideal museum that has not been investigated beyond the text description and basic sketches. From this, further lines of enquiry can be generated as Perret sets out very specific requirements for his ideal museum, for instance that it should be planned across one floor as much as possible to allow natural lighting from above (Perret 1929b).

1.4.3 Lutyens' Liverpool Metropolitan Cathedral

The final case study explores Sir Edwin Lutyens' partially built design for the Metropolitan Cathedral at Liverpool (see Figure 7.1). The cathedral design was vast in scale, second only to St Peter's Basilica in Rome. Construction began in 1933 but was abandoned in 1941 as wartime restrictions resulted in a lack of labour and materials. After both the architect and Archbishop who commissioned the building died, the decision was taken to complete the crypt only and in 1959 an architectural competition was announced to provide a new design incorporating the crypt; which forms the current built design by Sir Frederick Gibberd. A wealth of archival information relating to Lutyens' design still exists including drawings, a physical model, perspective images, newspaper articles, correspondence between various parties as well as several biographies. These sources offer the potential to generate several lines of enquiry to augment critique of the cathedral design using digital techniques.

1.5 Limitations

The nature of the case studies means that only significant works of architecture by renowned architects are being explored. This is due to the fact that, because of their significance, they generally have a large amount of primary and secondary information available enabling enhanced critique using digital techniques. The investigation of less significant architectural designs such as domestic buildings could also be researched, and explorations into such works are included in the review of literature later on, however, they are beyond the scope of the research presented here.

The methodological approach limits the research in terms of investigating the broad areas of computer aided architectural design, history of architecture as well as architectural critique. Because of this breadth, focus is placed on both digital techniques and historical enquiry, meaning that depth is limited in both areas when compared to, for example, a thesis primarily investigating the history of a particular architect and the buildings they designed, or a thesis primarily researching a specific aspect of digital modelling. However, these limitations result in a methodology that is clearly defined in terms of the use of digital techniques to enhance critique of historic architecture.

Due to the breadth of the thesis in terms of using digital techniques this results in a lack of depth in researching them as already discussed. It must therefore be stated that the work presented here consequently relies on digital techniques that are valid in terms of their ability to generate accurate results. For example, digital auralisation techniques are not yet advanced enough to a non-specialist to provide realistic and reliable results. On the other hand, digital visualisation and modelling tools have consistently developed over the last thirty years becoming increasingly accurate and accessible to those in the architectural profession and beyond. Therefore the research presented here relies on these tools rather than those in which validity is still questionable to develop the methodological process and enhanced understanding of the three case studies outlined in section 1.4.

1.6 Outline of structure

The flow diagram in Figure 1.2 demonstrates the structure of the thesis relating to the aims and objectives proposed in section 1.2. The research question comprises of five objectives which are linked to different chapters in terms of their proposed exploration of each objective.

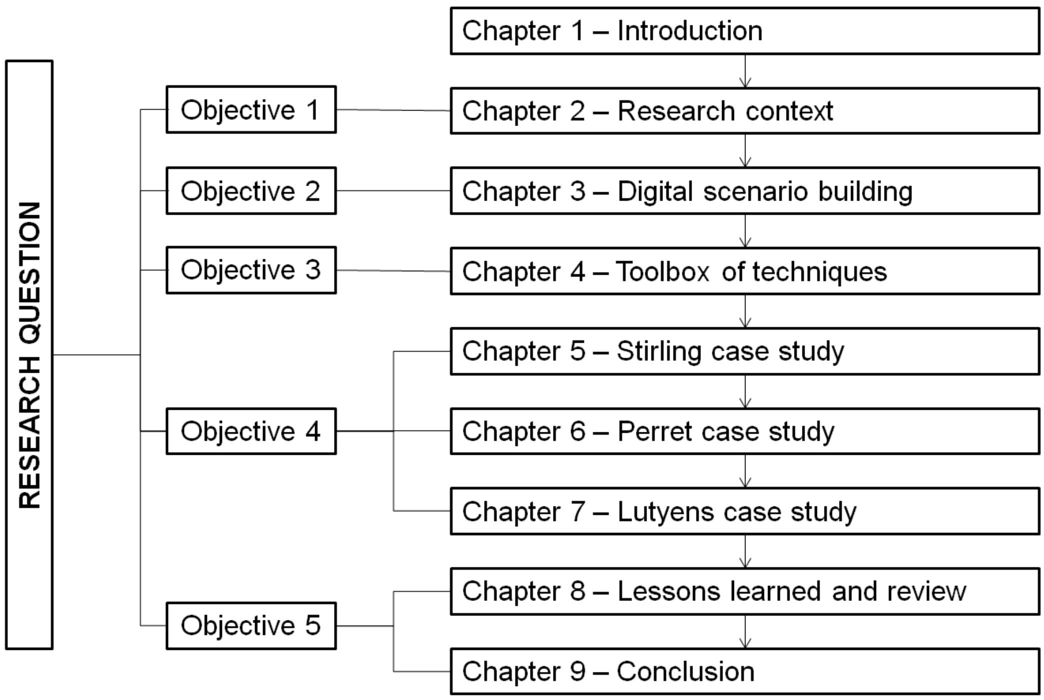


Figure 1.2: Outline of the structure for the thesis.

1.7 Point of departure

To re-iterate the points made in section 1.1 discussing the research value, the work presented here examines the studies of others as a starting point, and then differs in several ways. Early research in the field places focus on the newly acquired ability to create digital representations of lost, damaged or destroyed works of architecture, and the enhanced realism such visualisations provide compared to that of pre-digital techniques. This is highlighted by Mitchell (1992a) and becomes cemented in the fields of archaeology and architecture via key sources such as Forte and Siliotti (1997) and Novitski (1998). More recent research has begun to examine how specific digital tools can be used to enhance critique and understanding of lost, damaged or destroyed works of architecture, which is effectively demonstrated in papers by Richens and Herdt (2009) as well as Mark (2011).

The research presented here aims to build on the most recent studies in the field by providing enhanced critique and understanding of unbuilt, damaged and destroyed works of architecture. However, as a point of departure, the focus is placed on the process of creating a digital representation, the contextual studies this requires to form a satisfactory result and consequent knowledge gained from this, as well as developing a methodology for future research in the field. In this sense, the focus becomes less about the development of a particular digital technique and more about the enhanced understanding that can be acquired for a particular case study.

1.8 Thesis layout

The thesis is printed on double sided paper, as visual material plays a key supporting role to the text; therefore this enables accompanying images to be located as closely to the written elements as possible. When it is not feasible to locate images directly in the main body of the thesis, additional images for the three case studies can be found in Appendix A, B and C respectively. Appendix D discusses additional results as part of the Lutyens case study; however these are not included in the main body of text as the techniques used are not yet validated. Therefore their inclusion in the appendix is for illustrative purposes only. Appendix E provides additional supporting papers relating to the thesis and case studies.

2 Research context

> *"…the built environment we inhabit is just the residue of a much greater imaginative world that never saw the light of day, evoking what might have been or still could be – the unbuilt, the lost."* (Wilson 2004, p.23)

This chapter will consider works of architecture that challenge notions of reality, specifically the blurred boundaries between built and unbuilt architecture which consequently blurs the boundaries between reality and virtual reality. The role of memory relating to the built environment will then be discussed in the context of unbuilt, damaged or destroyed architecture.

In order to categorise and clarify the different facets of architecture in terms of their physical status they have been represented as a flow diagram in Figure 2.1. The different sections of the diagram consequently form titles for the start of discussions into their many facets.

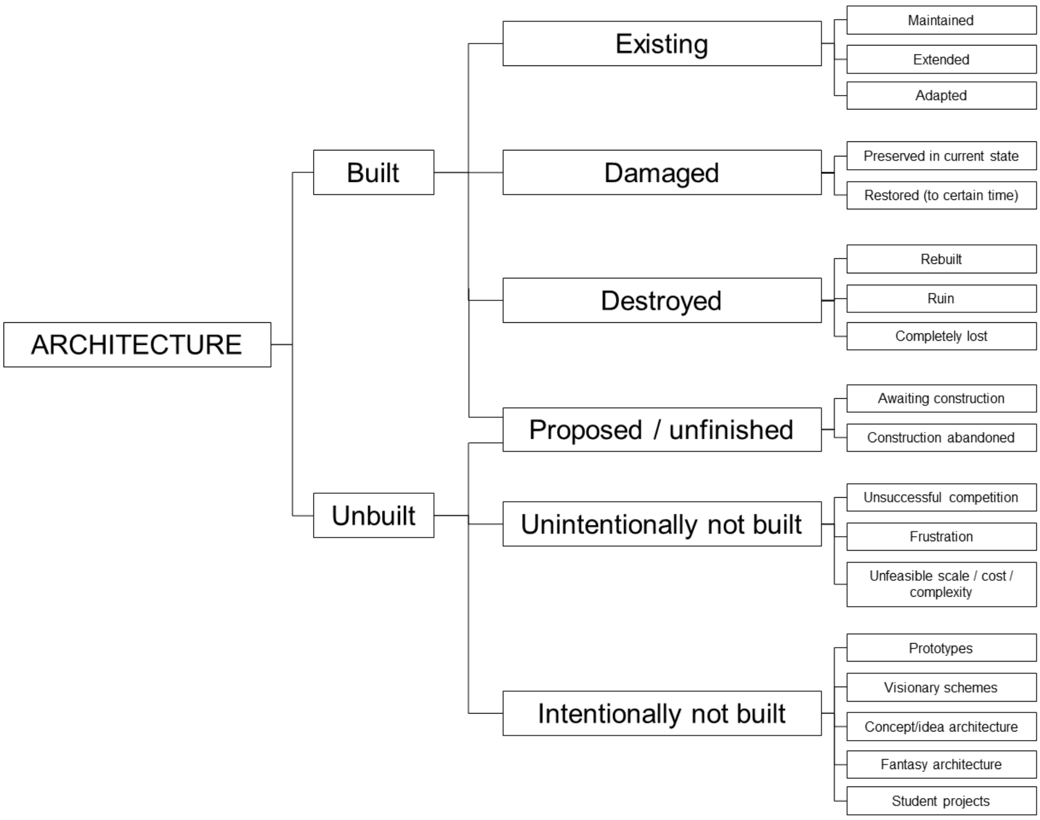


Figure 2.1: Flow diagram illustrating the different categories of architecture in terms of being built or unbuilt. Unbuilt facets adapted and expanded from Collins (1983).

2.1 Built architecture

Buildings and the process of designing is generally thought of as a response to a set of existing conditions which are conceived as a design and finally built (Ching 1996). This forms the basis of architecture in our built environment; when the set of existing conditions change, the building and its occupants have to adapt accordingly. Changes of condition could be that the building is damaged, destroyed, is in the process of construction or construction is left incomplete (see Figure 2.1). These different facets of built architecture will be discussed in the following sections.

2.1.1 Existing buildings

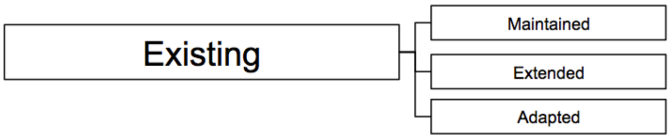


Figure 2.2: Flow diagram extracted from Figure 2.1 showing the facets of existing architecture.

When we consider the built environment, it is most commonly referred to in terms of buildings that exist in a physical sense. However, these are influenced by numerous factors such as weathering over time as well as social, economic or political changes which results in different facets of existing architecture (see Figure 2.2). In the first instance, built architecture has to be maintained due to the ongoing effects of nature and the environment, in which weathering has the potential to destroy a building. Maintaining a building may simply require the repainting of a rendered wall or more serious issues such as repairing or replacing timber elements that have failed. Maintenance on a grand scale can be seen in a recent project at St Paul’s Cathedral that included cleaning and treating all of the external stonework to remove the patina caused by weathering and pollution. On completing the restoration work, the cathedral Dean proclaimed that visitors ‘can now witness Wren’s original vision and see the cathedral as fresh as the day it was completed’ (St Paul's Cathedral 2011). However, this process can also be viewed negatively as it eradicates the way in which weathering marks a building over time and gives a sense of age (Mostafavi and Leatherbarrow 1993).

> *“Restore the object thoroughly and you cancelled both its documentary value – making it an unreliable witness to the time of its origin – and its*

> *capability to convey a sense of historical distance, of the time elapsed since its creation"* (Forster 1998, p.25)

The fourth dimension of time consequently plays a key role in such discussions, as it constantly changes the physical state of a building. The potential loss created by removing a sense of age can be seen more strongly in the rebuilding of damaged or destroyed works of architecture, which will be discussed in detail later.

Existing buildings have to adapt due to social and political changes, for example a building may change its use or have to adjust due to increased/decreased numbers of users. The consequence of a change of use could result in the layout of the building being amended, for instance housing built around 1830 on Abercromby Square in Liverpool was later amended to become university buildings, including the Liverpool School of Architecture. Such existing buildings may require additional spaces or uses by means of extension; this can be seen at the Liverpool School of Architecture, which was extended in the early 1930s to a design by Reilly, Budden and Marshall. This was itself extended in the 1980s by King and McAllister to account for additional students and to offer improved facilities (Sharples 2004).

More recently, buildings have required modernisation to improve performance in terms of environmental sustainability, for example improving levels of insulation and installing double or triple glazing (Smith 2001). However, making such alterations will almost certainly have an effect on the appearance of a building, marking another step in their development. To summarise, the history of existing buildings is complex with many layers of changes and amendments throughout time.

2.1.2 Damaged and destroyed buildings

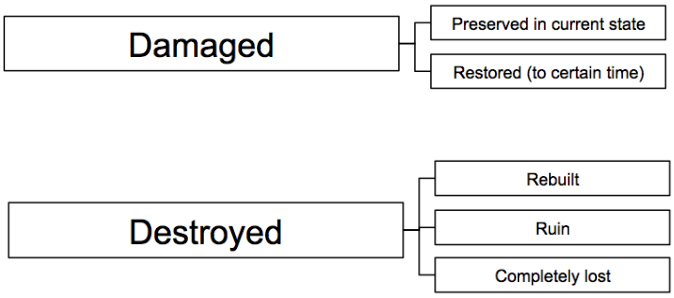


Figure 2.3: Flow diagram extracted from Figure 2.1 showing the facets of damaged and destroyed architecture.

The boundaries between buildings that are deemed damaged and those that are considered destroyed are blurred. Consequently, the many facets outlined in the two diagrams in Figure 2.3 overlap and are interconnected. For example, a building that is damaged and restored compared to a building that is destroyed and rebuilt bear similarities as a subject of discussion depending on their level of decay. Therefore, the two areas are examined under a single section heading.

As previously discussed, buildings are subject to decay and therefore require maintenance. Without this upkeep, they may become permanently damaged which could lead to their eventual destruction. Other factors that could lead to this end include acts of vandalism and war as well as political and economic changes. If a building is damaged beyond repair, they may have to be demolished. Alternatively they could be preserved in their current condition or restored/rebuilt to a certain time in their past; which is a common scenario when dealing with significant and important works of architecture.

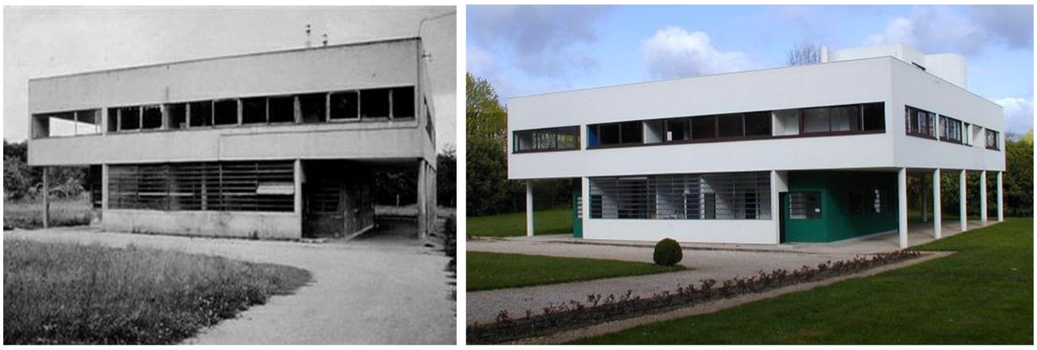


Figure 2.4: Le Corbusier's Villa Savoye in a damaged state (left) and the current building following numerous restoration efforts (right). Left image credit: Mostafavi and Leatherbarrow (1993, p.8), right image credit: cambridge2000.com.

Important works of architecture such as the Villa Savoye by Le Corbusier often obscure a complex history as a result of a process of preservation and restoration (see Figure 2.4). This can be seen at the villa as it is currently presented in a state akin to the day that building work was completed on site ‘in its original pristine condition’ (Murphy 2002, p.80). The design, completed in 1931, began to decay as soon as it was erected with the Savoye family reporting leaks all over the house; eventually abandoning it in 1938, which increased the level of deterioration further. The house was used by German occupying forces during the Second World War as well as Allied forces after the liberation of France, following which it was used as a barn for animals (Morel-Journel 1998). In the late 1950s the house’s condition had seriously declined and the land was acquired to build a secondary school in its place. During this time it was used as a youth club in which alterations were made to the layout to make it safe for children, for example blocking access to the roof terrace (Murphy 2002). The plan to demolish the house enabling the school to be built led to an outcry from international architects, which resulted in the French Minister of Culture giving the building listed status in 1964. An initial phase of restoration work was carried out in the 1960s followed by a second phase between 1985 and 1992, resulting in the restoration of the house to its original condition (Morel-Journel 1998).

> *"The programme faithfully restored the villa to Le Corbusier's designs as if a time warp had occurred. Now a museum with listed status, the villa exists as a simulacrum of Le Corbusier's original plans with all traces of the intervening years totally erased."* (Hypo 2010)

The official guidebook for the design features no images of the damaged building and only briefly mentions its poor state before restoration (Morel-Journel 1998). Therefore, the viewer is presented with what they believe to be the original design, when in fact it is a simulacrum. This means that 'restoration projects typically conjure up a past that never was and compel the present to acts of homage before a vacant throne' (Forster 1998, p.31).

Other iconic works of architecture such as the German State Pavilion in Barcelona by Mies van der Rohe bear a similar history in terms of authenticity. The temporary building was constructed for the International Exposition in Barcelona in 1929 and was immediately disassembled afterwards, therefore being an example of built architecture that has been demolished. The decision was taken to reconstruct the building on its original site in the 1980s after it became an embodiment of 'architectural purity of form and design' (Levine 2008, p.15). Similar to the Villa Savoye, this also begins to blur the boundaries of reality in built works of architecture:

> *"Remembered essentially through two-dimensional black-and-white photographs, it achieved a kind of iconic status available perhaps only to things that exist exclusively in the realm of thought. Now it exists once again as a three-dimensional, experiential, in color. Yet, should one really say, "once again"? A replica of the building has replaced the photograph as the agent of preservation. The question is whether "more" or "less" has been preserved."* (Levine 2008, p.15)

Zimmerman (2006) states that the resulting reconstruction of the German State Pavilion between 1983 and 1986 is still challenged by the power of photographs of the original building, even though the reconstruction is photographed on a daily basis. This could be seen as a subconscious questioning of the current built pavilion's authenticity.

Acts of war have considerable significance to the discussion of damaged and destroyed buildings. Architecture, and the destruction of it through war, can be used as a method to eliminate 'the cultural artefacts of an enemy people or nation as a means of dominating, terrorising, dividing or eradicating it altogether' (Bevan 2006, p.8). One such act of destruction occurred during the Second World War in which the Allies heavily bombed the city of Dresden in Germany. This created a firestorm that, in addition to the tens of thousands of lives lost, also destroyed more than 15 square kilometres of the city's primarily Baroque architecture. This included one of its most famous landmarks, the Frauenkirche or 'Church of Our Lady'. The church was built between 1726 and 1743 to the design of the city architect Bähr and featured a 96 metre high dome that dominated the Dresden skyline (see Figure 2.5). The firestorm caused by the Allied bombardment raised the temperature inside the church to over 1000°C. This resulting heat caused the columns supporting the dome to explode, and consequently the church collapsed under its own weight.


Figure 2.5: The original Frauenkirche before destruction by Allied bombing (left) and the new rebuilt church (right) featuring stonework from the original building. Left image credit: Prints & Photographs Online Catalog (2011), right image credit: Dresden Tourismus GmbH (2011).

Following the Second World War, the ruinous remains of the church lay as a ‘memorial to Allied atrocity’ under East Germany’s Soviet rule (Jarzombek 2004, p.55). With the reunification of Germany in 1989 efforts were made to begin a process of rebuilding the church, which were finally completed in 2005. The rebuilding could be seen as a propaganda tool as the West were rebuilding the East that they had destroyed; the Frauenkirche became a symbol of ‘the city’s past, its survival and its rebirth’ (Jarzombek 2004, p.55). The church rebuilding utilised computer aided architectural design and manufacturing techniques such as CATIA (Computer Aided Three-dimensional Interactive Application) and databases to catalogue the existing stonework that remained in the rubble. The idea was, as Jarzombek (2004) states, to create ‘embedded memory’ by placing the original stonework in its perceived original location in the new construction, however many of the stones were randomly placed over the façade (see Figure 2.5).

Bevan (2006) discusses rebuilding as a way of forgetting, as the void space left by a destroyed building can be more powerful than the building itself. In the case of rebuilding the Frauenkirche this meant erasing all memory of the Second World War and the subsequent German Democratic Republic rule. The rebuilding of the church exposes a multi-layered record of Dresden as well as ‘the history of the problematic interweaving of overlapping and competing narratives about its past and future’ (Jarzombek 2004, p.51). Again, the Frauenkirche begins to question reality in architecture, as the building is a reproduction of its original self.

In contrast to works of architecture that have been completely destroyed and rebuilt such as the Frauenkirche, other designs for example the significantly damaged Parthenon in Athens are being restored to a certain point in their history. The Parthenon, which is the centrepiece of the Acropolis in Athens, is arguably the most distinguished surviving piece of Ancient Greek architecture today. Construction of the temple began in 450 BC and took less than ten years to build. Throughout its long history, it has decayed considerably due to the effects of nature and man. The most destructive period for the building was during the Venetian-Turkish wars in 1687 when a cannon ball penetrated the roof and exploded the central chamber. This resulted in the roof being completely destroyed and the rest of the building severely damaged. For the next two centuries the site was subject to removal of its stone and metal, for instance the now controversial removal of sculptures by the Earl of Elgin to the British Museum in London.

In 1975 a project began to preserve the damaged Parthenon in its current state, with the plan projected to take approximately ten years. It soon became clear that this was unachievable due to the efforts of a previous attempt at restoration in 1898 by the civil engineer Balanos. His aim was to improve the aesthetic appearance of the monument, but the process used to achieve this was later found to be unsympathetic to the longevity of the building. One of the architects working on the current restoration described Balanos's conservation techniques as harmful to the original materials, often drastic, and carried out by unskilled labourers. Because it only aimed to improve aesthetics, various pieces of the monument were misplaced and the work was not based on extensive archaeological and architectural research (Labrinou 2009). When the Parthenon was originally built, the Ancient Greeks secured the marble blocks together using iron clamps placed in carefully carved grooves. It is believed that molten lead was then poured over the joints to act as a cushion against seismic shocks and protect the iron from corrosion. Balanos used crude iron in his restoration and overlooked the lead techniques used by the original Greek builders. This resulted in rainwater entering the joints, rusting the iron and eventually cracking the marble. The current restoration team soon realised they were faced with a monument in a state of near collapse. According to the director of the restoration project, their approach was to 'restore the maximum amount of ancient masonry while applying the minimum amount of new material' (Hadingham 2008).

After the structure of the building was made safe, the team set about locating the various pieces of the monument that were strewn across the site and fitting them back together as accurately as possible. Although a computer database was set up for this task initially, the team soon found it was easier to carry out the operation by hand. The techniques the Ancient Greeks used in building the Acropolis such as entasis, making an outward curve on the columns to create a visual illusion that they look parallel rather than thinner in the middle, provided clues to the locations of the blocks based on their slightly different diameters. The restoration team were able to reposition around 500 of the 700 blocks on site based on the shape and depth of the cuttings on the surviving pieces (Hadingham 2008).

Modern materials and techniques aided the restoration process; rather than using iron to hold the blocks together, titanium was used because of its strength and resistance to corrosion. When a new piece of marble was needed to fill in missing sections of original pieces, they were made to match exactly the original damaged section. These were hand carved using traditional techniques, however, the team are more recently using laser scanning and cutting with some of the larger pieces of marble (Labrinou 2009). When the pieces were fitted together, a fine Portland cement was used to allow the blocks to be unassembled easily should future generations find superior ways of restoring the monument. A difference in colour was visible between the old and new sections of the blocks; therefore an artificial coloured patina was applied to the new sections to reduce the visual difference. This difference is barely visible from a distance, although it becomes apparent at close range (See Figure 2.6).

Figure 2.6: The Parthenon in Athens. From a distance, the visual difference between original and new material is minimal (left). On closer inspection, differentiation between original and new materials is revealed (right). Image credits: André Brown.

The approach to the rebuilding of the Frauenkirche differs to the restoration of the Parthenon. The former aims to make the difference between old and new materials explicit whereas the latter aims to minimise them. This is due to their different agendas, with the Parthenon restoration aiming to make safe the building in its current state, or a state prior to the Balanos restoration of 1898. Therefore the building will still be considered as severely damaged or ruined even when the restoration work is complete. In contrast, the Frauenkirche is a fabrication in terms of materiality besides a small number of sections that remain standing from the original building, hence being called the ‘new’ Frauenkirche. The age of the original structures influences the decision of whether to restore to a certain period or the original design’s completion date; it seems more acceptable to rebuild or fully restore a relatively modern building such as the Villa Savoye (80 years old) or the Frauenkirche (260 years old) compared to an ancient structure such as the Parthenon (2500 years old).

Another facet of damaged or destroyed buildings is ruins. These may require minimal maintenance for safety, but the overriding agenda is to leave them in a ruined state. An example of this is the village of Oradour-sur-Glane in France which was destroyed by the Nazis on 10th March 1944 with the death of 643 villagers (Bevan 2006). The remains of the village now stand frozen in time as a memorial to those who lost their lives (see Figure 2.7). Similar statements can be seen such as the Church of St Luke in Liverpool, as well as Coventry Cathedral, which was left in its ruined state with a connection through to a new design by Sir Basil Spence. Ruins can be seen as a record of events of terrible suffering, which act to 'promote forgiveness rather than as a statement of defiance' (Bevan 2006, p.191). This contrasts greatly to some restoration projects such as the Frauenkirche which could be seen as acts of defiance.

Figure 2.7: The ruined remains of Oradour-sur-Glane in France now stand as a memorial to those who lost their lives in the Nazi destruction of the village. Image credit: Castrique (2006).

So far the section has discussed buildings that were built and maintained, extended or adapted as well as buildings that were damaged or destroyed and either rebuilt, maintained or left as a ruin. However, many works of architecture have been completely lost. This can be seen most commonly when a building is deemed unfit for purpose and is subsequently demolished and, more often than not, a new building erected in its place. This is undoubtedly the main cause for buildings to be lost completely, however traces of them may still exist in-situ in the form of foundations, or elsewhere as building materials removed from a site. Additionally, the site that destroyed buildings occupied may inform the design of a new building, for instance late 19th Century housing in Liverpool is currently being demolished and replaced by new 'improved' housing; however the new designs still follow the same street pattern formed by the housing it is replacing. Such acts of destruction are generally seen as progress, however in some cases this can later be viewed with regret as architectural fashions change and we realise the value of works of architecture that are now lost;

> *"It is not always the case that what is lost is replaced by something worse, and yet demolition makes many of us sad because it strips away memories, childhood, old patterns and ways of life."* (Glancey 2008, p.10)

Alternatively, buildings that have been lost without trace can take on a legendary status blurring the boundaries between what is real and what is not. This can be seen in ancient structures such as the statue of Colossus of Rhodes. The statue, one of the ancient wonders of the world, straddled the harbour at Rhodes and was allegedly so large that sailing ships could pass underneath it (see Figure 2.8). The structure, built between 292 and 280 BC, keeled over in 226 BC as a result of an earthquake. The remains lay for 800 years until they were broken up and allegedly sold off to an Arabian merchant (Glancey 2008).

Figure 2.8: Colossus of Rhodes depicted by Martin Heemskerck in the 16th Century. Image credit: van Heemskerck (2012).

No archaeological remains have yet to be found of the statue; therefore all source information is secondary. This can be seen in written accounts as well as visual depictions which have been passed down from generation to generation, adding to the mystery of Colossus. Due to this lack of primary information, images vary with some suggesting the statue straddled the harbour and others suggesting that it did not. This skewing of reality begs the question; did Colossus of Rhodes ever really exist?

2.2 Unbuilt architecture

Examining the various facets of built architecture reveals their fragile existence, which facilitates the validity of discussions into unbuilt architecture. If the reality of the built is challenged, then the unbuilt has to be recognised as a facet of reality as 'the built environment we inhabit is just the residue of a much greater imaginative world that never saw the light of day, evoking what might have been or still could be – the unbuilt, the lost' (Wilson 2004, p.23). Unbuilt architecture will be discussed in the following section based on Figure 2.1. This ranges from works that are yet to be built or were left unfinished, were unintentionally not built or were intentionally not built.

2.2.1 Proposed or unfinished buildings

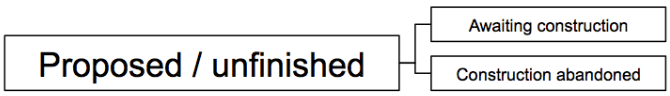


Figure 2.9: Flow diagram extracted from Figure 2.1 showing the facets of proposed/unfinished architecture.

Proposed or unfinished buildings are the most ambiguous facet of unbuilt architecture, as they could also be referred to as built architecture (see Figure 2.1). In the majority of cases, it was the intention of the designer that these projects would be built physically; hence the reason they could be classed alongside the built (Collins 1983). This is especially true when construction of a design begins and is subsequently abandoned. The facets of proposed and unfinished architecture are shown in Figure 2.9.

An example of unfinished architecture is Lutyens' design for Liverpool Metropolitan Cathedral which will be investigated later as a case study. Construction began on the project in 1933 but was abandoned during the Second World War due to wartime restrictions. After the war, both the architect and archbishop who initiated the design had died, and the new archbishop decided to abandon the scheme primarily due to costs increasing almost ten-fold from £3 million to £27 million. The decision was taken to complete the crypt of the design, of which construction had progressed significantly before the war, and hold an architectural competition for a new cathedral design incorporating the Lutyens crypt. The competition was won by Gibberd and his design now stands on the site (see Figure 7.11). Lutyens' design supports the blurring of boundaries between the built and the unbuilt as the completed crypt is evidence of a serious intention that the scheme was going to be physically built. It also acts as a reference point to indicate what could have been.

As already seen in examples of damaged and destroyed buildings, acts of war are a major contributor to their demise. It is also the case with some unbuilt works of architecture that war can influence their outcome, such as the Liverpool Metropolitan Cathedral example. More recently, the US-led invasion of Iraq in 2003 resulted in the partially built al-Rahman mosque being left unfinished. Construction began on the scheme in 1998 as a tribute to Saddam Hussein's power and was due to be completed in 2004 (Chatriwala 2005). Unsurprisingly, the issue of what to do with the partially built scheme has proved sensitive as the structure is being used for prayers by Shiite Muslims, whereas others see it as a reminder of Hussein's regime.

One of the most notable examples of unfinished architecture is the Sagrada Familia church in Barcelona (see Figure 2.10). The gothic revival design by Villar began construction in 1882; however, Gaudi took over a year later and redesigned the church significantly. Gaudi was renowned for his freeform façades that defied rationalism, as seen in his notable projects such as the Casa Mila apartment block as well as the Sagrada Familia itself. In 1911 Gaudi became ill and had to spend several months recovering in the Pyrenees Alps. It is suggested that during this time of ill health he realised that in the event of his death it would be almost impossible for continuators to finish the church based on the highly plastic architectural language; therefore Gaudi decided to form a more rational approach to the design, such as the use of hyperboloids or ruled surface geometry (Burry 2005).

Figure 2.10: The fluidity and plasticity of Gaudi's early designs for the Sagrada Familia church can be seen in the Nativity Façade (left) compared to the Passion façade (right) which utilises ruled surface geometry; a technique Gaudi established in his lifetime.

Vital information sources were lost during the construction project, partly due to the death of Gaudi who was accidentally killed by a passing tram in 1926. Additionally, the majority of his architectural drawings and models were destroyed during the Spanish Civil War of 1936 to 1939. Construction was able to continue due to the knowledge of the architect's employees and apprentices, who became known as the 'Gaudi Disciples' (Burry 2008). In 1980 Burry joined the team responsible for the continuing construction and is now the executive architect and researcher. Computer Aided Architectural Design was introduced to the project as a way of interpreting and enhancing understanding of the complex geometry for construction purposes. The process began with model makers painstakingly restoring the fragmented pieces of the original models, which were then converted into digital representations. Finally, computer aided manufacturing techniques were used to translate the digital representations into physical stone pieces for the continuing construction. This process of interpreting the 'freeform' language into geometric shapes, by Gaudi and his successors, has allowed the construction to continue via the use of modern techniques on a building originally designed over 120 years ago.

The unfinished project has caused debate over whether it should be finished at all with prominent architects such as Le Corbusier, Mies van der Rohe and Gropius all signing a manifesto in 1953 stating that construction should cease and the unfinished building remain as a monument to the work of Gaudi (Schumacher 1991). This critique is dismissed by the team completing the Sagrada Familia who state that the objective has always been 'to provide a completed building for the purpose of spiritual congregation rather than fulfil any wider cultural interest through 'freezing' the incomplete work' (Burry 1993, p.9). Evidence to support this can be seen in the construction of religious buildings throughout history, where it was often the case that construction time would be longer than the lifetime of the original architect or master builder, therefore making the use of a continuator a standard procedure. On the contrary though, it highlights attitudes in contemporary society towards partially built architecture. The authenticity of the project has also been questioned over the use of reinforced concrete instead of stone as originally intended. It is argued that Gaudi would have had to use concrete eventually due to high costs of stone material and changing attitudes towards construction (Burry 1993). Morales, who led the reconstruction project of the Barcelona Pavilion, states that this is falsification against Gaudi's ideas as reinforced concrete would have been available to him as a construction technique, however he chose to use stone as he thought 'rock was important for a church' (Schumacher 1991). The debate over the authenticity of the continuing construction is similar to that of reconstructing damaged or destroyed architecture; especially the fact that it can be presented as an authentic built design when in reality the building process is a lot more complex.

Another facet of unbuilt architecture is designs that are proposed but are yet to begin construction. The length of time of this part of the design process varies from project to project, however some schemes wait years to begin construction and as time passes the likelihood that they will ever be built at all decreases. An example of this can be seen in Foster and Partners Millennium Tower which was first conceived in 1989 and was eventually abandoned due to an economic downturn in the Far East (Bingham et al. 2004). The likelihood of the 170 storey high tower ever being built seems farfetched, however it was genuinely considered for some time. The project remains as an example of highly regarded architecture that was not built. The blurred boundaries between the various facets in Figure 2.1 are apparent in this example as such schemes could also fall into the category of unintentionally not built architecture.

2.2.2 Unintentionally not built designs

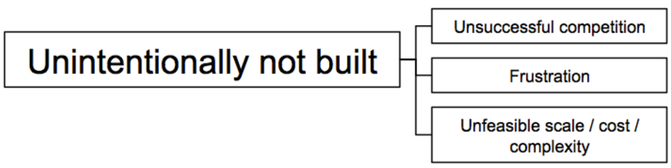


Figure 2.11: Flow diagram extracted from Figure 2.1 showing the facets of unintentionally unbuilt architecture.

The boundaries between unintentionally unbuilt works of architecture are blurred with proposed or unfinished buildings in terms of the reasons why they remain incomplete. The main facets for buildings being unintentionally unbuilt outlined in Figure 2.11 are a result of the design being an unsuccessful competition entry or reasons of frustration preventing construction as well as unfeasibility due to cost, scale or complexity (Collins 1983).

A large proportion of designs that are not built unintentionally are unsuccessful competition entries. Because competitions have several entrants in which there can only be one scheme chosen to be built, a number of unbuilt designs are generated as a result. An example of this can be seen in the Fourth Grace competition to design a future landmark on the Liverpool waterfront in 2002. Four practices were shortlisted for the design including schemes by Foster, Rogers, Cullinan and Alsop. The scheme was won by Alsop resulting in the other shortlisted designs falling into the unbuilt category. A year later, Alsop’s scheme was also abandoned therefore joining the other competition entries to remain unbuilt (see Figure 2.12).

Figure 2.12: Alsop's abandoned Fourth Grace design in Liverpool. Image credit: Virtual artworks (2011).

Alsop’s winning competition design for the Fourth Grace site is an example of a scheme being abandoned due to unfeasibility; in this case it was due to costs and concerns over the impact of the design on the waterfront’s World Heritage site status. However, the design still remains as part of the history of Liverpool in the run up to the Capital of Culture year in 2008.

Perret’s unbuilt design for the Musée Bourdelle, which will be discussed in detail later, also falls into this category of unbuilt architecture. The design was proposed in 1931 as a museum to house the works of Perret’s collaborator and friend, Antoine Bourdelle, however the design was abandoned and the less expensive option of refurbishing the existing buildings on site was chosen. The scheme is still seen as an important example of Perret’s museum design and is discussed alongside his built work (Britton 2001).

The final reason for designs remaining unbuilt unintentionally is reasons of frustration. This could be due to problems including the death of the client or architect, resistance from the local community or planning department, the site changing, a different design being chosen or the scheme being deemed too radical (Collins 1983).

2.2.3 Intentionally not built designs

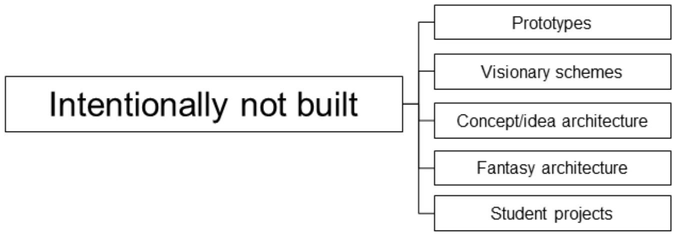


Figure 2.13: Flow diagram extracted from Figure 2.1 showing the facets of intentionally unbuilt architecture.

In contrast to unintentionally unbuilt architecture, some projects are not ever intended to be built (see Figure 2.13). This could be for reasons such as being experimental designs in the form of prototypes, visionary and conceptual ideas. A large number of such experimental schemes also present themselves through the architectural projects of students. The significance of intentionally unbuilt architecture is discussed below;

> *"Imagined architecture is an important mental construct, a means of testing and evaluating architectural processes, even in 'unbuildable' situations. Imaginary architecture is not only pure design, it is also pure architecture*." (Lloyd Morgan and Zampi 1995, p.11)

Designs that are not related to a specific client, site or time which still fulfil a specific purpose can be referred to as prototypes (Collins 1983). These unbuilt designs act as feasibility studies or hypothetical proposals to further knowledge which may then be applied to projects that are intended to be built. This can be seen in Perret's prototype for an ideal museum; the Musée Moderne, of which the design ideas were then applied to his Musée Bourdelle design. Similarly, visionary schemes also act as feasibility studies as they address current issues but resolve them in ways that are deemed unbuildable (Collins 1983). Prominent urban examples of intentionally unbuilt schemes include theoretical studies such as Le Corbusier's 'City of Tomorrow' and Wright's Broadacre city. Another of Wright's schemes, the Illinois Mile High Skyscraper demonstrates architects using visionary design to expand knowledge and explore possibilities in built architecture. The office tower design was presented to the press in 1956 and would have been 1690 metres high if realised. It was seen as a solution to urban sprawl by building upwards instead of outwards. Wright suggested the design could be built, however interest from investors could not be found (Sky and Stone 1983). This is unsurprising considering the worlds current tallest building, the Burj Khalifa, is 830 metres tall and therefore only half the height of Wright's design. The work of Archigram can also be seen as an example of visionary architecture that can be used to influence ways of living and future design; especially in terms of technological capabilities, for instance Peter Cook's 'Design for Solar City' (see Figure 2.14) was a radical early example proposing solar power in housing design (Bingham et al. 2004).

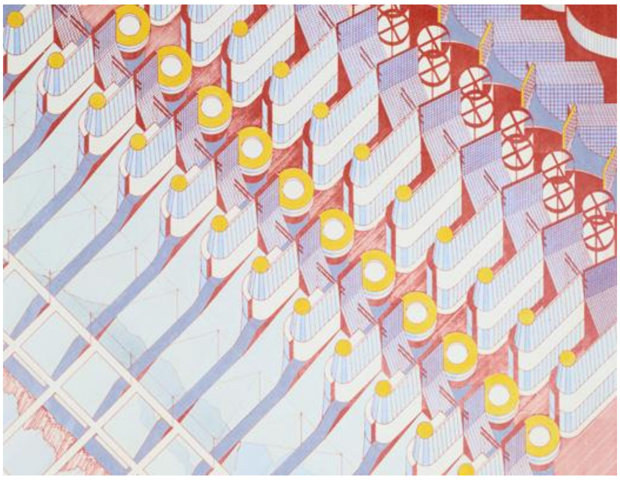


Figure 2.14: Design for Solar City by Peter Cook in 1980 is an example of how conceptual unbuilt design can be used to influence designs that are intended to be built. Image credit: Bingham et al. (2004, p.45).

A further facet of the intentionally unbuilt is fantasy architecture. Early films such as Fritz Lang's Metropolis in 1927 construct a fictional city forming a backdrop to the narrative. Other examples include Tolkien's Lord of the Rings trilogy of books, which provide rich descriptions of the fantasy world of Middle Earth. These stories were later turned into a series of films in the early 2000s enabling the fantasy architecture to be represented using digital techniques.

The most common form of intentionally unbuilt architecture can be seen in student projects. This is because their intention is purely to develop design skills to prepare future architects for practice where they will be required to build physically. Because such projects are not intended to be physically built, they can produce more imaginative designs as they are 'inspired not by ordinary programs but by design competitions and imaginary places students read about in books' (Novitski 1998, p.106). Student projects can later become significant in the body of work of an architect, for instance Stirling's thesis project whilst studying at the Liverpool School of Architecture is discussed in several biographies of his work as a demonstration of his formative years as an architect (Stirling 1984, Maxwell 1998a, Vidler 2010). The fact that intentionally unbuilt works of architecture such as Wright's Illinois Mile High Skyscraper and Stirling's thesis project are included amongst the architect's most recognisable works is a further indication of the blurring between what is real and what is not.

2.3 Reality and the built environment

The various designs in section 2.2 discussing different facets of built and unbuilt architecture begin to question the nature of reality in relation to the built environment. It also brings to light tendencies to reconstruct damaged or destroyed works of architecture as well as increasingly prominent studies into unbuilt designs of architects alongside those which were built. The following section will address this in detail, particularly focussing on the way in which buildings can be seen as memory prompts and how rebuilding a design is often selective and artificial. The role of modern media upon the way we perceive buildings, especially those we have not visited, will be discussed which then leads into an evaluation of the blurred boundaries into virtual reality.

2.3.1 Artificial and selective memory

The suggestion of physically rebuilding a damaged or destroyed work of architecture has to be addressed in two ways; firstly it can only be seen as an artificial mnemonic device, and secondly the question must be asked why a particular design is selected for rebuilding. Rebuilding or restoring works of architecture can be a powerful and persuasive tool due to their perceived permanence (Bevan 2006). This results in it being easier for many people to accept what they are seeing as real, even though it may in fact be a reconstructed or restored building.

In addressing the artifice of reconstructions Benjamin (1936) discusses how they lack presence in time and space and the unique existence that comes from being in a particular location at that time. This subsequently determines the history of a piece of art or architecture during its existence. He also states that this history is shown through physical changes in condition as well as changes of ownership, as discussed in section 2.1.1 examining weathering of buildings and changes of use (Benjamin 1936). In 1849 Ruskin is also critical of restoration and rebuilding;

> *"The thing is a lie from beginning to end. You may make a model of a building as you may of a corpse, and your model may have the shell of the old walls within it as your cast might have the skeleton, with what advantage I neither see nor care..."* (Ruskin [1849] 2004, p.25)

That said, he continues to declare that in some cases restoration is necessary, however, it should be 'understood on its own terms' (Ruskin [1849] 2004, p.25).

This critique is applicable to reconstruction and restoration projects such as the Frauenkirche and Villa Savoye where the difference between what is simulated and what is real becomes entangled. In this sense they become the perfect simulacra in which Baudrillard (1994) states that they exist in the 'hyper-real.' The hyper-real is the scenario where the signs of the real are substituted with the real, meaning that reality can no longer be thought of in terms of what is built, and what is not. Disneyland is discussed as an imaginary place designed to make the rest of the world look real; whereas in reality the rest of the world is also imaginary or hyper-real (Baudrillard 1994). This can be seen with the restoration of the damaged Villa Savoye; when compared to the original scheme it is easier to accept the restored version as *imaginary* (see Figure 2.4). However, if you compare the restored version of the Villa Savoye to Disneyland, it becomes a lot easier to accept it as *reality*.

Further blurring of reality can be seen in Warsaw where large sections of the Polish city were purposely destroyed by German troops towards the end of their occupation in the Second World War. As with other cases discussed, the decision was taken to rebuild a large number of the city's lost buildings. This raises the question of whether an artificial history is being created or a warped heritage;

> *"Was history being replaced by heritage when Warsaw's citizens chose to rebuild the historic core of their capital as an exact copy of what was lost? Purists may decry the decision as fakery and as Disneyfication, but to Varsovians it was a matter of pride and defiance to demonstrate that their culture had not been decapitated..."* (Bevan 2006, p.181)

The act of rebuilding can be seen as a necessity for the city to prevent its identity from disappearing; memories of what existed were not enough therefore artificial recreations were required as mnemonic devices to recapture the 'lost' history (Bevan 2006). However, in doing so, the entire wartime experience that occurred is suppressed, hence an artificial and selective memory being formed of the city.

Similarly, in the case of rebuilding the Frauenkirche discussed in section 2.1.2, the city of Dresden is selectively creating an artificial memory of itself as depicted in the 1930s; ‘the historian must thus be on guard to transcend the false painting of memory and modernity’ (Jarzombek 2004, p.53). However, this artificial creation via rebuilding is selective and therefore warped, as can be seen in the decision to rebuild the Frauenkirche, a Christian church, and not to rebuild the Jewish Synagogue destroyed by the Nazis during Kristallnacht. The new synagogue was built as a low modernist building, consequently removed from the Dresden skyline that its predecessor occupied (see Figure 2.15). In addition to this, attitudes towards erasing the country’s Fascist period can be seen in the restoration of the Taschenbergpalais; the building was used as a Nazi headquarters however a book celebrating the restoration project barely mentions this fact (Jarzombek 2004).

Figure 2.15: The original Dresden synagogue (left) occupied the skyline alongside the Frauenkirche. However, it’s replacement (right) is a low modernist building. Left image credit: Thümling (2011), right image credit: Godel (2010).

2.3.2 Alternative mnemonic devices

Artificial and selective mnemonic devices only act to enhance the blurring of boundaries between the virtual and the real. The complex and problematic nature of physically rebuilding architecture facilitates a discussion into alternative solutions for mnemonic devices.

Modern media, especially the internet, has enabled access to a wealth of information faster than ever before. For example, if a person were to plan an architectural trip to a city, they could quickly establish a route and research the buildings they wanted to visit online. This can similarly be seen in the use of books. In this sense, the buildings have therefore already been visited before the trip has even begun. Similarly, if a student of architecture presents a precedent study of a building, it is more often than not the case that they have not physically visited the building and have based their research on books and online sources such as digital images and videos. Bastéa (2004) discusses this development by splitting memory into two parts; memory through experience (body) and memory through education (mind). Using these terms, body memory would be the actual lived experience of a building through visiting it and mind memory would be the learned experience of a building through devices such as books, the internet or word of mouth. However, body memory is also ultimately part of mind memory as lived experiences are passed on to others as learned experiences;

> *"Memory of place seems to work in a similar fashion. We revisit our earlier experiences, adjust them, edit them, alter them, or erase them. We might experience architecture through our body but we remember it in our mind and heart."* (Bastéa 2004, pp.10-11)

This can be seen in the selective rebuilding of Dresden where peoples lived memories have been edited to form learned memories of others. Similarly, Bevan (2006) sees the viewing of buildings as prompts for memory, rather than them literally having 'memory' engrained into their fabric.

When comparing architecture that has been damaged or destroyed to the unbuilt, the potential use of alternative devices for memory, or research, becomes more significant. The use of learned memory is an essential tool for evaluating the unbuilt based on their nature. Therefore, such techniques can be adopted and used as an alternative to physically rebuilding a damaged or destroyed work of architecture. Questioning the nature of reality through the investigation of such projects, and whether or not they are in fact virtual reality, enables scenarios such as digital techniques to be suggested as devices to enhance understanding of lost or unbuilt works of architecture.

It must be stated that the use of media other than physical rebuilding cannot avoid artificiality as 'virtual depictions are empty (and) devoid of human beings' (Korn 2004, p.27). However, this is exactly the reason why alternative media should be used as it provides distance and prevents us from falling under the illusion that what is presented is reality, as can be seen in cases such as the Frauenkirche (Korn 2004).

2.3.3 Reality / virtual reality

The previous sections discussing the various facets of built and unbuilt architecture act to highlight how tendencies to view the world in terms of physical characteristics are increasingly irrelevant and should therefore be thought of in bits instead of atoms (Negroponte 1995). This is proposed in the sense that bits are not physical matter whereas atoms are. Such digital, or metaphysical, tendencies can be seen in modern living;

> *"In what ways can we talk about the real world, when to some extent we actually live in a virtual world, one in which the constraints imposed by social and political rules, by work systems, by personal and interpersonal behaviour are increasingly defined not in terms of physical absolutes but in terms of options that are mediated by cultural phenomena?"* (Lloyd Morgan and Zampi 1995, p.148)

Additionally, it is suggested that 'just as a building is only one version of an architectural idea, so all architecture can be said to be virtual, and true architecture beyond the real' (Lloyd Morgan and Zampi 1995, p.154). Laimer (1992) is quoted saying that 'however real the physical world is... the virtual world is exactly as real and achieves the same status, but at the same time it also has this infinity of possibility' (Laimer cited in Whyte 2002, p.29). This philosophy can be used to legitimise the investigation of historic works of architecture using digital techniques.

However, the use of virtual reality should not be seen as a replacement of reality, rather as a method of enhancing it. This is because virtual reality has different qualities to reality such as its relationship to time being distorted, for example a digital representation of a building may require multiple models simulating different points in time in order to understand it. On the other hand, the partial and abstract nature of being able to present multiple representations is one reason why virtual reality can be so useful (Whyte 2002).

Consequently, the use of digital techniques takes advantage of the often ambiguous reality of the built environment and is therefore utilised to enhance studies of it. For example, a project by Google has enabled the viewing of areas destroyed by the Japanese tsunami of 2011 using their street view tool. Viewers are able to compare areas before and after the tsunami evoking memories of what once was. It should be noted that the term virtual reality is meant as opposed to reality, rather than an immersive digital environment

2.4 Chapter summary

Section 2.1 explores the various facets of built architecture ranging from those that exist physically to those that have been damaged or destroyed. Focus is placed on specific examples of built architecture that question notions of reality and challenge perceptions of the built in order to demonstrate that the study and critique of unbuilt architecture discussed in section 2.2 should be equivalent to that of built architecture; as they are more similar in terms of their ‘reality’ than it may first appear. This is made apparent using case study examples of unbuilt architecture that are comparable to built architecture based on their significance.

The blurring of boundaries between built and unbuilt architecture is then used to form the start of a discussion into artificial and selective memory in section 2.3.1. The potential problems with rebuilding damaged or destroyed works of architecture are argued, particularly how such projects can be viewed as ‘Disneyfication’ of significant buildings as they are no longer real, rather a representation or imaginary version of reality. This is further discussed in section 2.3.2 where the role of memory is split into two sections of body and mind, therefore distinguishing between experiences that are acquired through encountering events physically and encountering events through another device such as digital media. This demonstrates further that we often view built architecture in the same way as unbuilt architecture; for instance many people investigating a built design will only have encountered it through media such as photographs, text, drawings and the internet which is the same media that is potentially available to view unbuilt designs. This is particularly apparent in modern society where the role of digital media is increasingly dominant. Continuing on from this, the chapter finishes by taking the approach of Negroponte (1995) that the world can be seen in bits rather than atoms, or rather that the world can increasingly be seen as digital rather than physical. This consequently leads to a discussion of different scenarios in the following chapter that utilise digital representation techniques as a method of critiquing works of architecture.

3 Digital scenario building

> *"Experimental video, computer graphics and virtual images have radically transformed the late-twentieth-century understanding of reality and continue to challenge the complex discourse surrounding visual representation"* (Pérez-Goméz and Pelletier 2000, p.3)

This chapter will discuss different scenarios that utilise digital representations as a method of critique in the form of reports, predictions, reconstructions and simulations. These four facets will be used to form section headings in which specific case studies undertaken by previous researchers will be explored. Finally, a process for avoiding uncertainty and ambiguity in such digital representations will be investigated.

Scenarios can be formed to enhance critique of an architect and works of architecture, which are represented differently depending on a building's status (see Figure 3.1). The titles listed in the diagram could be challenged as other researchers in the field pose different views and different definitions; however, Figure 3.1 has been developed for the purpose of rationalising and categorising different scenarios for the purpose of this thesis.

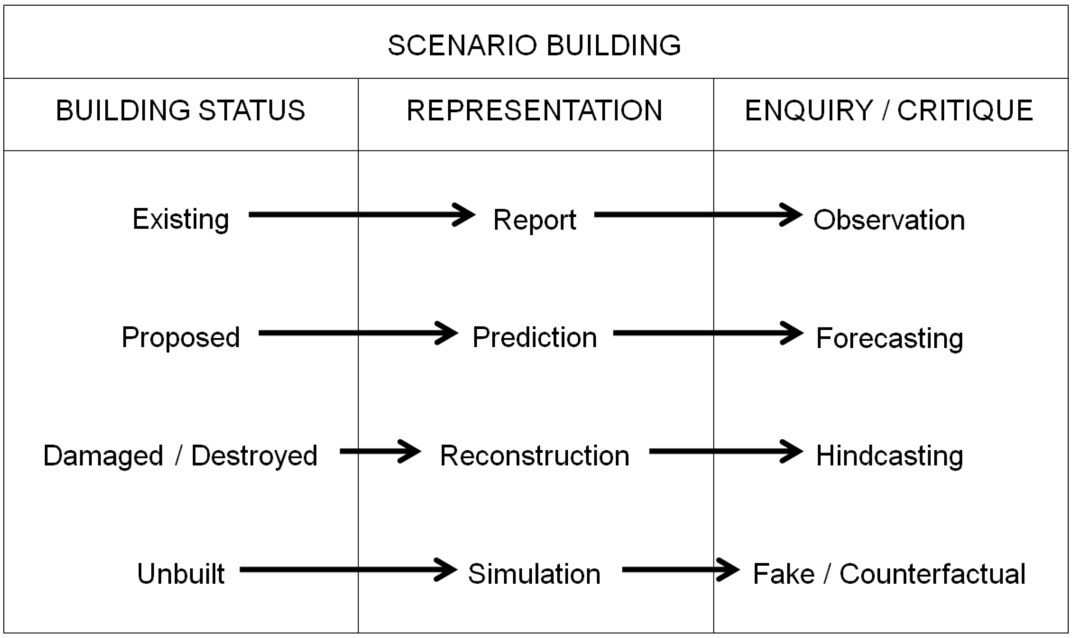


Figure 3.1: Scenario building diagram demonstrating the building status in relation to the digital representation technique required and consequent lines of enquiry and critique.

The building statuses listed in the first column of Figure 3.1 are taken from the flow diagram of the different facets of architecture in Figure 2.1. The second column includes types of digital representations based on the status of the building and the third column indicates the type of critique or line of enquiry required based on the representation created. For example, if an existing building is created as a digital representation it is referred to as a report and the lines of enquiry and critique would be formed by observations of it. The following sections will review specific cases that have utilised aspects of scenario building to enhance understanding of works of architecture and the built environment with focus primarily on the unbuilt, damaged or destroyed.

3.1 Reports and observations

Reports are the simplest form of digital representation as they are based on existing buildings. Therefore they can be surveyed and presented by studying what already exists using traditional measuring techniques. These can then be translated into two-dimensional computer aided design drawings and subsequently into three-dimensional digital models. More advanced methods of surveying what already exists include photogrammetric techniques and 3D scanning techniques such as point cloud modelling (Mitchell 1998). These will be discussed in detail in the following chapter.

In producing a report of a building, it is critical that accuracy is provided to ensure that errors are kept to an acceptable minimum in the same way that newspaper photographs, scientific or medical data avoid such errors (Mitchell 1998). This enables the report to be used as objectively as possible as an observation tool with the potential to inform design decisions if the building in question relates to the proposed design of another. An example of this can be seen in digital city modelling where the current urban fabric is presented digitally and used to test proposed designs against. This highlights how reports require accuracy that should be comparable to studying the building physically; if this is not the case it could result in errors occurring if a proposed design was to be built physically. Digital reports may also be used to visualise artefacts of historic, cultural and social importance which are inaccessible for reasons such as being too remote, costly or hazardous to visit; an example of this being the digital report of Skara Brae, a Neolithic settlement in Scotland (Maver and Petric 1999).

Virtual reports can also act paradoxically as a method of increasing knowledge of the real, as opposed to using the real to increase understanding of the digital as previously discussed when investigating reports conventionally (Di Mascio 2009). This is examined by Di Mascio in a case study using the ‘trabocchi;’ pile driven wooden structures in Italy suited to marsh lands, lake shores and coastal areas which are situated above water to easily enable fishing (see Figure 3.2).

Figure 3.2: The Trabocco of Punta Turchinio are complex structures that are very difficult to understand using conventional drawing techniques. Image credit: Di Mascio (2009, p.179).

The structures physically exist, however, they are vulnerable due to their location and materiality which means they are at a high risk of being damaged or destroyed. Additionally, the structures represent the heritage and way of life for many settlers from areas of France and Germany into Italy, of which only 25 still remain (Di Mascio 2009). The complexity of the structures meant that creating a report of them to aid future restoration or rebuilding projects would be difficult to create and understand using traditional two-dimensional architectural techniques. Therefore, three-dimensional digital modelling techniques were employed to create a more detailed report of them, as well as enabling a comprehensive study of their composition (Di Mascio 2009). This was greatly helped by the ability of the three-dimensional model to generate perspective and exploded axonometric views; especially as these could be taken from any position in virtual reality as opposed to the restrictions of reality.

The study of the ‘trabocchi’ is important as it indicates how digital representation techniques can be used to enhance understanding of existing buildings, which can be seen as a starting point for the potential use of such techniques for unbuilt works of architecture.

3.2 Predictions and forecasting

The second scenario derived from Figure 3.1 is digital representations of designs that are yet to be built. Such predictions can be used to critique design proposals by forecasting their likely impact, as well as illustrating to a client and other stakeholders what the proposal will be like visually (Mitchell 1998). Predictions act alongside reports in many respects, as they form the context of the proposed design intervention;

> *"The simulator's task is to combine the essentially arbitrary facts of the design with relevant facts and rules about the physical world, then accurately derive the visual consequences."* (Mitchell 1998, p.12)

Predictions can regularly be seen on construction sites indicating what the building in progress will look like once completed. If the visual predictions aim to be photo-realistic they can then be tested against the completed building for accuracy, especially if the lighting conditions and same point of perspective are taken (Mitchell 1998). Digital predictions are now commonplace in the architectural profession as well as forming a key critique tool in architectural education.

The use of predictions as a tool of critique has been utilised by Harfmann and Akins (2000) as an alternative way of presenting building construction lecture material to students of architecture. This was achieved by borrowing techniques used in crime forensics; digital models of building components were used to demonstrate and rigorously investigate various assemblies and construction methods and the implication they had on a proposed design. It was felt that traditional methods of teaching were inadequate and did not enable students to engage with and understand construction methods properly. This was due to the impracticalities of a class of students visiting a building site or bringing various physical examples of construction materials into a lecture theatre (Harfmann and Akins 2000).

Constructing the various components in three dimensions digitally allowed anomalies to be spotted easily, for example when a brick cladding system was assembled in conjunction with a steel frame with a base designed for the steel frame; the brick slips appeared to float. Once this anomaly was spotted, different ways of solving it could be tested (Harfmann and Akins 2000). The research is important as it defines the term digital forensics in architecture; such digital techniques could be transferred to studies of historic architecture.

In many respects, the boundaries are blurred between whether the use of digital representations by Harfmann and Akins can be classed as predictions, reports or simulations. This is because they could be produced using a range of case studies that are either existing buildings, proposed buildings or unbuilt works of architecture.

3.3 Reconstructions and hindcasting

Digital reconstructions of buildings that once existed but have since been damaged or destroyed begin to pose more complex issues regarding the way in which they are constructed. This is due to the fragmentary nature of evidence available to create such reconstructions; if a building is damaged or destroyed, it is likely that surviving source data will also be fragmented. Whereas reports are primarily based on evidence from an existing building and predictions on a proposed design's drawings, digital reconstructions rely on a variety of sources such as fragmented physical remains, historic images and photographs, surviving architectural drawings and written accounts. It is likely that this primary information will be incomplete, therefore additional sources such as investigating the architect's other designs, monographs and biographies as well as contemporary buildings and techniques may be required for inference purposes.

The source data available to produce digital reconstructions can be categorised into two sections; those based primarily on physical archaeological remains and those based primarily on representation media such as drawings and text. However, it must be made clear that these categories may overlap if additional source data is available, for example surviving drawings may be accompanied by physical remains.

When examining reconstructions based primarily on physical remains, many cases can be found in the field of archaeology, with one of the first publications exploring this being Forte and Siliotti's 'Virtual Archaeology' (1997). In the foreword of the book it states that the process of constructing a digital representation is more critical than traditional methods as it has to be created in a 'logical and structured and ultimately more fruitful way' (Renfrew 1997, p.7). This is because the three-dimensional nature of digital models results in them having to be considered thoroughly and systematically with archaeologists and other parties answering questions regarding construction and likely scenarios of what once was. On the other hand, traditional two-dimensional representations such as hand sketching can easily disregard parts of the image that are unseen, hence being less critical.

Archaeological fieldwork paradoxically involves damaging or destroying sites of investigation as layers of history that have accumulated over time have to be excavated to reach older remains below (Forte 1997). There is also a risk that excavation will damage or destroy the artefacts in question, such as burial chambers in Egypt containing tombs being opened, which consequently affects the microclimate, resulting in rapid deterioration of the spaces and artefacts. The use of virtual reality could help to minimise such destruction, as the analysis switches from physical to digital, however there is still a risk of permanently damaging an archaeological site due to the excavation process to obtain primary data. Crucially, the majority of cases presented by Forte and Siliotti (1997) are critical in the sense that they investigate the source data in order to produce a satisfactory virtual reconstruction, however, they are rarely considered beyond this.

Introducing critique and analysis of damaged or destroyed architectural and archaeological sites using digital techniques is referred to as hindcasting (Knight et al. 2001). This is proposed in the sense that layers of history excavated are presented backwards in time, as opposed to using predictions for forecasting forwards in time. Hindcasting investigates 'the potential benefits that 3D modelling and subsequent computer-based analyses can bring to historical research over and above straightforward virtual reconstruction' (Knight et al. 2001, p.531). For example, a case study investigating the abandoned settlement of Manah in Oman presented several iterations of the area over time in order to demonstrate scenarios such as changing tribal ownership patterns (Knight et al. 2001). Similar studies have been carried out with focus on how such techniques can be used to augment lecture material in architectural history by presenting the built environment digitally at different periods of time;

> *"...research has shown that students encounter difficulties in understanding the sequence and the overlapping of events over the course of a site's history when using traditional learning methods."* (El-Khoury et al. 2006, p.833)

By producing a series of models rather than one single reconstruction of an artefact over time, a more thorough and truthful account of it is formed (see Figure 3.3). This contrasts to physical reconstruction projects such as the Frauenkirche where the aim is limited to providing one 'definitive' representation, which can be deceptive in terms of fully explaining the building's entire history.

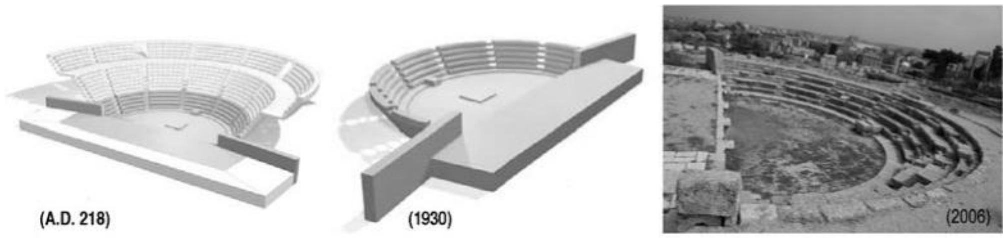


Figure 3.3: A series of representations showing the development of the Roman theatre in Byblos, Lebanon. Image credit: El-Khoury et al. (2006, p.836).

The use of digital tools to enhance understanding of physical architectural and archaeological remains can be traced back at least to 1985 where a study of Bakenrenef's tomb in Egypt used two-dimensional techniques. The project aimed to piece together more than 8000 broken off segments from a wall of hieroglyphs which was achieved by scanning the pieces digitally then arranging them in the presumed correct order. Poorly preserved pieces were inferred by comparing them against the best preserved pieces, such as using their colours to match against (see Figure 3.4). Referring back to Negroponte (1995), who states that the world should be seen in bits rather than atoms, digital techniques were advantageous as many of the pieces were situated in museums around the world, meaning it would have been a hugely political and difficult task bringing them together physically (Carmela Betro 1997).

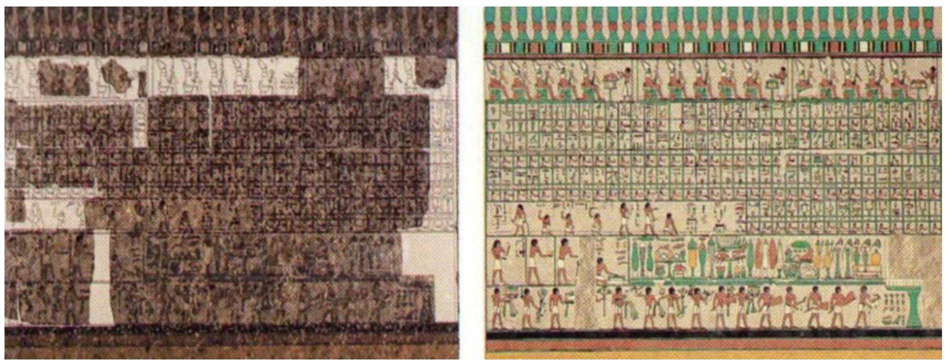


Figure 3.4: Original pieces of Hieroglyphs from Bakenrenef's tomb (left) were scanned digitally and re-presented to include the inferred sections (right). Image credit: Forte and Siliotti (1997, p.36).

A more recent example of digital reconstruction based on physical remains investigates Ancient Greek Ionic Capitals (Richens and Herdt 2009). The research presented two sets of models; digital reports of the capitals in their current state, formulated using point cloud scanning, and full digital reconstructions based on the scans (see Figure 3.5). As an analysis technique this can also be seen as hindcasting; working backwards in time from the current state of the artefacts. The capitals were scanned at various locations in Greece as well as the British Museum, again demonstrating how digital media is very valuable for comparing information that may be difficult to achieve physically. As the research is based primarily on physical remains, it highlights the potential problems with traditional media such as creating architectural drawings of the capitals using callipers and a profile gauge;

> *“Usually plan, front and side elevation are produced with some profiles, but multiple sections only rarely. Not surprisingly, given the complex three-dimensional nature of the objects, such drawings do not provide a full description.”* (Richens and Herdt 2009, p.810)

The process of reconstructing the capitals was not without interpretation. For instance, certain areas could not be scanned which left gaps in the digital model. These were capped as they needed to be solid and ‘watertight’ for rapid prototyping; therefore the missing data was coloured black to distinguish it from the other elements. In this way the viewer was able to differentiate which sections were interpreted and which were a direct translation from the scanned reports. Such issues of ambiguity will be discussed in detail in section 3.5.

Figure 3.5: Physical remain of a capital in the Delos Museum (left) compared to the digital report overlaid against the digital reconstruction (right). Image credit: Richens and Herdt (2009, p.813).

The project demonstrates how the laser scanned reports act as a durable, accurate and complete record of the current state of the capitals which when ‘compared to the traditional measured drawings, (are) objective in the sense that they are free of selection, interpretation and internal inconsistencies’ (Richens and Herdt 2009, p.815). Additionally, although the digital reconstructions are interpretive, they are more plausible than traditional drawings because of the rigorous process needed to construct them in three dimensions.

As previously mentioned, the issue of interpretation in digital reconstructions is critical as ‘such geometric representations though useful may actually convey a misleading degree of completeness and finality that hides many discontinuities and fragmentary knowledge’ (Bharat 2005, p.1). This can be seen as a dangerous tool in the field of architecture and archaeology, as the resulting digital representation may be used only to convey ‘pretty pictures’ (Goodrick and Earl 2004). Research utilising Chartres cathedral as a case study discusses how digital models can be deceptive as the cathedral took over thirty years to build with many different teams of masons, as well as the second tower being built 350 years after the main building (Bharat 2005). The digital representation can be seen as a report, starting from the current state, and then looking at the various points of significance in its history via hindcasting, such as adding a second tower. There are many competing theories about the process of construction of the cathedral which may not be apparent in straight forward digital reconstruction. Consequently, it is argued that it should ‘suggest evolving commentary of arguments or interpretations rather than conclusive documents’ (Bharat 2005, p.2). The research by Bharat (2005) also exposes a problem in the digital reconstruction community that there is ‘no tradition of critique and scholarship’, hence the many different methodologies that emerge through studying the field. It does, however, indicate that multiple interpretations of a digital reconstruction are required to present a more truthful account of a building. This sentiment is echoed by Goodrick and Earl (2004) when investigating how archaeological digital reconstructions are formulated;

> *“Upon interacting with the model the specialist immediately began asking questions such as ‘what if that stone was there’, ‘what if we approached from here’, and so on, making emotional response judgements to the artificial space. In part this prompted the current model which presents the different interpretations of the orientation and configuration of missing stones. Noticeably, however, such explorations of models are rarely presented in print.”*

This lack of analytical discussion in documentation of research is addressed by Mark (2011, p.868) who states that dialogue into how a reconstruction is inferred should be recorded to ‘help the next generation of researchers to either more completely validate or to challenge the logic with which the three-dimensional computer model was made’. Such speculative reconstruction is especially apparent with archaeological remains, as they tend to be below ground and consequently higher levels of a structure such as the roof will more often than not have to rely on increasing levels of inference. In a case study of Thomas Jefferson’s Montecello in North America, digital reconstruction techniques were used to convey to visitors what the now destroyed building may have looked like (Mark 2011). The whole reconstruction process was recorded, including dialogue and conflicting opinion between relevant experts, hence several likely scenarios of what may have been. For example, contemporary construction methods played a key role in establishing the digital reconstruction; however this had to be amended as additional information and opinions were taken into account. Crucially, the reconstruction is itself interpretive as it is presented alongside the source data in the form of plans of the surviving archaeological ruins as well as the reasoning why and how assumptions of unknowns were made (see Figure 3.6).

> *“Having access to this primary information, researchers or more casual visitors in the future may be able to better judge the validity of the assumptions made, retrace the thinking that led to them and add their own perspectives.”* (Mark 2011, p.869)

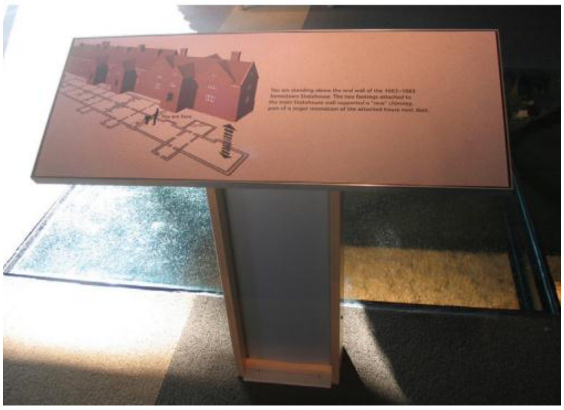


Figure 3.6: Display of the Montecello reconstruction placed in relation to the physical site data; the foundations. Image credit: Mark (2011, p.869).

Other studies into digital reconstruction attempt to future proof the data by making clear the process of reconstruction in relation to the source data available (Masuch et al. 1999, Kensek et al. 2002). Such studies will be discussed more thoroughly in section 3.5. An example of this highly analytical approach to digital reconstruction is demonstrated in an investigation into Thule Whalebone architecture, where physical whalebone remains were constructed digitally then assembled in various scenarios in order to enhance understanding of their symbolic importance to ways of living of Thule people (Dawson and Levy 2005). The cases discussed represent a transition away from straight forward digital reconstruction towards an increasingly analytical approach in contemporary research.

Examining digital reconstruction projects based primarily on media such as architectural drawings, photographs and text contrast to those based primarily on archaeological remains largely because of the point in time in which they were originally constructed. Reconstructions based primarily on physical remains tend to be much older than those based on images and text; for example an investigation into Jewish Synagogues destroyed in Germany just before the Second World War were based primarily on drawings, as very little physical evidence still remained (Darmstadt University of Technology, Department CAD in Architecture 2004). Additionally, in scenarios where physical remains may be present, it is probable that these may only be in the form of excavated evidence such as surviving foundations, therefore sources including architectural drawings greatly enhance the validity of such reconstructions. Also when dealing with ancient remains the likelihood that original documentation will have survived, if ever created at all, is doubtful.

Wright’s Larkin building, originally built in 1906 in New York, was demolished in 1950 and replaced by a car park. The building was digitally reconstructed by the Savannah College of Art and Design based on sketches, construction drawings, black and white photographs and written accounts as well as excavating part of the car park site to get brick samples of the original building for colour and texture mapping (Novitski 1998). The use of construction drawings in particular indicates how there may have been less issues of ambiguity assuming that they were all available. However, the need to consult written accounts by Wright and others indicates that this was not the case, yet methods of interpolation and extrapolation are not discussed in the written documentation of the case.

The already mentioned project to digitally reconstruct synagogues in Germany addresses this issue of missing data, even though it is stated that they were based on extensive and highly reliable source information (Martens and Peter 2002). The reliable source data included planning and alteration drawings, however, information regarding internal fixtures and fittings were scarce. Therefore supplementary information such as a small number of surviving black and white photographs of the interior were used. The research acknowledges that due to this, the precise colour and materiality of the lost buildings cannot be assured. This is crucial as it prevents the viewer getting into the situation where they assume that what they are looking at is fact. Martens and Peter (2002) also discuss how surviving photographs of a damaged or destroyed building can act as a mechanism to check for discrepancies in the digital reconstruction in order to maintain a high level of accuracy. Similar to some examples of archaeological digital reconstructions, such as Mark (2011), the synagogue project begins to investigate how such representations can be used as analysis tools. For example, the layer structure of three-dimensional digital modelling software can be utilised to highlight and isolate particular elements including columns or windows (see Figure 3.7).

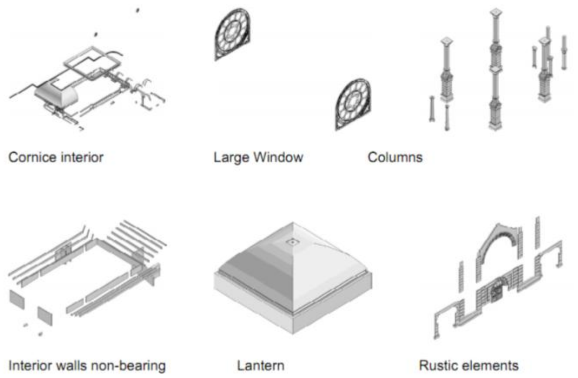


Figure 3.7: Various elements of the digital reconstruction of Synagogue Kluckygasse are isolated so they can be examined individually. Image credit: Martens and Peter (2002, p.354).

Put simply, the case studies discussed so far demonstrate that the more source data available for a digital representation; the more accurate they are likely to be. They also confirm how digital reconstructions began simply as a visualisation tool similar to two-dimensional sketches or physical models and then became more complex as it became apparent of their use as analytical tools.

Shape grammars and parametric modelling are utilised as an analytical tool by Coutinho et al. (2011) to provide a contemporary interpretation of Alberti’s column system. Alberti’s treatise documenting his ideal design solutions were text based, therefore offering a different source of primary information to create a digital reconstruction of a design. This project builds on research investigated by others using shape grammars in a digital context (Li 2000). The project therefore utilises grammars ‘as a complimentary tool to be used by architectural historians to test hypotheses raised after documental sources’ (Coutinho et al. 2011, p.789). In this sense, the research can be seen as generating lines of enquiry in order to provide enhanced knowledge of Alberti’s designs. Again, the importance of such studies is their ability to interpret a design using text based documentation, rather than image based documentation which is often seen as the most common source in such research.

3.4 Simulations and counterfactuals

In contrast to digital reconstructions of damaged or destroyed buildings, digital simulations of unbuilt architecture do not have physical remains as a reference source. Therefore, as opposed to using hindcasting to analyse what once was, simulations are used to counterfactually investigate what could have been.

Counterfactuals literally mean scenarios that are counter to fact, or events that did not happen. Predictably, this type of enquiry has been regarded with suspicion in the broader field of historical research, with investigation into the subject often dismissing it as being mere ‘parlour-games’ (Climo and Howells 1974, Carr 1990). In architecture, digital simulations of the unbuilt can be used to form the starting point of a counterfactual line of enquiry, with the created simulation being used to test ‘what if?’ scenarios. Mitchell adds to Carr’s concern by stating that;

> *“...counterfactuals, in general, are very slippery things. They are only of real interest if the counterfactual premise specifies an apparently plausible alternative at some particular juncture in history.”* (Mitchell 1998, p.11)

The inclusion of plausibility and realism is essential in arguing the case for counterfactual history; without plausibility the enquiry becomes mere fantasy. In this sense, the subject is repeatedly its own enemy as it has a tendency to discredit itself by suggesting implausible scenarios (Ferguson 1999). This is because central to all historical enquiries is evidence, and in many cases of historical research you cannot have direct evidence when dealing with a scenario that is by definition counter to fact (Bunzl 2004). This opinion comes from a deterministic approach which frequently prevails in history; the view that everything is predetermined along a chosen path over which we have no control. This attitude consequently renders counterfactuals as useless, as no alternatives could have possibly occurred anyway. Similarly it has been argued that history should not try to explain what may have occurred, only what did occur based on the evidence available with conclusions prepared from that alone (Oakeshott 1986).

However, architecture is unique in the sense that representation techniques are required to construct a building, therefore by their very nature they leave behind representation evidence of what could have been physically built, hence validating research into counterfactual scenarios. Ferguson (1999) defends the use of counterfactual scenarios in line with Oakeshott’s comments;

> *"The historian attaches his own meaning to the surviving remnants of the past which he finds in his pursuit of an answer to a given question. Equally clearly, his answer, when it is published, must make some kind of sense to others. But who chooses the original question? And who is to say whether the reader's interpretation of the finished text will correspond to that intended by the author? Above all, why should counterfactual questions be ruled out?"* (Ferguson 1999, p.52)

This alludes to the fact that if a number of historians studied the same subject, although they may produce similar conclusions, they will all vary to some degree. This is important as it highlights that counterfactuals are one way of interpreting events that happened; to suggest that there can only be one overall or definitive version of a historical event is false as previously discussed in earlier sections of the chapter. Deterministic approaches to history results in all of the options or different possible scenarios being closed as they have already happened and are set along a predetermined course anyway. In contrast, in the present there is an unlimited number of paths we can take into the future if we reject deterministic principles. What counterfactuals allow us to do is put ourselves in the place of the actor at the time and try to understand the different options they had available in *their* present.

Suggesting alternative truths in history must be as plausible and realistic as possible. This is achieved by studying contemporary empirical evidence such as architectural drawings, images and text which gives them their explanatory power (De Mey and Weber 2003). Based on this, an investigation into all of the alternatives available to the person/scenario can then be considered. Often, the counterfactual argument considered would have been more likely than the actual outcome at the time (Ferguson 1999). For example, when Lutyens began designing the Liverpool Metropolitan Cathedral in 1929, it is highly unlikely that he would have considered the prospect of completing the crypt only, and introducing a new design by another architect.

Counterfactuals enable us to show the importance of an event, for instance 'X happened and consequently led to Y, but if it had not then Z might have, which shows us how important X was'. We can enhance our understanding of what actually happened by understanding what did not; which is referred to as contrastive reasoning. In this sense, counterfactuals are useful for augmenting the traditional aim of historical discourse, even if they are inherently fictional (De Mey and Weber 2003). If the aim of counterfactuals is to understand the difference an event made, the role of determinism is also irrelevant as it does not matter whether an event is predetermined or not; the value lies in how significant it was (Bunzl 2004, Bulhof 1999).

The idea of constructing counterfactual or fake scenarios of the architectural unbuilt via digital simulations are used to propose ‘an alternative version of an object, or a set of facts surrounding that object to provoke debate and reaction’ and ‘to foster richer debates, and to challenge accepted premises’ (Brown 2001, p.698). Brown (2001) investigates counterfactual scenarios using an incomplete scheme by the architectural practice Connell, Ward and Lucas in London (see Figure 3.8). The drawings found to construct the digital model were predictably incomplete; therefore the context of the design had to be understood, such as investigating the architect’s other work in terms of innovative techniques they utilised, what the contemporary climate was like in terms of prevailing styles and economy, as well as understanding the urban and physical context of the design (Brown 2001).

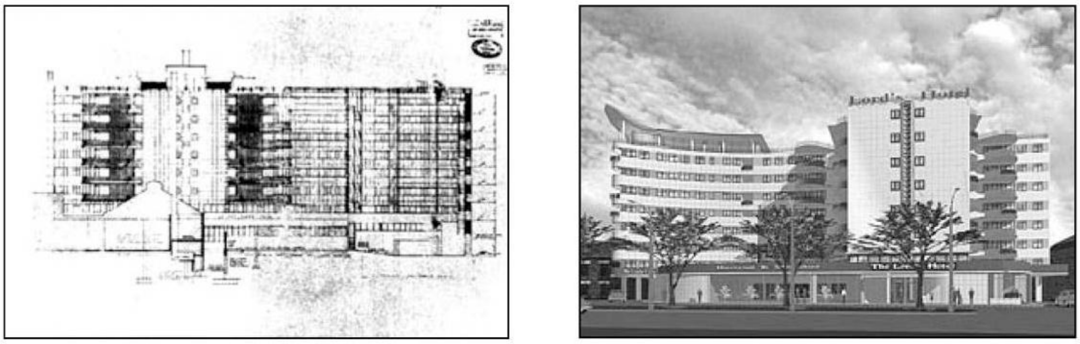


Figure 3.8: Original drawing of the Lords Court design by Connell, Ward and Lucas (left) and the digital simulation (right). Image credit: Brown (2001, p.701 and p.703).

One finding from analysing the digital simulation revealed that the building was completed physically to first floor level, rather than just the foundations as previously thought. The research suggests that the digital model can be used to pose lines of enquiry such as ‘whether the practice deserves a more prominent place in the history of the Modern Movement’ (Brown 2001, p.700). Studies prior to this tend to be less analytical and more focussed on producing images captured from a three-dimensional digital model as well as providing digital walkthroughs. This can be seen in examples illustrated by Novitski (1998) such as a digital simulation of Wright’s Illinois Mile High Skyscraper, which was discussed in section 2.2.3. However, such studies were crucial developments in digital studies of unbuilt, damaged or destroyed architecture, and the time the research was produced reflects the lack of analysis illustrated as such techniques were relatively new.

In terms of source data, some unbuilt works of architecture remain primarily as written documentation, for example Wojtowicz's study of Le Corbusier's vision for a set of villas as discussed by Novitski (1998). The research investigated the architect's writings, one in which he describes the geometric logic that forms a basis for his designs. Only a few sketches of the villas were produced, but primarily based on the writings available describing their geometry, Wojtowicz was able to produce simulations of the villa designs using guidelines set out by Le Corbusier such as the use of the golden rectangle (see Figure 3.9).

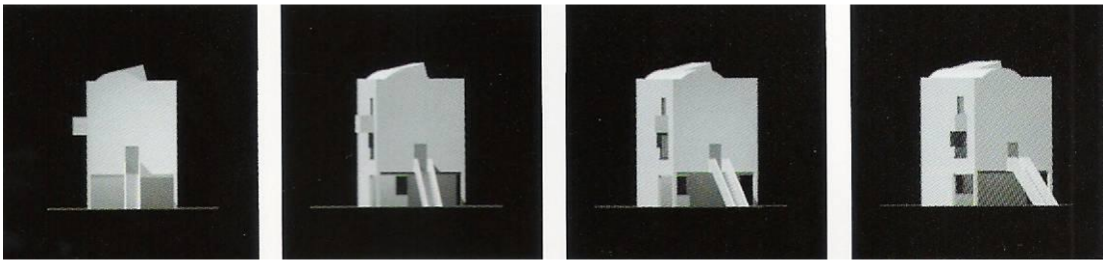


Figure 3.9: Wojtowicz's visual simulations of Le Corbusier's unbuilt villas are produced primarily on written documentation. Image credit: Novitski (1998, p.89).

Sass (2001) also primarily used written sources to investigate Palladio's unbuilt villas and how rules he wrote can form the basis of a simulation. These took the form of a 'villa manual' which would ultimately lead to the simulation, or 'villa model'. Examples of rules generated from studying the written sources were 'staircases may not obstruct other places, nor be obstructed by them', and 'three openings are required in staircases' (Sass 2001, p.217). Such rules begin to suggest how models of historic unbuilt or destroyed architecture could be represented parametrically. The rules created were not always successful; for example, a comparison between plan and elevation drawings revealed that they did not match. Therefore the author created a series of logical steps to ensure clarity in the modelling process, such as making sure the initial shape was correct and then adding further detail (Sass 2001). These rules were based on a grid which was formed on the dimensions of a Vicenzentine brick. The very process of constructing the model using Palladio's rules revealed elements that did not work such as windows being too tall to fit floor to ceiling heights on some floors. This process helped to redefine the rules as well as providing new information about the designs;

> *"Conflicts were the project's greatest asset as they lead to design investigation or intention. Palladio's designs thrived on conflicts between the rules. Adhering to major design rules while breaking lesser rules*

> *forced him to invent new design solutions to classical design problems."* (Sass 2001, p.223)

Some sections of the model which were unknown such as determining which historic order the columns were. Therefore several alternatives were presented showing different column types based on research into similar contemporary buildings. The project demonstrates how simulations of unbuilt works of architecture can enhance knowledge of an architect through a process of rigorous questioning and analysis. Other investigations into Palladio's unbuilt work have focussed more on producing a photo realistic simulation and consequent spatial analysis this enables, as well as the morphology of the design development (Sdegno 2008). The intention of this research is closer to the first Palladian example which reveals there is much that can be learnt from the modelling construction process and resulting analysis in addition to straight forward spatial analysis via techniques such as digital walkthroughs.

3.5 Problems with ambiguity and uncertainty

The case study examples discussed in the previous sections of the chapter demonstrate that the source data available to produce digital representations is almost always incomplete. Therefore there is a danger that the viewer of such representations may believe that what they are seeing is complete, whereas in fact it is highly likely they will have been created based on incomplete information. This can also be seen in the built examples discussed in chapter two, which are ambiguous in terms of levels of reality such as the Frauenkirche and the Villa Savoye. Consequently, methods need to be addressed to avoid ambiguity and clarify the different levels of inference required when constructing digital representations of damaged, destroyed or unbuilt works of architecture.

3.5.1 Levels of inference

Elements of a digital representation being constructed will require levels of inference in order for them to be visualised completely. One solution to this is simply to present only the known information, however this could lead to an incomplete picture of a design which may not be an appropriate representation depending on the nature of the study. As such, the degree of inference varies depending on the nature of the source data as demonstrated in Figure 3.10 (Masuch et al. 1999):

Level of inference	**Definition**	**Example**
Primary evidence	Actual evidence directly available for representation.	*Architectural section drawing of an unbuilt design.*
Deductions	Information that can be deduced directly from findings.	*Excavated foundations of a destroyed building indicate a wall.*
Analogies	Information derived from other contemporary architecture.	*Course stone is used in similar local buildings of the same period.*
Assumptions	No evidence available but known elements indicate something had to be there.	*Building had to be two storeys as walls were too thin to support three floors but too wide for a single floor.*

Figure 3.10: Table demonstrating levels of inference when producing digital representations of damaged, destroyed or unbuilt designs. Adapted and expanded from Masuch et al. (1999).

The starting point of creating a digital representation is therefore to investigate all of the primary evidence available such as physical remains, architectural drawings, models, surviving images and text. If a complete reconstruction can be created from this information then it will avoid ambiguity of any kind, however, this is a highly unlikely scenario. Therefore the next step is to deduce from the primary evidence whether unknown elements can be inferred directly, such as foundations of a destroyed building indicating where a wall once was. If this process is undertaken and there are still unfinished sections which need to be completed then the next step is to form analogies based on evidence from other contemporary sources. For example, a surviving building from the same period and of a similar style would form a key piece of evidence to fill in unknown elements of the digital representation in question. Finally, assumptions may have to be made if the primary evidence suggests a section is missing but there is very little evidence to suggest how it could be built, for example wall thicknesses indicating how many storeys a lost building may have been (Masuch et al. 1999). Figure 3.11 has been created to explain the process:

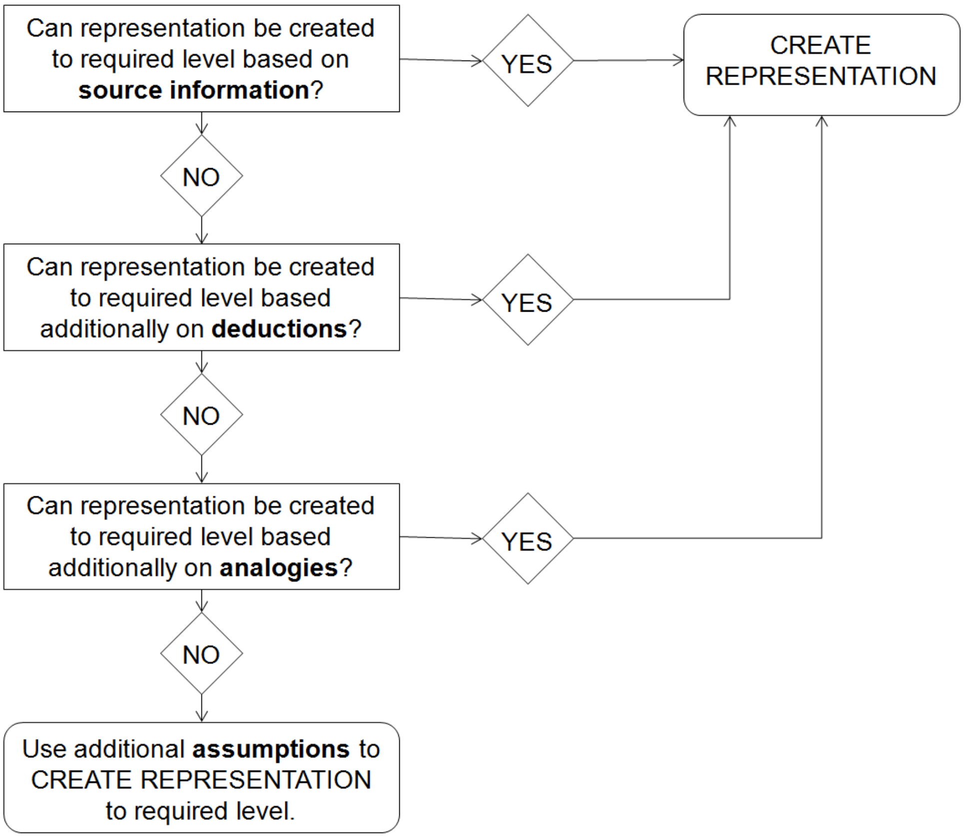


Figure 3.11: Flow diagram demonstrating a process to undertake when creating a digital representation of a damaged, destroyed or unbuilt work of architecture.

The process that has to be carried out in order to create a representation is itself the start of a critical review into unbuilt, damaged or destroyed architecture. This is because of the systematic and methodical critique that has to be undertaken in order to make deductions, analogies and assumptions to fill in missing information.

3.5.2 Avoiding ambiguity

Now that a method has been defined in Figure 3.11 to aid the process of creating digital representations, techniques need to be identified to demonstrate to the viewer that what they are viewing is almost certainly based on partial information. The following suggestions are made by investigating various sources dealing with the issue of avoiding ambiguity in digital representations (Mark 2011, Knight et al. 2001, Kensek et al. 2002, Kensek 2005).

- Leave unknown elements of the representation blank.
- Show the reconstruction overlaid on the actual evidence collected.

- Label the missing elements to indicate they are based on partial information.
- Visually show the missing elements are different by using colour, shades, greyscale against colour, line drawings, alternate patterns or dashed lines.
- Show several alternative scenarios to represent missing elements.

The first instance of leaving unknown elements blank would allow the clearest reading of the material in terms of avoiding ambiguity. However, this may conflict with the purpose of the digital representation, for instance if a lighting study was performed on a design it is highly likely that a complete digital model would be required, therefore an unfinished representation would be unacceptable. Consequently, methods should be used such as displaying the inferred representation alongside a representation showing the actual evidence collected only. Additionally, the inferred representation could be displayed alongside the original source data to allow the viewer to see for themselves which elements are known and which are inferred (Kensek 2005). Other methods could also be utilised such as labelling the inferred sections of the digital representation.

Knight et al. (2001) produced digital representations of ancient settlements in Manah based on partial information and displayed them using line drawings in monochrome; rather than full photorealistic renders as used in other schemes with more amount actual evidence available. Therefore, an amount of interpretation was required when viewing the images which is suggestive that not all information was known, whereas photorealistic images are much more suggestive of truth, hence avoiding their use.

On the other hand, Kensek et al. (2002) state that levels of uncertainty should be shown directly in the digital model rather than implying them with other methods, for example, using line drawings and monochrome. This could be achieved in several ways as outlined above, such as presenting a representation using false colour (see Figure 3.12). For instance green could show a high level of confidence in the source data suggesting it is realistic and red could suggest much less confidence (Kensek et al. 2002). Similarly, varying opacities could be used with opaque representing most confidence to transparent representing least confidence (see Figure 3.12).

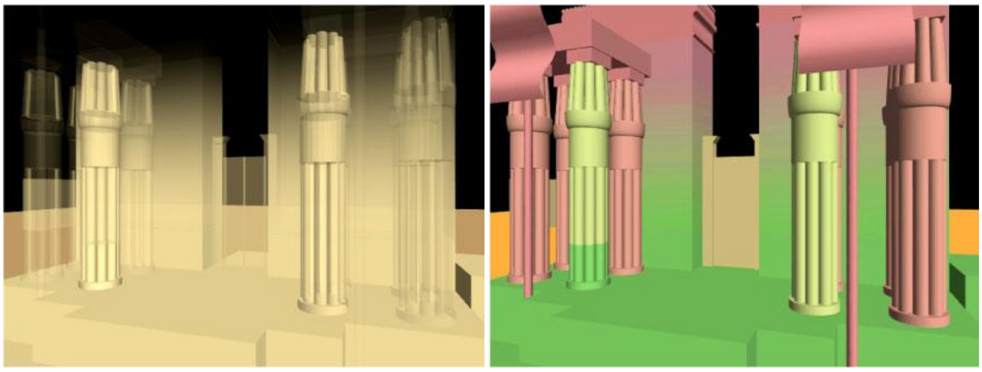


Figure 3.12: Kensek et al. (2002) suggest different levels of confidence in a representation using different opacities (left) and different colours (right). Image credit: Kensek et al. (2002, p.292-293).

The final method of avoiding ambiguity is to present several versions of unknowns. This suggests a much more critical analysis of unbuilt, damaged or destroyed works of architecture which can be seen in the study of Jamestown and Monticello;

> *"...the range of digital resources embodies several alternative lines of reasoning beyond that which can be provided by the three-dimensional model. It provides a representation not only of the structure but also of the archaeological evidence, and the assumptions and reasoning used to reconstruct buildings on the site."* (Mark 2011, p.871)

This highlights how representations of the most likely scenario based on the evidence available can be presented alongside several other versions indicating different scenarios of what might have been; therefore the quality of the representation is not compromised by avoiding ambiguity in a single model.

3.6 Chapter summary

The aim of this chapter is to introduce an approach to digital scenario building based on Figure 3.1 in order to provide rationale to a subject that is often fragmented in terms of an overall theoretical approach. Each scenario is dependent on the building's status in terms of being existing, proposed, damaged/destroyed or unbuilt which then enables the process of creating a representation and initiation of analysis. Based on this, case studies investigating aspects of digital scenario building by other researchers are then discussed in line with the different sections of reports, predictions, reconstructions and simulations. This is undertaken in order to understand what has already been achieved in the field, which elements can be utilised for the research presented here and finally to demonstrate which elements are not appropriate. The review of other research reveals that the majority of earlier cases have focussed on spatial analysis of digital representations whereas later cases tend to focus on one analytical technique. Therefore the introduction of a methodology for critique that was suggested in chapter one represents an original approach using a combination of techniques to analyse damaged, destroyed and unbuilt architecture (see Figure 1.1).

The chapter concludes by discussing the problems with ambiguity and uncertainty in creating a digital reconstruction or simulation of a design. This is one of the most conflicting areas of the research as it is crucial that the viewer understands that the representation is almost always based on fragmentary evidence. Therefore methods of providing clarity are discussed in section 3.5.2 as well as suggesting a flow diagram representing best practice when dealing with unknowns in Figure 3.11. The next stage of the research is to address the various techniques available to analyse digital representations, as the literature review shows that the focus should be on critique and analysis rather than simple visualisation and spatial studies.

4 Toolbox of Techniques

> *"Like other instruments, such as telescopes and microscopes, computers can help designers see what cannot be seen by the naked eye... In that capacity they go beyond drafting and modelling tools, because the visualisation can reveal details and nuances that formerly only a very talented artist could draw."* (Kalay 2004, p.75)

This chapter will consider the development of representation techniques throughout history and their influence on art and architecture. This will give particular focus on how the use of representation techniques has resulted in enhanced critique of a subject and a quest towards objective truth. An overview of the introduction of computer aided techniques in the architectural profession will then be discussed in order to demonstrate their impact. Finally, the chapter will present a comprehensive range of digital tools available in which their potential use to enhance critique of damaged, destroyed or unbuilt works of architecture will be examined.

4.1 Development of representation techniques

The use of mediating techniques in architecture is not a new one; links between drawing and building can be traced back to the Near and Far East, Mesopotamia, Ancient Egypt and Greece. Since these times architects and master builders have made use of devices that represent significant buildings to enable their construction, rather than being the literal 'maker' of the buildings themselves (Pérez-Goméz and Pelletier 2000). Consequently, when architects build, they 'influence construction only indirectly, at a distance' (Allen 2009, p.3). These devices primarily include representations such as drawings, text and models. Over time, their use has gradually increased until representation eventually became an inherit part of the architectural design process.

4.1.1 Introduction of the mediator in Ancient Greece

Earliest history suggests that representation was not needed in buildings such as primitive huts, which were simply built by the occupier without the need of an architect. Additionally, it is argued that in Ancient Greek times scale drawings of temples would have lacked calibration devices to check measurements, therefore construction inaccuracies may have occurred. Consequently, the focus would have been on creating repeatable components governed by rules and proportional systems. Also, the focus of such monumental buildings was governed by religious beliefs rather than aesthetic appearance (Porter 1997).

However, the use of mediating techniques was utilised by the Ancient Greeks. An example of this can be seen in the Temple of Apollo in Didyma, Turkey, where Haselberger discovered evidence of architectural drawings scribed into the stonework of the ruins (Hadingham 2008). It is likely this would have been drawn by the master craftsman who was in charge of all aspects of the building from design, distribution of labour, budget and construction. It is also suggested that if preliminary drawings or devices were used at all, these would have been for smaller parts of the design such as a column capital (Porter 1997).

4.1.2 Pre-Renaissance representation

Modern architectural representation has its roots in the Renaissance from the fifteenth century onwards. Before this, little documentation of representation techniques survive with a small number of exceptions such as a marble plan of Rome, a parchment plan of St. Gall Abbey as well as a set of drawings for Reims Cathedral (Ackerman 2002). We have to assume that before the Renaissance, architects and master masons would have designed mentally and communicated their ideas verbally or using full scale drawings and models. In this sense, medieval architects would have been like their ancient counterparts as they were directly in charge of, and worked directly in, the spaces they were designing. The nature of Gothic churches ‘reaching towards the heavens’ is also suggestive of a lack of representation techniques used in the building process:

> *“The spontaneity with which the great Gothic churches sprung up against gravity and the sky suggests they were never fully put down on paper. They arose unforeseen.”* (Porter 1997, p.11)

Textual evidence indicates that in some cases the plan of a building was drawn directly on the ground or into a prepared plaster screed floor. Also, important elements such as rose windows of a Gothic cathedral would have been incised onto the masonry for direct copying (Ackerman 2002). Representation techniques would also have been utilised by directly copying elements of built architecture.

Of the little drawing done, such as those by Villard de Honnecourt for Reims Cathedral in approximately 1220-1235, most were drawn on parchment. This was an expensive material and consequently was reused by scratching away the surface, offering further evidence of why architects at the time did little sketching or representation of their ideas graphically (Ackerman 2002). Of the drawings produced, some were orthogonal, such as plans and elevations; however, many of these elevations included non-orthogonal elements within them.

4.1.3 Renaissance representation

Paper making techniques invented in China, passed to the Islamic world and finally to Europe through the Muslim arrival in Spain in the mid-twelfth century began to make representation drawings increasingly widespread. Paper began to overtake parchment as the drawing tool of choice in 1465 when the printing press was introduced to Italy from Germany (Chapman and Faietti 2010). Although expensive initially, paper allowed architects and artists to experiment with ideas rapidly through sketching and communicate them more effectively with others, resulting in increased dialogue and critique. Renaissance architects also developed the use of physical modelling; whereas medieval architects used models to test structural qualities, Renaissance architects utilised them as design aids to explore ideas of mass and space (Porter 1997).

Renaissance theorists such as Alberti believed that orthogonal drawings were most appropriate for architectural representation, not perspective images, as their role was to communicate a design idea objectively. He stated this was because orthogonal drawings allow measurements to be taken enabling construction or analysis (Ackerman 2002). This demonstrates a shift towards drawing to scale rather than at 1:1, with the role of mediating techniques becoming increasingly important. However, the reality was that most Renaissance architects did use perspective images to convey their ideas. This is because they allow a design to be visualised in three dimensions on a two-dimensional plane, which is especially useful for clients to view, who would undoubtedly have found architectural conventions difficult to understand (Ackerman 2002). Perspective images work on the presumption that parallel lines, which do not converge, join together at a vanishing point. The use of perspective in Renaissance building offered a technique for architects to visually convey their designs in context from a chosen viewpoint, therefore negotiating ‘the gap between idea and material’ (Allen 2009, p.3). The use of perspective images to demonstrate architectural forms became the dominant technique in the discipline that would not be significantly challenged until the late nineteenth century.

4.1.4 Physical modelling

As discussed in section 4.1.3, it was not until the Renaissance period that physical models were widely used architecturally; before this, historians have argued that their use was mainly symbolic, for example depictions of architecture featured in jewellery (Morris 2006). The main use for physical models in the Renaissance was to act as supporting representations to drawings; however, Alberti began to challenge this relationship;

> *"Alberti in 1452 augments any previous conception of the model and sets parameters for subsequent model critique. Making the model a conceptual device for the architect rather than just a prop for the client was a defining shift on model thinking and one that still persists as a new idea."* (Morris 2006, p.17)

Although Alberti and other Renaissance architects such as Brunelleschi began to use models as design aids, for the most part they remained 'polished and rhetorical' in the late-Renaissance and Baroque periods where the perspective image remained the key representation technique (Morris 2006). It was not until the Bauhaus in the 1920s that models were utilised fully as tools for analysing designs and exploring them creatively; a process that is still essential in architectural education today.

4.1.5 Glass and mirrors

A range of mediation devices have developed in the arts to aid the process of creating an image. This includes the studies of Alberti who opposed perspective in architecture; however, he did devise a system of placing a grid in front of a screen to aid artists with their perspective drawing (Naughton 2000). This use of frames to draw attention to a particular field of view as well as glass lenses and mirrors to flatten perspective are particularly important;

> *"The coincidence of developments in lens and mirror technologies and the development of accurate portraiture at around 1420 suggests that the link between ways of seeing and visualization is much older than usually described."* (Hockney 2002, p.8)

This is significant as it reiterates that the development of art is inherently linked with mediating devices and affects the way we view and understand the world (Whyte 2002). The invention of the microscope and telescope in the sixteenth century was important in perspective as it 'rocketed the vanishing point into outer space and towards infinity...' (Porter 1997, p.17). This is further evidence of how glass was used as a mediating device to change people's perception and understanding of the world.

The German painter Albrect Dürer made many devices that metaphorically objectified reality (see Figure 4.1), such as a glass panel with a grid between the subject and painter, which takes a section through the cone of vision enabling a perspective image to be drawn (Pérez-Goméz and Pelletier 2000). His devices built on the work of Alberti whose own machine became known as 'Alberti's window' (Naughton 2000). This is noteworthy in the development of representation techniques as it suggests that from the Renaissance onwards, we have increasingly seen the world through a framed view.

Figure 4.1: Illustration of the draftsman's net, a device to aid perspective drawing by Albrect Dürer. The grid cuts through the field of vision splitting it into a grid which is then transferred to paper. Image credit: Dürer ([1525] 2011).

Perspective images, including those created using techniques by people such as Dürer and Alberti, are not without their critics. Although such images aim to objectify a scene as much as possible, they do not convey aspects of visual experience including 'binocular vision, movement of the eye, focusing in depth, the full gradient of light and shade' (Evans 1995, p.126). Consequently, representation techniques had to develop further in a quest for objectivity.

4.1.6 Camera obscura and camera lucida

Following on from aids to perspective drawing, in the eighteenth century there was a growing interest in optical devices as tools to provide a more objective truth. Daniele Barbaro first described the camera obscura in 1569, but it was not used as a tool to aid drawing; rather it was simply used as an optical demonstration (Pérez-Goméz and Pelletier 2000). The camera obscura works in the same way as the eye; light passes through a small opening into a dark space and projects an inverted image onto a surface opposite. As a consequence of the growing interest in the camera obscura, the need for perspective machines decreased ‘because it was no longer necessary to “demonstrate” the geometric construction of perspective through a mediating device’ (Pérez-Goméz and Pelletier 2000, p.287). This is very important in suggesting how new technologies replace old ones in a quest for objective truth.

The role of mediating techniques in the arts, particularly perspective drawing, was further diminished with a growing desire to depict the scientific and natural appearance of the world as accurately as possible. In the nineteenth century this was achieved using the camera lucida; a development of the camera obscura which projects a faint image onto a surface that can be traced over. Whereas the camera obscura was primarily used as a device of ‘wonder’, the camera lucida was specifically used as a method of representing the physical environment as objectively as possible. As it developed, parts were added such as lenses and mirrors meaning that objects could be drawn from afar without disturbing them, such as wild animals. In this sense the camera lucida is a direct precursor to the photographic image (Pérez-Goméz and Pelletier 2000).

4.1.7 Photography: Sallie Gardner at a Gallop

The research of Eadweard Muybridge into animal locomotion forms a key example of how new techniques can be used to challenge traditionally held conventions. Muybridge was commissioned by Leland Stanford to prove that a horse has all four hooves off the ground when galloping. Muybridge did this using photography, which is arguably one of the mediums closest to depicting reality; photographs are made of fossilised light, which is a direct physical imprint in the same way as a fingerprint (Mitchell 1992b). Muybridge took a series of photographs of the horse Sallie Gardner at close intervals to prove the theory (see Figure 4.2).

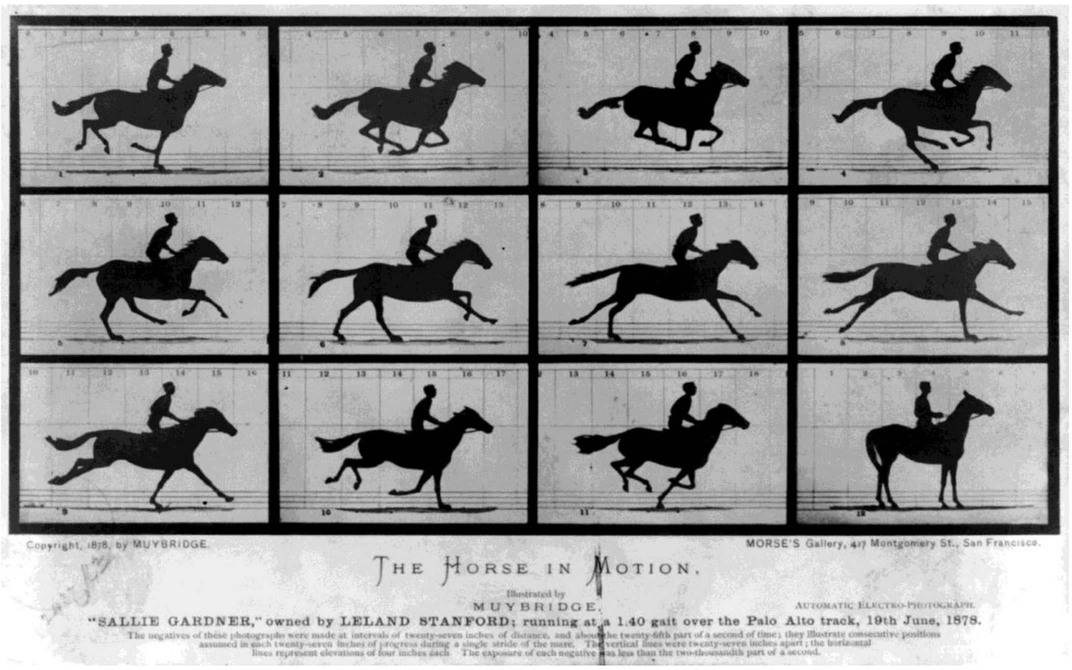


Figure 4.2: Eadweard Muybridge's photographic slides of 'The Horse in Motion'. Notice how the two slides in the centre of the top row demonstrate that the horse has all four hooves off the floor as well as being in a completely different position as drawn in artistic conventions. Image credit: Muybridge ([1899] 1957, p.53).

As well as proving that horses raise all four hooves off the floor, the experiment also revealed that depictions of horses galloping in art of the time were incorrect (see Figure 4.3). Muybridge describes these conventions in art as follows:

> *"In its most pronounced realization it is characterized by a body, neck and head, all of abnormal length, and arranged in a nearly horizontal line. The anterior legs, in almost parallel lines, have their feet a few inches below, and in advance of, the nose. Both hind feet are thrust far to the rear, with their shoes turned upwards."* (Muybridge [1899] 1957, p.53)

He is particularly scathing of this convention shown in Figure 4.3, stating that it 'exhibits an entire absence of observation, unprejudiced impression, or serious reasoning' (Muybridge [1899] 1957, p.53). Muybridge was able to demonstrate that photographic techniques are 'capable of revealing the structure of nature without imposing any inappropriate theories upon it' (Pérez-Goméz and Pelletier 2000, p.287). In essence, Muybridge provided irrefutable evidence using a tool for augmenting knowledge.

Figure 4.3: 1821 Painting of ‘The Epsom Derby’ by Théodore Géricault depicting horses in the so-called ‘flying gallop’ position. Image credit: Géricault (1821).

‘Sallie Gardner at a Gallop’ is particularly important in relation to the methodology proposed in Figure 1.1. Muybridge’s experiment can be demonstrated using this methodology; the line of enquiry is Stanford’s request to show all four hooves of the horse off the ground whilst galloping, the representation created in order to enhance critique is the photographic image, serendipitous results were found which enabled art conventions to be challenged as well as the photographic images proving Stanford and Muybridge were correct.

The photographs shown in Figure 4.2 are important for their ability to capture an object in movement, but also for their ability to show movement in an object. Étienne-Jules Marey developed this process of ‘chronophotography’ further; whereas Muybridge created his photographs using a series of cameras that were consecutively activated, Marey used a single plate which resulted in images ‘physically integrated in a superimposed pattern of movement’ (Scharf 1962). The resulting abstract images, due to their accuracy of presenting animation, became paramount in physiological studies. Again, this demonstrates how the emergence of new representation techniques in history can create enhanced understanding on a given subject.

4.1.8 Axonometric representations

In architectural representation, the use of axonometric and isometric drawings would challenge the dominance of perspective drawings in the profession in the late nineteenth century. Unlike perspective images, axonometric and isometric projections have no vanishing point hence they could technically continue infinitely

(Pérez-Goméz and Pelletier 2000). Such drawings provided a kinetic medium based on space and time; providing a potentially seamless and continuous image rather than a series of separate images had perspective been used (Krikke 2000). This ability to scroll in any direction is crucial to the axonometric; a modern example of this can be seen in Bing's online maps which have a bird's eye view option, created by taking aerial photographs which are then ortho-rectified enabling scrolling across a map in any direction (see Figure 4.4).

Figure 4.4: Bing maps use ortho-rectified images to provide an axonometric projection or bird's eye view. This allows for scrolling in any direction. Image credit: Bing maps (2010).

Axonometric drawings first came to Europe in the seventeenth century; as with many progressions in design, this was because of their potential use in military operations. Axonometric drawings offered geometric qualities in which correct measurements could be taken, offering accuracy in all three axes for construction purposes (Ackerman 2002). Additionally, their use as an analytical tool using calculus and geometry 'made it possible to see graphic data not as a more or less approximation of sight, but as a way of calculating and predicting abstract qualities or behaviours' (Allen 2009, p.14). This highlights the use of axonometric drawings beyond their visual qualities and suggests their advantages in military systems as well as architectural design.

Isometry, a form of axonometric projection, was invented in 1822 by the Englishman William Farish. Isometric drawings work by constructing a base line with two 30° angles, rather than two 45° angles, and then projecting heights vertically. This foreshortens the angles projected in comparison to the standard axonometric.

Farish invented isometry (see Figure 4.5) in response to the pressing need to represent mechanical drawings objectively due to the emergence of technologies in the Industrial Revolution; he understood that perspective images distorted the true geometry of objects (Krikke 2000). Axonometric projection was taught in engineering schools in the late nineteenth century for its technical abilities which can be seen as a result of Farish's work (Pérez-Goméz and Pelletier 2000).

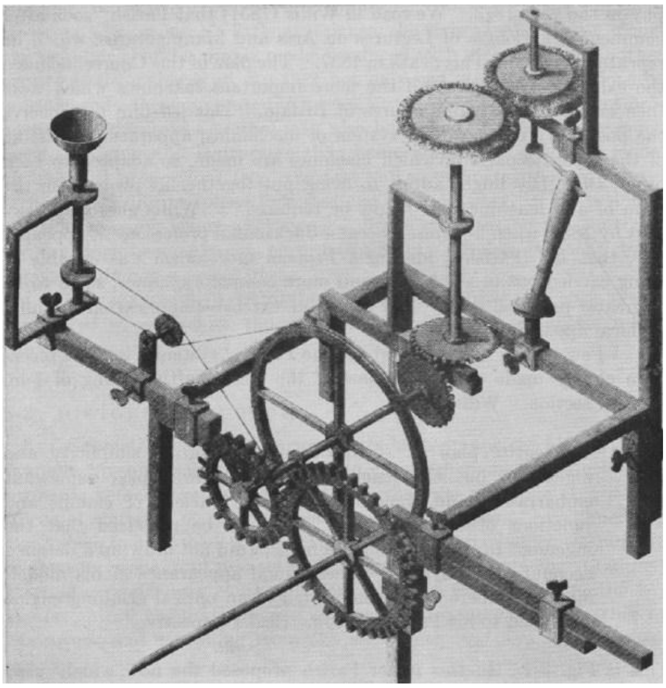


Figure 4.5: William Farish invented isometry to enable accurate mechanical drawings. Image credit: Farish (1822).

The discovery of a vanishing point to produce perspectives dominated European techniques in architecture until the work of Auguste Choisy in the 1870s and early twentieth century Modernist architecture. Choisy adopted axonometric drawings as a way of visually describing the history of ancient and medieval architecture (Ackerman 2002). He believed they could 'demonstrate what he assumed to be the deterministic principles according to which the great buildings of history were achieved' (Pérez-Goméz and Pelletier 2000, p.314). Choisy's work is a key example in demonstrating how representation techniques can be used to augment our understanding of historic architecture; revealing a more objective truth. The use of axonometric drawing meant that unseen views could be created, such as worms-eye views (see Figure 4.6). He used the technique effectively to explain elements of ancient designs such as wall construction.

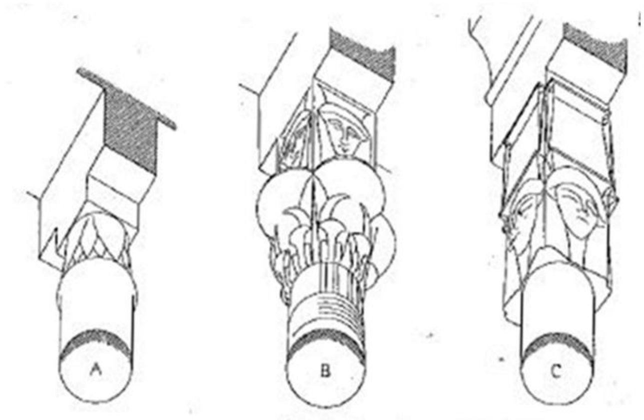


Figure 4.6: Choisy's drawings re-present historic architecture as objectively as possible using worm's eye view axonometric drawings. Image credit: Choisy (1899, p.45).

In the 20th century axonometric drawings became prevalent in architecture largely due to a De Stijl exhibition in 1923 which was visited by Le Corbusier and Mies van der Rohe amongst others (Krikke 2000). People such as Le Corbusier and Gropius rejected perspective 'as limited, finite and closed' (Porter 1997, p.20). Theo van Doesburg saw axonometric drawings as the ideal method of representation for the abstract forms of De Stijl, as they allowed for reversibility, for example they do not distinguish front from back, left and right and possibly up from down (Pérez-Goméz and Pelletier 2000). After this the use of axonometric drawings became widely used in architectural practice and education. This can be compared to Gehry's use of computer aided design at the Guggenheim museum in Bilbao, which acted as a catalyst enabling digital techniques to reach a wider audience.

4.2 Modern mediator: computer aided design

The development of mediating techniques explored in section 4.1 demonstrates key stages in the history of representation and how such techniques have influenced the architectural profession. In 1977, Mitchell stated that the 1980s would see the use of computer-aided design techniques change the profession radically. This proved to be true, and over the last thirty-five years the role of the computer has rapidly increased, becoming part of our everyday lives. As a mediating technique, the use of computer aided design has direct links with devices in history, with the computer screen working 'as if it were a window looking on the world of the drawing sheet' (Jones 1986, p.3). To fully understand the potential that digitally mediated techniques can provide, it is important to understand the origins, applications and advantages that computer software and hardware has enabled.

4.2.1 Beginnings in engineering and manufacturing

The use of interactive computer graphics has its roots in the 1950s where the US Air Force's SAGE Air Defence System allowed targets to be displayed using cathode ray tubes (CRT). However, it was not until engineering and manufacturing companies became involved that the use of computer aided design increased significantly (Jones 1986).

The architectural profession lagged behind engineering and manufacturing companies in their speed to exploit the computer mainly because such firms tend to be large with the ability to secure capital to invest in expensive equipment, whereas architectural practices tend to be relatively small hence unable to make such investments. In addition to this, the cost of design in engineering, such as cars or planes, is a fraction of the cost of the end product whereas in architecture the design cost is a lot greater as designs are almost always one-offs (Mitchell 1977). Therefore, it was much more difficult for architectural firms to gather the necessary capital compared to the benefits this would bring. However, by the 1970s some national and international architectural practices as well as educational institutes were able to experiment with the potential uses for computer aided design as a specialist resource (Jones 1986). An example of this is Otto & Behnisch's design for the Munich Olympic park roof held in 1972 in which the engineers, in conjunction with Stuttgart University, used computer methods to refine the load bearing capacity of the substantial roof structure (Otto 2005).

During this time, a similar attitude was taken in architecture to that of engineering and manufacturing; due to the significant capital and human resources required, the computer should be used for highly repetitive design projects, such as hospitals and commercial offices (Dobson 2005).

4.2.2 Introduction of the personal computer

As computers developed, the cost of hardware decreased and performance increased, in addition to which they became physically smaller in size. This enabled an increased complexity in digital modelling that could be handled by a single person computer (Dobson 2005). The machine that made this possible was IBM's personal computer launched in 1981 (Jones 1986). This was a significant moment not only the development of architectural representation:

> *"The emergence of low cost personal computers in the 1980s heralded a watershed in the adoption of computer-based working throughout business, industry and society, and the design professions were no exception."* (Dobson 2005, p.17)

Once personal computers were available and affordable to architectural practices, the possibilities for computer aided design began to increase as appropriate software was developed.

4.2.3 Emergence of computer aided design software

The first piece of software to become available at an affordable price was AutoCAD in 1982, closely followed by others such as MicroStation, MiniCAD and CADDIE (Dobson 2005). AutoCAD and MicroStation still dominate the architectural software market today.

One of the aims of computer aided design in its formative years was to increase the speed of reproductions, for example, at the turn of the twentieth century copies of drawings were made using linen, since then blueprints were used and then photocopying (Jones 1986). Computer aided design software, coupled with the introduction of inexpensive plotting machines in 1982, increased the speed of drawing reproduction. This could then give the architect more time to design rather than drafting (Lloyd Morgan and Zampi 1995). In these early years, the use of computer aided design should probably have been called computer aided drafting, as it was used mainly in the post-design phases of a project (Szalapaj 2001).

Although the reduced price in software and hardware enabled computer aided design to enter a wider market, 'market economics also resulted in computer programmers becoming very distant from end users' (Bijl 2001, p.8). This meant that the software was becoming increasingly seen as a drafting tool rather than designing tool as previously noted. This differs from first generation computer software which recognised building specific objects such as windows and doors, whereas second generation software 'dealt with polygons, solids, NURBS and blobs,' which led to second generation software requiring additional specialist software to perform building or design analysis, hence architects 'gained computer-assisted drafting and rendering capabilities but lost the analytical capabilities that formed the basis for the introduction of computing into the profession in the first place' (Kalay 2004, p.70). However, in recent years this has begun to change, with computer aided design software being used at all stages of the design process (Szalapaj 2001).

4.2.4 University education as a catalyst for change

Dobson (2005) argues that computer aided design was met with resistance from some design tutors in schools of architecture, due to its reputation as a drafting tool rather than a design tool and was essentially ‘ghettoised’. It was only during the mid-1990s after two-dimensional and three-dimensional techniques were cheaply available and offered a level of visual sophistication to rival hand drawings that digital techniques began to become prominent in education (Dobson 2005). This occurred as a ‘quiet revolution’, with the students rather than educators being the primary drivers for change. This falls in line with mid 1990s students being the first generation to have computers as part of their everyday lives.

4.2.5 Three-dimensional digital modelling

The introduction of three-dimensional digital modelling in architecture also has its origins in automotive and aerospace engineering, where they were used to enable direct production from idea to end product without the use of intermediate drawings. They became popular from 1985 onwards as an add-on feature in two-dimensional drafting programs (Jones 1986). Gehry’s Guggenheim Museum in Bilbao is one of the first architectural designs to take advantage of this technology; a physical model was produced by hand then scanned into the computer and constructed digitally. This data was then used to manufacture parts using computer aided manufacturing, essentially eliminating the need for drawings (Szalapaj 2001). It is projected that this process will eventually end the need for paper drawings that ‘involve a complex shorthand and consequent errors due to interpretation’ as working directly to drive a machine is more efficient and accurate (Jones 1986, p.73).

Paradoxically, the main use of three-dimensional modelling in architecture has become primarily the production of visualisations to enable analysis and greater understanding of designs as well as a clearer vision for people unable to read architectural drawings. This directly relates to the historical use of perspective and axonometric drawings as visualisations, with digital techniques seeing a revival in producing perspective images as the computer makes the process of producing such imagery increasingly simple (Allen 2009). This paradox can be compared to the invention of the camera, where photographs were initially used to replicate paintings (Mitchell 1992a). In this sense, there is still a trend in the architectural community to view three-dimensional computer aided design as a tool for visualising schemes rather than exploiting its full potential in manufacturing terms. However, third generation computer aided design software has increasing focus towards analysis, where components are treated as objects that can act as 'transistors, capacitors and resistors' rather than merely shapes (Kalay 2004, p.71). For example, software could calculate fire egress in a design or assist with placement of furniture.

Three-dimensional digital modelling has developed rapidly; firstly integrated into traditional drafting programs such as AutoCAD and MicroStation, followed by specific three-dimensional modelling programs such as 3D Max, Rhinoceros and SketchUp. By the turn of the 21st century visual imagery created using three-dimensional computer aided design software had become widespread due to the fast paced development of the computer (Dobson 2005). The importance of the computer cannot be underestimated;

> *"The changes are occurring very rapidly compared to the sedate pace of fast evolutions in architectural design, thus shaking the foundations of the profession as no other invention has done before – not even the invention of scale drawing in the Renaissance, which established the profession of architecture in the first place."* (Kalay 2004, p.81)

This highlights the impact that the introduction of the computer has had on the profession and how its utilisation and capabilities are developing constantly. This can be used to initiate a discussion into the various digital representation tools available to enhance understanding and analysis of architecture; with particular emphasis on how they can be used to enhance understanding of unbuilt, damaged and destroyed works of architecture.

4.3 Digital forensics: a toolbox of techniques

As demonstrated in section 4.2, the use of digital technologies in architecture has developed rapidly over the past thirty-five years and continues to develop at a pace. 'CAD models in architectural design ...need to be assessed not in terms of their quality of presentation but as objects with which to carry out precise analytical functions' (Szalapaj 2001, p.7). Contemporary techniques offer an opportunity not only to analyse existing and proposed buildings, but also to analyse unbuilt, damaged or destroyed buildings. This can be seen as a toolbox of techniques to aid a digital forensic process. This is meant in the sense that if an aspect of a particular case study is unknown, then appropriate digital techniques can be utilised in order to provide new evidence to support or challenge theories held. These techniques will be examined in the following subsections in line with the potential they have to augment and enhance critique.

4.3.1 Point and line representations

Point representations, or pixels, work using a Cartesian co-ordinate system; where a point is defined using a set of co-ordinates. This point is displayed using information such as a certain colour or intensity to form a larger picture. The denser the sample, the more accurate the point representation will be at describing something (Mitchell 1992a). Point representations work in two dimensions (x and y) as well as three-dimensional volumetric pixels (x, y and z); these representations are known as voxel models.

Besides point representations, line representations are one of the most basic forms of three-dimensional digital modelling techniques, more commonly known as wireframe models. In two dimensions, line drawings produced using computer aided design work like stretching an elastic band over a series of points to create a representation such as a plan, section or elevation. In three dimensions this produces a wireframe model, which has its origins in the Italian Renaissance where perspective drawings were constructed providing very similar results (Mitchell 1992a). Wireframe models produce an 'x-ray' view of a design, as the lines represent boundaries and consequently have no surface enabling you to see straight through the object. These models 'represent the essentials of a building's geometry in elegantly sparse and economical fashion, but they are too radically abstracted to serve as the basis for generation of sophisticated displays and analyses' (Mitchell 1992a, p.55). Such models were introduced in the 1960s and represent the first available digital three-dimensional representation technique, hence their importance. However, their simplicity results in them not being able to support area or volume calculations, which could be utilised for analysis purposes (Kalay 2004).

Because line drawings produce an 'x-ray' view of the representation, they can be juxtaposed against other images. This could be used in analysis to highlight situations such as similarities and differences to other designs, or to represent an unbuilt, damaged or destroyed building in the context they would have been located. An example of this can be seen in Figure 4.7, which shows a digital line drawing with added shading of an Aztec temple overlaid in situ in its original location in modern Mexico (Levine and Tisserand-Gadan 1997). If the viewer is aware of the modern Mexican location, they are immediately able to reference where the temple would have been, using the overlaid image. Additionally, it highlights the vast scale of the temple in relation to current buildings on the site.

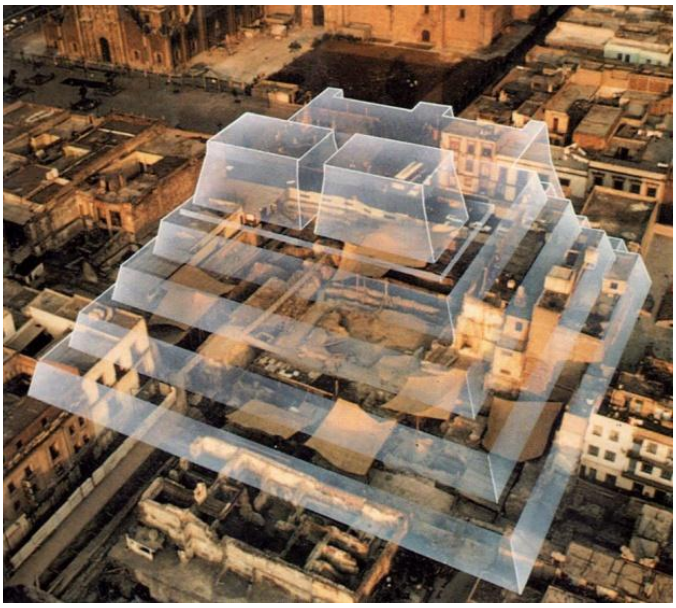


Figure 4.7: Line drawing with additional shading of a lost Aztec design overlaid onto its original site in modern Mexico. Image credit: Levine and Tisserand-Gadan (1997, p.262).

4.3.2 Surface modelling

Surface models are a more sophisticated representation than wireframe models as they contain data about the area enclosed within a series of lines. Surface modelling can hide hidden lines to produce an image that represents the basis of a building's visual qualities (Mitchell 1992a). In addition to this, surface models make it easier to visualise where two objects intersect and can also form the basis of animations to allow walkthroughs of a design. Programs such as SketchUp primarily use surface modelling due to its ease of use when constructing a model in comparison to the relatively high quality of representation that can be produced. One negative aspect of surface modelling is it cannot demonstrate the volume of a design or design component, as it does not have the capabilities to understand where objects intersect therefore overall areas or volumes cannot be calculated (Kalay 2004). An example of this is a single cube which would strictly speaking be six polygons;

hence not having a volume when discussed alone or with the intersection of another cube.

Surface models are useful in analysing unbuilt, damaged or destroyed architecture due to their ability to create photo realistic visualisations when utilised in conjunction with techniques such as ray tracing and texture mapping; which are described more thoroughly in later sections. Mitchell (1992a) used these techniques to demonstrate how Palladio's Villa Rotunda would have looked if the original dome design had been constructed (see Figure 4.8). Crucially, the counterfactual visualisation requires manipulation once it is rendered using graphics editing software to ensure visual believability. The comparative images enable the viewer to visualise the differences between the two designs much more clearly than if they studied the original drawings alongside Palladio's actual built design.

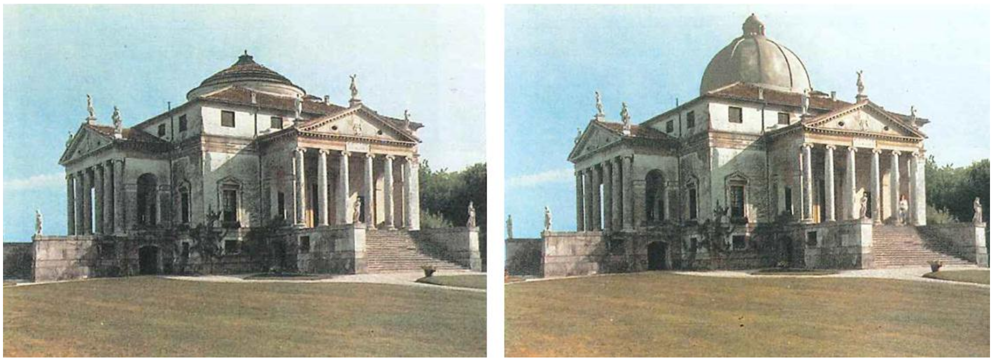


Figure 4.8: Mitchell (1992a) compares the built design for Palladio's Villa Rotunda (left) to a counterfactual version generated using digital techniques (right). Image credit: Mitchell (1992a, p.56).

4.3.3 Solid modelling

Surface and solid models both have the ability to create a wide range of visualisations, especially when used in conjunction with rendering techniques. However, solid models are more powerful in terms of their analytical abilities as they are able to process how edges and surfaces work together to enclose a solid object. Two-dimensional computer aided design, wireframe modelling and surface modelling can be compared to designing using a pen and paper. Solid modelling is different to these as it is more comparable to designing with wooden blocks, foam or card (Lloyd Morgan and Zampi 1995). Solid modelling works typically by providing primitive shapes such as cubes, cylinders and solids of revolution and then transforming them using different commands (Mitchell 1992a).

Boolean operations are one of the main ways of transforming solid objects with commands such as union, intersect and subtract. In solid modelling, providing a realistic image is not necessarily the main focus; the most important aspect is that it helps to analyse the underlying rationale of a particular scheme (Lloyd Morgan and Zampi 1995). This is because they offer a geometrically complete description of a scheme allowing spatial clashes to be detected by determining if a particular point is solid or void, or if two solid elements overlap as well as enabling analysis of thermal and structural qualities once materiality is added (Mitchell 1992a). In this sense, solid modelling provides an opportunity for 'greater awareness of architectural design representation of space and form' (Szalapaj 2001, p.7).

The use of solid modelling was central to furthering understanding of the partially built Sagrada Familia church in Barcelona. The team in charge of the ongoing construction used Boolean operations to digitally construct the complex ruled surface geometry over a number of steps (see Figure 4.9). Such solid modelling techniques were crucial in analysing the fragmented primary evidence that remained from Gaudi's work and increased the speed of the process significantly. Before this, the investigation relied on physical plaster models which were a lot slower in terms of ability to manipulate and reconfigure elements to find the correct arrangement for the various parts of the church (Burry 2005).

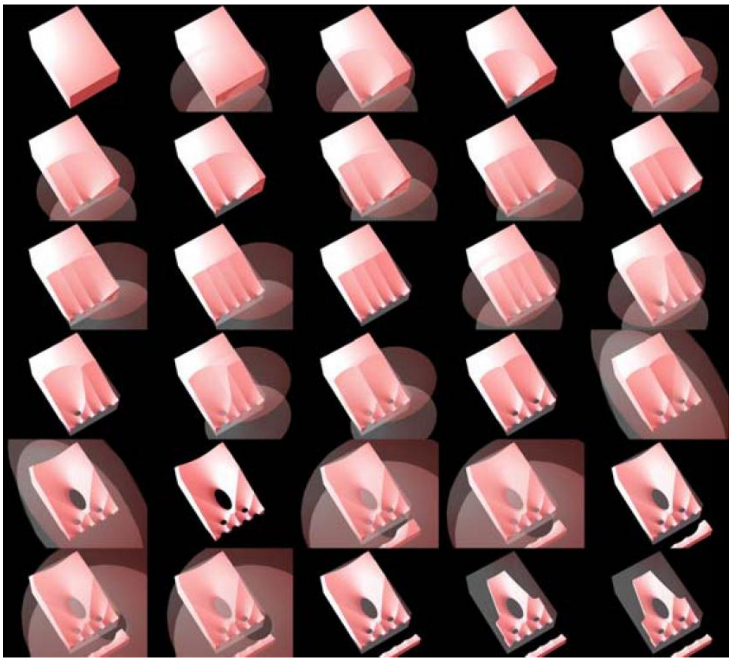


Figure 4.9: From top left to bottom right, the process of working from a solid rectangle to a window of the Sagrada Familia design is revealed using Boolean operations and ruled surface geometry. Image credit: Burry (2005, p.8).

Further to solid modelling, constructive solid geometry can be utilised to aid analysis of a digital representation. These models are formed by a series of geometric solids which have been manipulated using processes such as Boolean operations. For example, an object created by subtracting a cylinder from a cube using constructive solid geometry would remember the original geometries of the shapes. The representation stores the process of model making in a database hence it can be called upon as evidence when analysing a design (Kalay 2004).

4.3.4 Texture and bump mapping

Depending on the line of enquiry followed, a representation may be required to be as photo realistic as possible, such as Mitchell's Villa Rotunda comparative in Figure 4.8. In this instance, ray tracing and radiosity renderings could be used, which will be discussed in detail in section 4.3.6. Before such renders are produced, the digital model can be enhanced by applying photo real digital images to it. These can be sourced by accessing libraries of textures included in modelling and rendering software or prepared directly from a source, such as digitally photographing or scanning a brick wall then editing it using graphics software to ensure it is orthographically correct. It is important to keep the size of the digital model as low as possible, hence keeping the file size of textures and materials to a suitable level also. In addition to textures, bump mapping can be used in the rendering process. This introduces irregularities into the surface of the texture map whilst maintaining the geometry of the digital model, and consequently tricks the eye into seeing a more roughened surface (Kalay 2004).

4.3.5 Walkthroughs and virtual reality

Once a three-dimensional digital model has been produced, it can be used in its simplest form to investigate the spatial analysis of a design. This can be achieved using techniques such as a walkthrough, where the viewer navigates around the digital model from a human perspective, or a flythrough, where the viewer can explore from any position within the model. Such representations could make use of film techniques, where the route around a digital model is predetermined, or enable the viewer to explore the model themselves using games engine software such as Quest 3D.

Virtual reality systems can be defined into three areas; immersive, non-immersive and augmented reality. Immersive reality was first invented by Sutherland in 1970 where he used a headset to produce immersive computer graphics in flight simulation;

> *"...his research into flight simulation displays is one of the key antecedents to a completely new and exciting technology which has been compared to Brunelleschi's discovery of perspective and to the invention of television."* (Porter 1997, p.138)

Immersive techniques developed in the late 1980s with hardware such as head mounted displays and data gloves or large wall displays. An example of immersive techniques can be seen in Maver and Petric's (1999) investigation of Scottish archaeological sites, in which a large curved wall display provided immersive virtual reality (see Figure 4.10). The idea of these technologies was to enable the viewer to become as immersed as possible within the virtual environment, resulting in a more thorough understanding of the archaeological remains. However, these techniques have become less popular with developments in technology such as augmented reality.

Figure 4.10: Maver and Petric (1999) used a curved wall display to provide immersive virtual reality for digital representations of Scottish archaeological sites. Image credit: Maver and Petric (1999, p.8).

Non-immersive virtual reality techniques have also become more popular than immersive techniques due to their accessibility; essentially the digital model is viewed through a screen and therefore does not require the expense of additional specialist hardware. In this sense the technique can be seen as similar to perspective, where the viewer looks through a 'window-on-the-world' where their total field of view is not taken up (Lloyd Morgan and Zampi 1995).

The third technique that could be used to enhance analysis of unbuilt, damaged or destroyed architecture is augmented or mixed reality (see Figure 4.11);

> *"There is an increasing interest in augmented and mixed real/virtual applications where the user can be simultaneously looking at virtual data and aware of their real world context, rather than being completely immersed."* (Whyte 2002, p.6)

The applications of such techniques have begun to be explored in architectural research, such as an investigation using a toy helicopter mounted with a camera that augments the city image with an overlay of a digital model (Koch et al. 2011). Its use in digital reconstruction projects has also begun to be explored such as the Jamestown research discussed in section 3.3 (Mark 2011). Augmented reality is increasingly relevant due to the emergence of new hardware such as smartphones and tablet computers, which have become increasingly popular hence enabling such technologies to reach a wider audience. Smartphones or tablet computers could allow viewers to visualise unbuilt, damaged or destroyed buildings overlaid onto the original site and context of the design.

Figure 4.11: Classic set up of augmented reality. Image credit: Koch et al. (2011, p.844).

4.3.6 Rendering and lighting analysis

Digitally rendered images can be produced using either solid or surface models. This can utilise different methods such as Gouraud shading, Phong shading, ray tracing and radiosity rendering. Such techniques, which have the ability to simulate both natural and artificial lighting, can produce photo realistic visualisations.

Ray tracing works by sending out rays in all directions from a specific viewpoint and calculating the values this creates (see Figure 4.12). This technique is very similar to devices such as Dürer's draftsman's net as discussed in section 4.1.5; an imaginary grid is placed between the camera and subject and traced onto the screen exactly as the image appears (Lloyd Morgan and Zampi 1995). Ray tracing can be used to highlight shadows and reflections and can also render transparent and translucent objects (Szalapaj 2001). Although ray tracing is a powerful tool for rendering a scene, this view dependence means that it cannot be used when rendering a three-dimensional space for the purpose of a digital walkthrough; 'if the point of view is changed, the entire image must be recalculated' (Kalay 2004, p.177).

Digital renders are one of the most common techniques employed when investigating a damaged, destroyed or unbuilt work of architecture, especially photo realistic visualisations. This is because they offer a depiction of a design which, with current technology, is the closest possible interpretation to reality itself, or as close as a photograph of such designs had they been built. The latest use of these techniques offers very convincing results, as can be seen in a study of an unbuilt Frank Lloyd Wright design in Venice (Sdegno 2011).

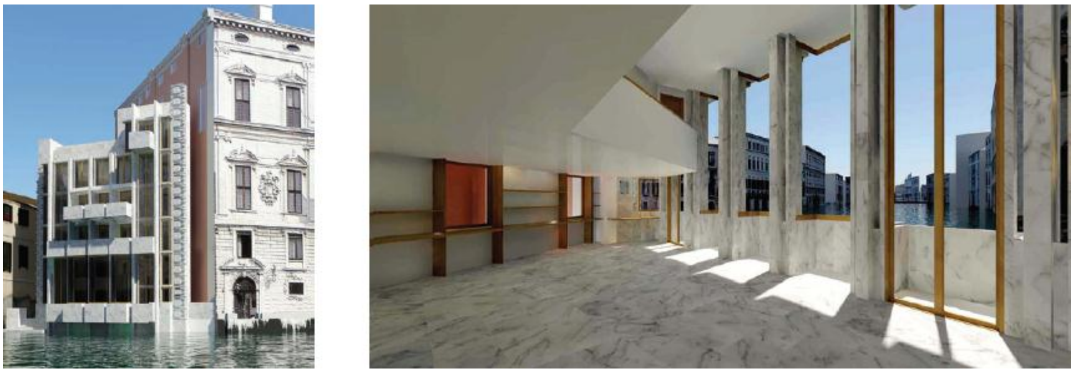


Figure 4.12: Ray traced visualisation of an unbuilt Frank Lloyd Wright scheme in Venice. Image credit: Sdegno (2011, p.965).

The most complex visualisation method for three-dimensional representations is radiosity rendering which produces a render of a three-dimensional model, not a still image, and can consequently be viewed from any point in space. Each object in the digital model is defined in terms of how much light energy it emits and reflects (Szalapaj 2001). The fact that radiosity renders a three-dimensional model means it is most appropriate for walkthroughs where the viewer decides the route. However, ray tracing could still be used for walkthroughs where the route is predetermined, as a film could be made by stitching together a series of two-dimensional digital images in a similar way to traditional film techniques. It must also be noted that radiosity methods cannot render glass and shiny surfaces as it is based on light leaving a surface rather than the direction it came from. Consequently, a combination of ray tracing and radiosity can be used to produce an even more photo real representation, but only for a still image or film, not for a walkthrough where the viewer decides the route (Kalay 2004).

The techniques described above are very useful for providing enhanced qualitative information on the visual appearance of how a design would have been lit. However, other techniques are required in order to provide quantitative analysis. This can be achieved using software such as Autodesk Ecotect Analysis which enables daylight factors and levels of illuminance to be simulated, giving direct numerical data of the likely scenarios of lighting. Such software can display data numerically or over an analysis grid in two or three dimensions, making it a more straight forward process to answer lines of enquiry. This technique could be useful when investigating damaged, destroyed or unbuilt works of architecture where lighting is particularly important, such as galleries and museums.

4.3.7 Acoustic analysis

Ray tracing can also be used for acoustic analysis in exactly the same way as described in section 4.3.6, except instead of calculating a scene using light rays, sound rays become the basis of the representation. This can then be used to predict the flow of acoustic energy and describe ‘the loudness, reverberance, intimacy and clarity of sound’ as well as ‘strength, time of arrival and direction of travel of acoustic energy in the room’ (Szalapaj 2001, p.25). This technology can also be used to auralise a room; firstly a sound is recorded in an anechoic chamber, which is acoustically ‘dead’, then this sound is implemented in the ray tracing procedure to see how that particular recording would sound in a digitally constructed space (Szalapaj 2001). Such techniques would be ideal in the context of this research where acoustics are of high importance, such as places of worship, galleries and concert halls.

4.3.8 Thermal, bioclimatic and structural analysis

Environmental conditions such as wind and temperature can also be analysed within a digital representation. Models can be exported to programs such as Autodesk Ecotect Analysis, which calculates heat gains and losses as well as illuminance levels and daylight factors across a given area, as described in section 4.3.6 (Autodesk 2011). Computational fluid dynamics can be used to analyse wind pressures on a design, which produces a dataset that can be converted directly into a three-dimensional model to visualise the wind effects within the context of a digital model (Szalapaj 2001).

Lines of enquiry such as whether or not a building will be structurally sound can be simulated using software such as Scan&Solve, a plug-in for Rhinoceros that performs basic stress tests on a model and illustrates them within the model using a colour coded system demonstrating stress levels (Freytag 2011). This can be used to evaluate issues such as distribution of stresses or temperatures in elements undergoing heat or force loads. These techniques would be particularly useful when augmenting critique of a damaged, destroyed or unbuilt design in which thermal, climatic and structural conditions are fundamental, such as bridges or towers.

4.3.9 Grammars, parametric modelling and design theory

Stiny and Gips first introduced shape grammar in 1971 as a way of generating geometries and their relationship to each other. This can be seen as a similar process to creating a sentence using textual grammar in which the words all bear a resemblance to each other to make a sentence (Kalay 2004). This has the potential to aid analysis of unbuilt, damaged or destroyed architecture in terms of uncovering grammars:

> *"The purpose of using shape grammars to describe forms that belong to a particular corpus of architectural or other works is to extract the essence of a work and to uncover the rules that govern it. By doing so, we gain a measure of control over the knowledge embodied in that work."* (Kalay 2004, p.273)

Shape grammars can generally be seen as an evaluation of good design by architects, which can then be used to inform future designs (Szalapaj 2001). This links to digital techniques in the form of parametric modelling where the representation is created based on a series of rules using software such as Grasshopper; a plug-in for Rhinoceros. This software could then be used to test grammars or theories of a design. Such techniques began to be developed by Li (2000) and more recently by Coutinho et al. (2011) to re-interpret Alberti's treatise. This rule based system has also been implemented to study Palladio's unbuilt villas using 'recipes' primarily in the form of written text describing the designs. These rules are then translated into a three-dimensional digital representation for enhanced analysis and evaluation of Palladio's works (Sass 2001).

Additionally, design theory can be investigated in order to uncover rules, for example the use of the golden section. Such theories could suit a more schematic analytical representation of a design, as they allow you 'to carry out comparative analysis between building forms that would otherwise appear dissimilar in realistic presentations' (Szalapaj 2001, p.45). It is important to note that such theories could be uncovered without the use of digital techniques, however their use 'allows users to construct arcs and to find geometric features such as midpoints with comparative ease' (Szalapaj 2001, p.47). This is demonstrated in a digital report of Chartres cathedral shown in Figure 4.13, in which the representation was augmented enabling observations to be made such as the modular ratio between horizontal and vertical elements (Bharat 2005).

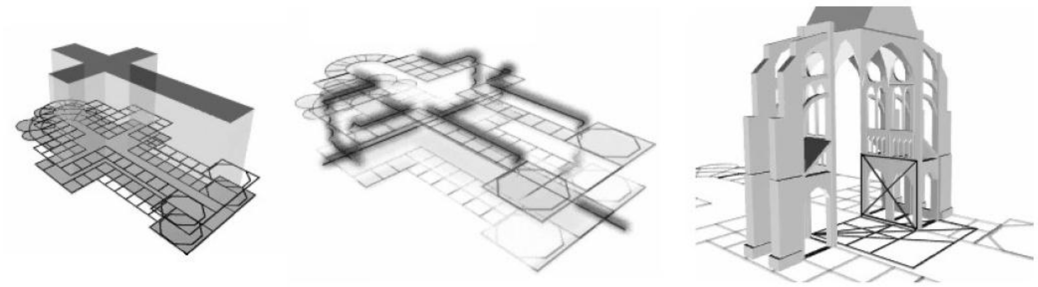


Figure 4.13: Digital report of Chartres cathedral in which observations can be made relating to design theory. Image credit: Bharat (2005, p.6).

4.3.10 Databases and building information modelling

Computer aided design began with a focus on creating information models and then saw a shift towards utilisation as a drafting tool as discussed in section 4.2. A revival of information embodied as part of the representation can now be seen. Initially this revival began with databases, in which models contained non-geometric attributes such as materiality, cost estimations, designer and manufacturer identity and energy consumption. In its current form, such techniques are known as building information modelling and have the potential to act as more inclusive representations and can therefore be used for analysis of non-geometric attributes of a design (Kalay 2004). These techniques could be utilised to support lines of enquiry into unbuilt, damaged or destroyed architecture such as estimations of construction time and energy consumption.

4.3.11 Three-dimensional scanning

Laser scanning techniques have become a valuable tool in augmenting understanding of damaged buildings, as discussed in section 3.1 in the form of two-dimensional reports of Egyptian hieroglyphs. Contemporary techniques such as photogrammetry, three-dimensional laser scanning or point cloud modelling can be used to create a report of the current state of existing objects or buildings, which can then be used as the basis of further analysis. This is especially applicable when dealing with damaged pieces of architecture, as seen in the study of Ionic capitals (Figure 3.5) which can form the starting point of a digital reconstruction process (Richens and Herdt 2009). Three-dimensional scanning techniques may also be applicable when a building has begun construction but was left partially built; such methods would provide an accurate report of the built sections of the design.

4.3.12 Rapid prototyping

Rapid prototyping enables a relatively quick physical model to be produced based on a three-dimensional digital model. The process works by splitting the three-dimensional digital model into multiple layers and printing them separately using resin to bond powder together. It makes possible the accurate modelling of complex freeform shapes as well as allowing a large amount of detail that would be difficult to achieve if modelled by hand, especially in the same time period.

Such modelling techniques are useful tools as they bridge the gap between virtual reality and reality; offering tactile and tangible objects to aid analysis. This is especially applicable to the research given the vast majority of people being unable to access virtual reality equipment and immersive techniques. Rapid prototyping offers an alternative to this which may help bring the analysis and findings to a wider audience. This process is becoming more widely used in the study of unbuilt, damaged or destroyed architecture, for example the investigation of Ionic capitals as discussed in section 4.3.11 by Richens and Herdt (2009). Here rapid prototyping techniques were used to display physical representations of the scanned reports directly alongside their reconstructed equivalent (see Figure 4.14).

Figure 4.14: Rapid prototyping was used by Richens and Herdt (2009) to offer physical comparatives between the scanned reports (grey) and fully restored reconstructions (white). Image credit: Richens and Herdt (2009, p.814).

4.4 Chapter summary

The chapter begins by discussing the development of representation techniques in the arts throughout history. This is important as it highlights different cases of how such techniques have resulted in new knowledge being found on a particular subject as well as offering enhanced critique. For example, Muybridge's research into animal locomotion provided irrefutable evidence that horses raise all four hooves off the ground when galloping, and Choisy's use of axonometric drawings offered a re-presentation and enhanced understanding of ancient architecture. It is important to note that such critique would not be impossible to achieve without mediating techniques; however, it would have been very difficult to provide such convincing evidence; there would be a danger that statements could be mere speculation. Therefore their use simplifies and enhances the research investigated.

The development of the computer and digital representation techniques is then specifically discussed in detail because of its links with this research. The section demonstrates how rapidly digital media has developed and how it is constantly moving forwards. This is investigated to highlight how these developments can be utilised not only to enhance understanding of proposed designs, but also to aid analysis of unbuilt, damaged or destroyed architecture. A series of tools are then discussed and presented to highlight how they can be applied in order to augment and enhance critique of such designs. These will then be utilised in the following chapters forming the three case studies to test and develop the research further.

4.5 Case study techniques and methodology

The three case studies investigating the architecture of Stirling, Perret and Lutyens utilise the toolbox of techniques in different ways. As a general rule though, all three cases require surface or solid modelling techniques to construct a digital representation. This then requires additional digital tools in the form of rendering and texture mapping to produce images or walkthroughs for the purpose of spatial analysis. Beyond this, each case study requires different techniques depending on the line of enquiry that is being pursued. For example, the Lutyens case study uses further solid modelling techniques to analyse the geometry of his design for the Liverpool Metropolitan Cathedral, as well as additional lighting and acoustic analysis to gather quantitative data. The Perret case study uses additional techniques such as rapid prototyping and the Stirling case study utilises design theory and near photorealistic rendering to propose counterfactual scenarios.

The methodology proposed in section 1.3.1 was developed after initial research for the first case study had been carried out. Therefore the Stirling case study, discussed in chapter five, can be seen as an explorative preliminary study in which serendipitous results were found to be substantial. Additional lines of enquiry could then be investigated once the case study was revisited. The Perret case study, discussed in chapter six, revealed several serendipitous results due to the significance of information found whilst constructing the digital representation of the Musée Bourdelle. Again, additional lines of enquiry could then be investigated once the methodology had been refined. The Lutyens case study, which is discussed in chapter seven, closely follows the methodology proposed in section 1.3.1. Therefore it primarily relies on results gathered from lines of enquiry pursued, with less serendipitous results found. In addition to the methodology developing, this is also due to the Lutyens digital representation being based on a near complete set of architectural drawings, therefore serendipitous results and methods of resolving unknown elements was less contentious.

The first two case studies are unbuilt designs; Stirling's Newton Aycliffe community centre was intentionally unbuilt, Perret's Musée Moderne was intentionally unbuilt and his Musée Bourdelle was unintentionally left unbuilt. Lutyens' design for Liverpool Metropolitan Cathedral can be classed as both built and unbuilt, as it was partially completed before construction was abandoned (see Figure 2.1). Although none of the case studies represent damaged or destroyed architecture, the principles and process applied using the methodology are the same.

5 Stirling case study: establishing principles and techniques

As an initial investigation exploring the use of digital techniques to augment understanding of damaged, destroyed or unbuilt works of architecture, the student work of Sir James Stirling was chosen as a preliminary study. It is important to note that this work was undertaken before the research methodology was finalised (see Figure 1.1). Its role was therefore to act as an explorative project, forming an initial investigation that helped to define the processes and techniques adopted in the methodology. The thesis project, from Stirling's final year at the Liverpool School of Architecture in 1950, provided a master plan for Newton Aycliffe in County Durham, England, and culminated in a design for a new community centre (see Figure 5.1). The design was intentionally unbuilt due to its nature as a student project.

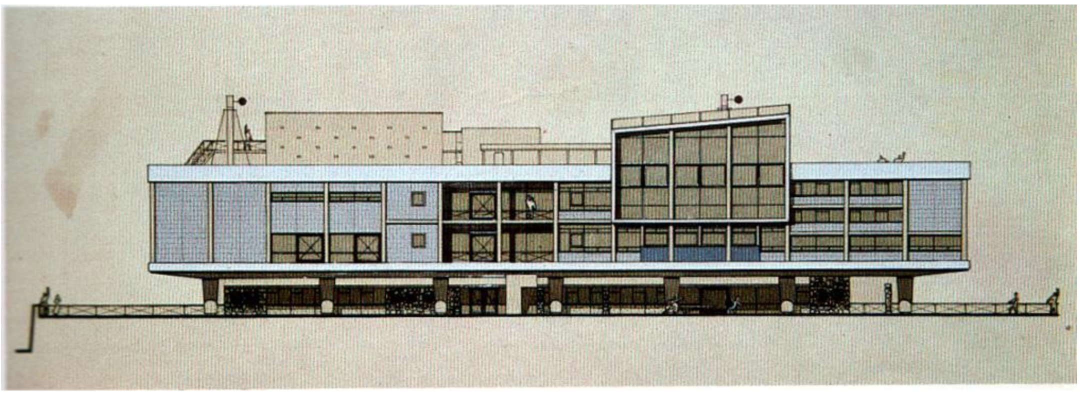


Figure 5.1: East elevation drawing of Stirling's design for a community centre at Newton Aycliffe in 1950. Image credit: Arnell and Bickford (1984, p.29).

The initial sections of this chapter are based on a preliminary investigation (Webb 2009) and will discuss the process of researching the design and its contemporary context, as well as how limitations and unknown elements of this information were resolved. An investigation into the techniques used initially to produce a physical representation, and later on a digital representation, will be discussed followed by findings; in which errors are found relating to the location of columns.

The preliminary study will then be revisited as new source data was discovered as part of the research presented here. This will form the basis of further discussion around the design that reflects the methodology devised for this thesis; in which enhanced understanding will be provided about Stirling's use of materiality and colour, as well as his use of the golden section.

5.1 Pilot study context

In 2008, Liverpool celebrated its year as the European Capital of Culture and as part of the events held across the city, a catalogue and exhibition called ‘The World in One School’ was launched (Dunne and Richmond 2008). This documented the history of the Liverpool School of Architecture and its notable alumni, including the fact that there have been six Royal Gold Medal winners amongst the former staff and students (Dunne and Richmond 2008). Stirling is one of the school’s most notable alumni and holds considerable admiration and influence in the international architectural community (Jacobus 1975, Rowe 1984, Girouard 2000, Berman 2010). In addition to receiving the Royal Gold Medal in 1980, he received the Pritzker Prize in 1981 as well as having the Royal Institute of British Architects Stirling Prize named in his honour. Stirling’s legacy can be seen in buildings such as the Engineering Faculty at Leicester University, which he designed in practice with Gowan between 1959-63, as well as later work with Wilford, for example the Neue Staatsgalerie at Stuttgart between 1977-84 (see Figure 5.2). As such a significant former student, it was decided that a physical model should be constructed of his Newton Aycliffe community centre design to form part of the ‘World in One School’ exhibition.

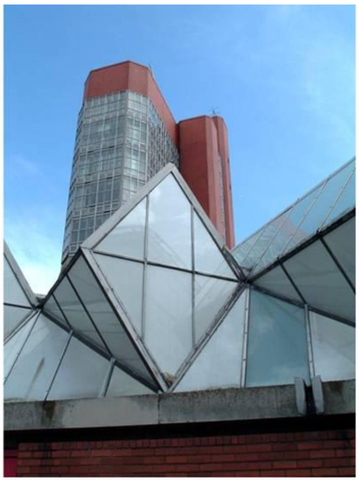



Figure 5.2: The Neue Staatsgalerie at Stuttgart by Stirling and Wilford (left) and the Engineering Building at the University of Leicester by Stirling and Gowan (right).

5.1.1 Why Stirling?

Stirling’s community centre design was initially conceived as being limited to a ‘reconstruction’ project. It was a result of reconstructing the lost model that the potential for such investigations in a research context was realised. Therefore, the rationale of its inclusion as a study was initially retrospective. In the first instance, the physical model was commissioned as a way of enhancing the exhibition staged in Liverpool, and later at the RIBA in Portland Place, London.

In gathering all of the source data available to construct the model, it soon became apparent that the information available was incomplete. This initiated an investigative process of how to fill in the missing elements of the design and how to make inferences based on other sources of information. The development of this process began to reveal new information about the design and acted as a catalyst and starting point for further research in this thesis. In this sense, the starting point for this project was arrived at somewhat serendipitously. The results reported here suggest initial findings into the use of computer mediated techniques as a method of augmenting understanding of an unbuilt work of architecture. Additionally, Stirling was chosen because of his connection to Liverpool as a former student and resident of the city, meaning that source information was accessible locally, making the logistics of the project more practical.

5.1.2 Sourcing primary and secondary information

The first task in preparation for constructing the physical model, which was aided using digital techniques, was to source all of the primary information available. The starting place for this was the University of Liverpool's archive, which has photographs of some of the original drawings and a photograph of a small-scale physical model produced for the Newton Aycliffe master plan design, which is now presumed to be lost. Additional sources of primary information were provided by the authors of the catalogue and exhibition in the form of further architectural drawings of the community centre design (Dunne and Richmond 2008).

Once it became clear that the drawings available were fragmented, additional information was sought by studying biographies and monographs of Stirling. This offered further architectural images of the community centre design as well as written descriptions of the design itself and the context in which it was produced (Arnell and Bickford 1984, Jacobus 1975, Rowe 1984, Stirling and Krier 1975). The key drawings can be found in Appendix A. It was also known that further drawings and information might have been available from the Canadian Centre for Architecture, where the majority of Stirling's work is archived. However, the budget for the project in comparison to the amount of information known did not justify visiting these archives.

5.1.3 Contemporary context of the design

In order to understand how Stirling came to design the community centre thesis at Newton Aycliffe, it is important to understand the context in which he was working and influences that had an impact on the design. This will then be used to aid decisions that may be required to resolve unknown elements of the design for interpolation and extrapolation purposes.

The starting point of this context was to investigate the history of the Liverpool School of Architecture in the period leading up to Stirling designing the community centre for his thesis in 1950. At this time, the school was undergoing a period of major transition. Between 1904 and 1933 Reilly was head of school, which was associated with traditional styles, particularly the Beaux Arts and Neo Classicism. After this, Budden became head and remained there during Stirling's education. Budden's era marked a significant move towards Modernist teachings in the school, although a traditional approach was still apparent. The students themselves began looking to the architecture coming from mainland Europe and were less influenced by historical sources (Dunne and Richmond 2008).

A significant shift in attitudes towards design also occurred with the arrival of the Polish School of Architecture in 1942-45. The Liverpool School of Architecture offered sanctuary for Polish architects and students during the Second World War with the idea that they would return home afterwards to assist in the rebuilding of their country (Dunne and Richmond 2008). In contrast to the more traditional style of Liverpool students, who used techniques such as watercolours, the Polish students primarily produced Modernist line drawings. This acted as a catalyst for students in Liverpool who were dissatisfied with the more traditional approach of the school. Stirling himself witnessed this after most of the Polish students had left;

> *"The School of Architecture was in tremendous ferment as the revolution of modern architecture had just hit it, second hand and rather late. There was furious debate as to the validity of the modern movement, tempers were heated and discussion was intense. Some staff resigned and a few students went off to other schools; at any rate I was left with a deep conviction of the moral rightness of the new architecture."* (Stirling and Krier 1975, p.14)

Due to this conflict of styles, Stirling's education was an eclectic mix. Maxwell, who studied at the Liverpool School of Architecture at the same time as Stirling, commented how design projects ranged from Cistercian monasteries to a Baroque garden pavilion and a Corbusian suburb (Maxwell 1998b). This meant that Stirling engaged with design in both historic and modern styles. He had an affinity for earlier building periods, such as English Baroque and Neo-Classicism as well as the works of engineers such as Brunel (Jacobus 1975).

During his final year at Liverpool, in which he produced the community centre thesis, the Modern Movement further influenced Stirling. He had access to books by Le Corbusier such as his 'Oeuvre Complete' and 'Towards a New Architecture'. Rowe, who tutored the thesis project, stated that the community centre design bears a resemblance to Le Corbusier's St-Dié Factory in its longer elevations (Jacobus 1975). He also comments that Stirling gained professional experience in New York the year before the thesis was undertaken. During this trip he visited many buildings in the city and further afield in the United States, by significant architects such as Wright, Breuer and Gropius. Rowe discusses the experience Stirling gained from his trip to America and how it influenced the thesis design, particularly how he believed it references Mies van der Rohe's IIT unbuilt library design and 'raised it up on Corbu style pilotis' (Rowe 1975, p.14). The thesis also utilises Corbusier's 'Plan Libre,' which combines various types of accommodation into a single building (Jacobus 1975). The comments by Rowe suggest that Corbusier's St-Dié Factory, Mies van Der Rohe's IIT library building and Breuer's houses could form key precedents when dealing with incomplete sections of the community centre design.

5.2 Addressing issues of incomplete source data

On receiving the original drawings for the project there were several pieces of information missing. The main problem in terms of constructing the physical model was the fact that of the four external elevations of the rectangular building, drawings for the two shorter elevations were absent. Additionally, several courtyard elevations were missing, as well as the second floor and roof plans. This section of the chapter will discuss the inferences made based on evidence available at the time to deal with incomplete source data as well as serendipitous results that were found as part of the construction process. Finally the projects that Stirling studied whilst designing the community centre thesis will be discussed in terms of how they can be used for inference purposes.

5.2.1 Inferences based on the incomplete information

The problem of the missing short elevations was dealt with using two separate techniques. The first of the two elevations was resolved by manipulating a perspective image that included one of these elevations (see Figure 5.3). Ortho-rectifying the image using graphics editing software enabled the underlying geometry of the façade to be made clearer, which allowed patterns and common components to be deduced based on the known elements of the design. This formed a reasonably strong certainty of Stirling's original intentions in relation to one of the missing short elevations.

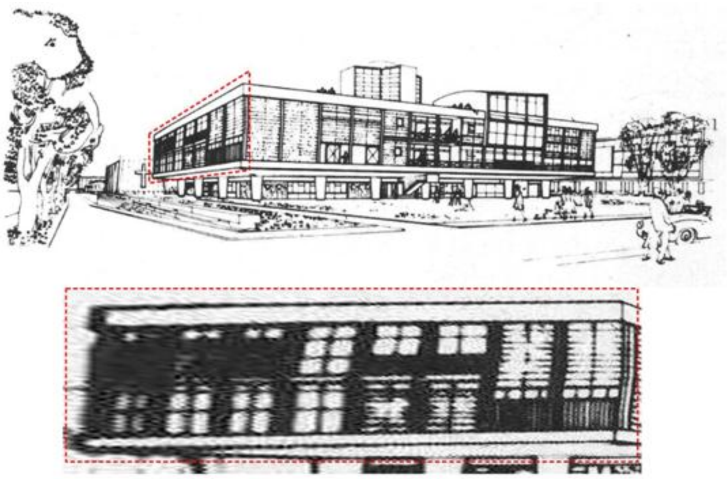


Figure 5.3: Stirling perspective (above) was digitally ortho-rectified to gain a clearer indication of the façade pattern (below). Original perspective image from Arnell and Bickford (1984, p.29).

The remaining short elevation proved a more difficult issue to resolve; an original section drawn through that part of the design revealed that the internal floor levels changed from being equidistant to a lower floor to ceiling height on the first floor, consequently making the second floor higher (see dashed lines in Figure 5.4). At this point a detailed study of the existing drawings was required in order to deduce where this change in level appeared on the external elevation. This change was already visible on the rear elevation of the scheme, of which drawings were available, and ended somewhere along the missing short elevation. As the design was based on a formal grid, it was feasible to interpolate based on examining the rear elevation and section. By studying these it became clear that the change in level took place in the library. Therefore by looking at the first floor plan, and locating the library, it was possible to deduce to a relative degree of certainty whereabouts the change in grid pattern ended along the missing elevation (see Figure 5.4). Without this line of enquiry to follow, it is unlikely that someone inspecting the drawings would realise that a change of level occurred in the design.

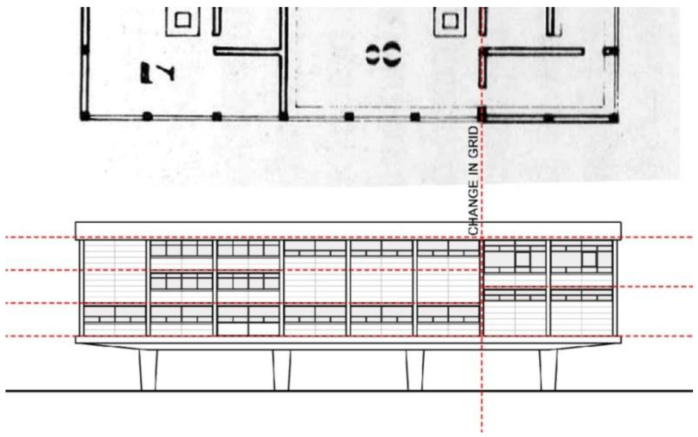


Figure 5.4: The interpolated short section: studying the original plan to see where the library was situated discovered the change in grid pattern. Original floor plan from Arnell and Bickford (1984, p.28).

5.2.2 Serendipitous results

The process of constructing the model revealed an inconsistency with the internal columns supporting a promenade deck that runs between the two courtyards in the centre of the design (see Figure 5.5). This inconsistency is not apparent from studying the existing drawings alone, hence the advantage of using digital techniques.

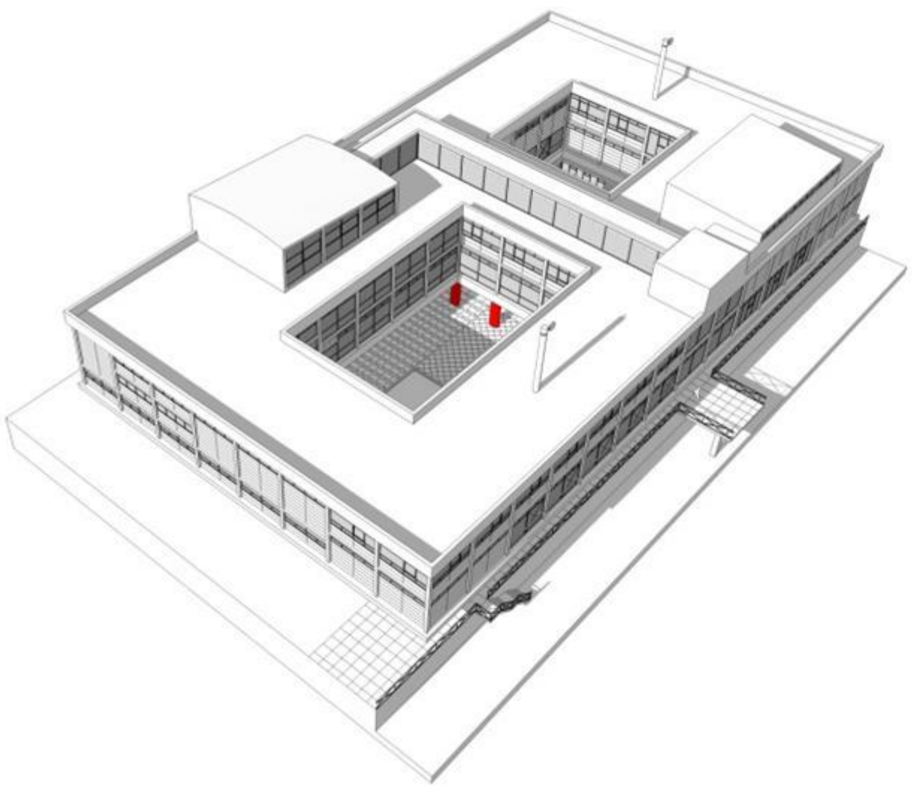


Figure 5.5: Digital representation of Stirling's community centre design. The contentious columns supporting the promenade between the two courtyards are highlighted in red.

Two versions of the ground floor plan were available for Stirling's design; the first being less detailed than the second, suggesting that it was an earlier version (see Appendix A - 5 and Appendix A - 7). The first plan shows the columns positioned centrally in the internal courtyard, which are of the same design as the majority of the columns; circular in section with their diameter increasing as they rise. The second, most finalised plan, employs a different column design altogether; extruded rectangles with rounded corners. When this information was translated into two-dimensional digital representations used to create the physical model, the overriding structural grid of the design informed the position of the columns based on their location on the ground floor plan as described above (see Figure 5.6). Once they were drawn digitally in three dimensions it became apparent that their positioning meant they would protrude past the façade they were supporting above, which is almost certainly an error on Stirling's part (see Figure 5.7). This is especially true as the earlier plan with centrally placed columns suggests the change in column design was last minute.

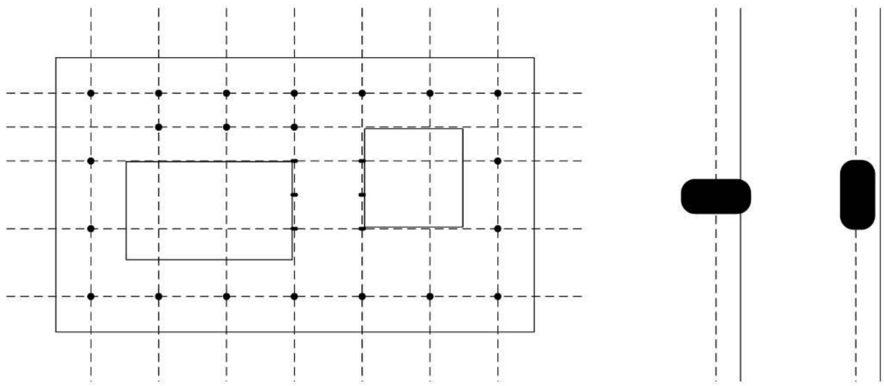


Figure 5.6: Two-dimensional digital representation of Stirling's design showing the structural grid in relation to the columns in plan (left). Zooming into the central section reveals how the column protrudes past the façade (centre right). This was resolved by rotating the columns by ninety degrees (far right).

After the model was completed, further study of the original drawings revealed that the columns shift away from the structural grid slightly in section, but remain in line with the grid in plan. This indicates that the section was drawn after the plan once Stirling had realised the problem. One can imagine with the deadline approaching, the thought of moving the columns in plan by a barely noticeable amount would have been low on Stirling's list of priorities. However, this inconsistency meant that a decision had to be made as to where the columns should be positioned in the physical model, bearing in mind that at this point their amendment in section was not realised. It was decided to keep the columns in line with the structural grid and rotate them by ninety degrees (see Figure 5.6 and Figure 5.7). This seemed like the most appropriate course of action as the rigorous structural grid underpinned the whole scheme.

This highlights a problem with constructing representations based on partial information, as it is impossible to be certain about such inferences. Additionally, interpreting the source data to fill in missing elements could be dangerous in terms of misinforming the viewer that what they are seeing is entirely based on fact. This issue can be addressed in the way the model is presented as discussed in section 3.5.2; for instance elements of the design that are unknown or based on educated guesses could, for example, be presented in a different manner such as being left empty or shown with less detail than the known elements (Kensek 2005).

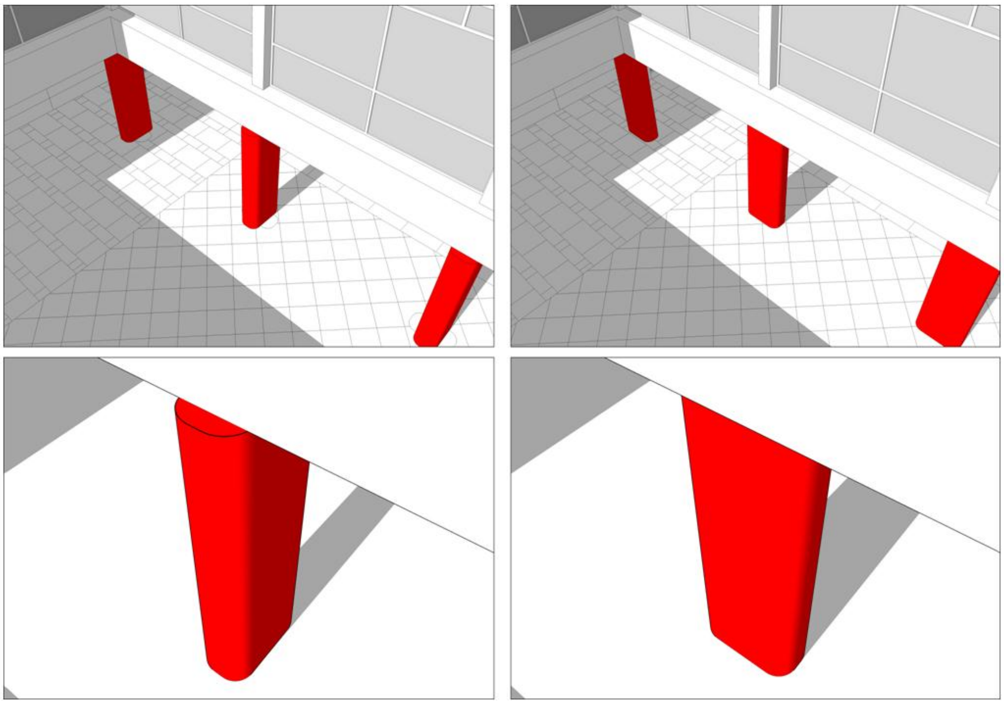


Figure 5.7: Digital model showing Stirling's final design with overhanging columns (left hand images) and amended design (right hand images).

5.2.3 Inferences based on Stirling's precedent studies

As discussed in section 5.1.3, Corbusier's St-Dié factory in France and Mies van Der Rohe's unbuilt IIT library design in America can be used as additional reference points and analogies to aid the construction process based on their likely use as precedent studies by Stirling, as discussed by Rowe (1975). Corbusier's St-Dié factory bears a strong resemblance to Stirling's community centre design; the core defining element being a concrete grid structure on pilotis (see Figure 5.8). The fenestration is also likely to have been an inspiration to Stirling; prefabricated timber frames that are mirrored and paired to create a façade that links to the modular nature of the grid, whilst retaining variety relating to the various functions of the building (Gans 2006). The scheme provides vital clues of materiality and space as to how the community centre design may have looked if it had been built. Mies van der Rohe's unbuilt library scheme at IIT also forms a good source of extrapolation for the model offering insights into the possible materiality of the design, such as the use of brickwork between the floor level and windowsill.

Figure 5.8: St-Dié Factory by Le Corbusier. The elevation treatment and use of pilotis bears a strong resemblance to Stirling's thesis project. Image credit: Gans (2006, p.90).

5.3 Constructing the physical and digital representations

As previously stated, the initial idea was to create a physical model for the 'World in One School' exhibition. However, a digital representation was also created after this in order to gain further understanding of the community centre design for this research. This section will discuss the techniques used primarily to create the physical model, as the digital equivalent will be discussed in more detail from section 5.5 onwards.

5.3.1 Techniques used and processes applied

Once all of the information was pieced together and inferences were made with regard to the unknown elements, the process of constructing the model could begin. Firstly all of the existing drawings were scanned digitally and scaled to size using a two-dimensional digital drafting package. The original drawings included a scale bar meaning that this was a simple process in ascertaining accurate dimensions. These sizes were double checked by measuring people and door heights in the drawings for clarity. The size of the structural grid was established next, as it underpins the whole design. This was calculated at 9700mm (32 feet) between supporting columns and subsequently 4850mm (16 feet) between each window module on the façade. After these ruling factors were recognised, the rest of the drawings were traced over digitally as two-dimensional vectors using the grid system as a guide. Once all of the known elements of the design were converted into digital line drawings, the inferred sections could also be drawn digitally based on the research carried out in section 5.2.

After the vector based drawings were completed, they were reconfigured to prepare them for physical production on a CNC router (see Figure 5.9). The process involved converting the drawings into the various layers that form the basis of the physical model. For instance, transparent acrylic was used for the glazed elements; therefore all of the drawings containing glazing were converted to this layer. In terms of representation, it was decided to allow the materiality of the design to be interpreted by the viewer as Stirling had not specified what each material was supposed to be; therefore white Foamex became the main material of the model. However, an indication of materiality can be seen in the use of colour and texture on some of the original drawings (see Appendix A - 2). For instance, the panels underneath some of the windows are hatched with lines therefore these could possibly be interpreted as a brick infill or timber cladding system. However, due to a lack of specific information on what Stirling specified for these items, it is left to the viewer to form their own conclusions. This interpretive indication of materiality was made apparent on the physical model using the engraving tool on the router which scores lines into the surface of the Foamex; therefore it was possible to represent the lines that were hatched on the original drawings.

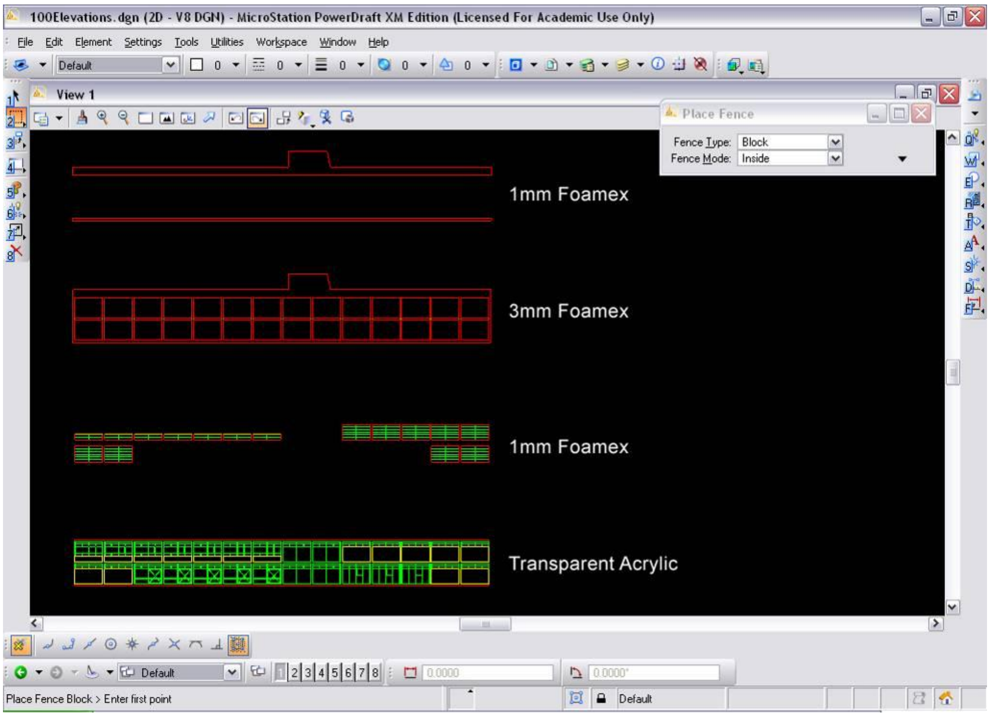


Figure 5.9: Screen image captured showing the digital elevation drawing was split into layers according to the process required using the computer driven router.

5.3.2 Manual and digital techniques

The construction of the model involved the use of both manual and digital techniques. Either alone would not have been enough to provide a satisfactory result. The router cut the numerous pieces based on the digital line drawings and they were then finished manually; first by sanding them and then finally by gluing them together (see Figure 5.10). Some aspects of the design were highly sculptural, such as the chimney stacks on the roof, and were consequently produced entirely by hand.

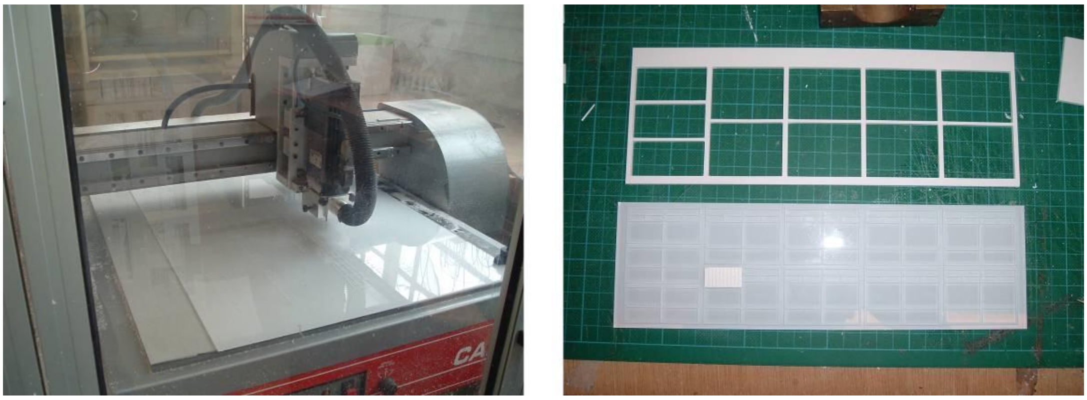


Figure 5.10: Above left: the router arm cutting various sections of the transparent acrylic to form the glazed elements of the design. Above right: the 3mm foamex sits above the acrylic once it has been finished by hand.

5.3.3 Lessons learned from constructing the model

There were several lessons learned in constructing the model, which could help with future exploration into digital representations as tools for augmenting our understanding of unbuilt architecture. In terms of the missing elements of the design, primarily the missing elevation, a different approach could have been taken to ensure the viewer of the model does not believe it is an exact replica of Stirling's original design. Firstly, the elevation could have been left blank or to only show the grid pattern that runs through the whole scheme ensuring the viewer realises that this element of the design is unknown. However, this would have left the model disjointed and because of the research undertaken it was felt that an extrapolated design was sufficient. Another way of resolving this would have been to present several options of how the façade could have looked (Novitski 1998). This would have been an unhelpful complication when you consider that the model was intended for public viewing in the 'World in One School' exhibition, and was shown as one piece within the overall exhibition to illustrate Stirling's Newton Aycliffe community centre design from his final year at the Liverpool School of Architecture, rather than an investigation into what the missing elevation may have looked like (see Figure 5.11). This issue could have been highlighted more clearly within the display though; with information showing which parts were unknown and which involved extrapolation from the known elements. This could also have included a brief description of the process of extrapolation to make the viewer fully aware of the nature of the model.

Figure 5.11: Physical representation of Stirling's unbuilt community centre design at Newton Aycliffe, which formed part of the 'World in One School' exhibition.

5.4 Initial findings based on the preliminary study

The preliminary study indicates that the production of digital or physical scale models to reinterpret an unbuilt design is highly valuable as a research tool. It enabled a rigorous and thorough analysis of Stirling's community centre design, resulting in new information being found. The process reiterates the fact that three-dimensional modelling is particularly good at aiding the interpretation of a design, rather than relying solely on a set of two-dimensional representations. For example, the process revealed that a two-dimensional section drawing of the community centre was deceptive; it appeared in the drawing that the vertical elements of the ground floor area meet the underside of the first floor slab (see Figure 5.12). Upon closer inspection when preparing the drawings for the model, it became apparent that they do not meet; Stirling only connects the two levels where the circulation punches through the first floor slab.

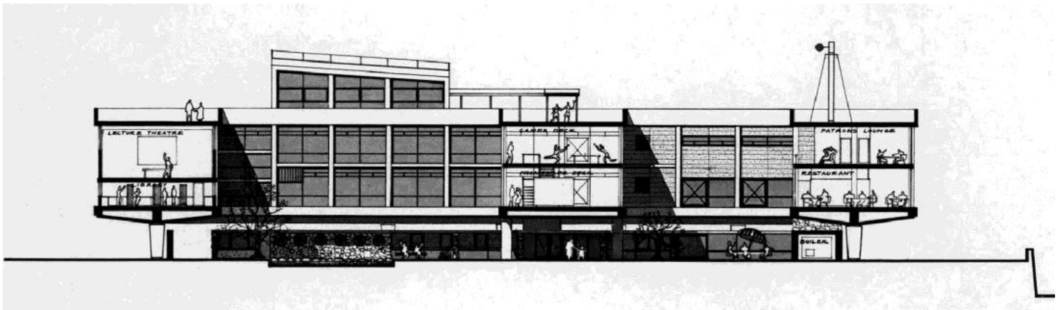


Figure 5.12: The original section showing the gap between ground and first floors as well as the columns below the deck appearing to sit correctly. Image credit: University of Liverpool Archives, reproduced by Dunne and Richmond (2008, p.56).

This demonstrates how such three-dimensional digital representations engage the viewer on a much greater level than the study of two-dimensional images and text alone. The World in One School exhibition is testimony to this as the community centre model was commissioned for that reason; it enabled the attendees to experience and understand the design far better spatially. Without the use of digital techniques the model would have been incomplete, giving the viewer a disjointed vision of the design. Therefore its application was necessary and resulted in twofold benefits; a complete design for the viewer and a more thorough investigation into the building by the researcher. The preliminary study demonstrates how thorough the exploration of a design has to be in order to produce satisfactory results, which consequently leads to a highly engaging research experience and augments the investigation into works of architecture.

5.5 Reappraisal based on additional information being sourced

As already noted, the preliminary study was prepared in 2008 primarily as a three-dimensional visual accompaniment forming part of the 'World in One School' exhibition. However, new information came to light in 2010 when 'James Frazer Stirling: notes from the archive' was published (Vidler 2010). To coincide with the book launch the Canadian Centre for Architecture, which holds the majority of archive information on Stirling, published additional source data online, such as drawings and written text including that of Stirling's community centre design (Canadian Centre for Architecture 2010). The drawing set also includes a detailed section of the community centre design that could be used to check whether the basic dimensions are correct (see Appendix A - 12). This additional information combined with that already sought for the preliminary study resulted in a near complete set of architectural drawings for the design. This then offers an opportunity to test whether the inferences made in the preliminary study were close to the actual design Stirling proposed. Therefore, the model will be rebuilt digitally and then compared to its preliminary equivalent. In addition to this, Vidler (2010) offers extensive discussion and critique of the community centre design in his book; hence lines of enquiry can be generated using the methodology proposed in Figure 1.1 to further investigate the design utilising digital techniques. In this respect, the additional information sourced offers an opportunity to test Stirling's design in line with the main body of research for this thesis.

5.5.1 Comparing the preliminary study to the reappraised simulation

The original model built both physically and digitally represents a 'best educated guess' based on the source data available at the time. The representation can be reappraised digitally using a further simulation taking into account the additional information that came to light in 2010. The reappraised digital model was a lot simpler to construct, as drawings including the short elevations, courtyard elevations, upper floor plans as well as multiple sections were available in addition to those sourced previously. Consequently, comparisons can be made between areas that were contentious in the preliminary digital model.

The first part of the preliminary model that had missing information was the two short elevations, as discussed in section 5.2.1. The first of these was resolved by deducing from an archive perspective image that was ortho-rectified to give a clearer indication of the façade pattern (see Figure 5.3). Once the digital model was simulated taking into account the additional source data, it became clear that this process was successful at informing the general pattern of the façade. However, it was less successful at predicting the various façade patterns in detail. For instance, the fenestration pattern was the same in both digital simulations in terms of which parts were infill panels and which were glazed, however, the detailing of transoms and mullions on the glazing as well as the type of infill panels proved to be inaccurate on the preliminary inferred façade (see Figure 5.13).

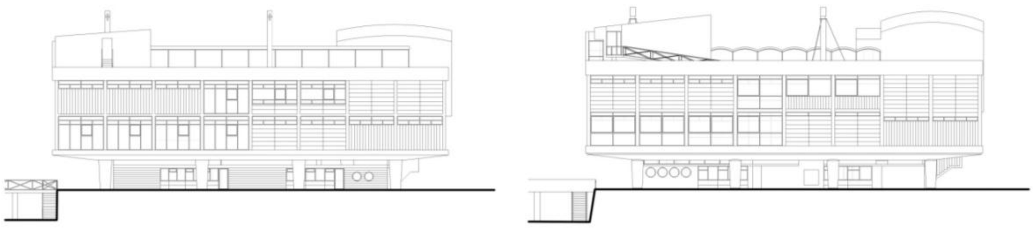


Figure 5.13: The preliminary model (left) is the same as the reappraised model (right) in terms of which parts of the façade are glazed and which are infill panels. However, the glazing detail and aspects of the infill panel materiality are incorrect.

The other missing short elevation, which proved to be more difficult to infer of the two (see section 5.2.1), was also incorrect. This was at the point in which the design of the community centre changes from two storeys above the plinth to three storeys. In this part of the design, the new source information reveals there is a lecture hall with raked seating that creates the junction between the two storey and three storey elements (see Figure 5.14). This is consequently expressed on the external façade. Considering there was not a second floor plan originally available and no indication of any other ramped element breaking the strict structural grid, the inferences made still stand as the most viable option given all of the information available at the time. The inclusion of the raked lecture hall can be seen as a first step for Stirling moving away from a strict 'Corbusian' grid towards more expressive forms, such as the lecture halls at the University of Leicester Engineering Building.

Additionally, the two isometric line drawings exported from the original and reappraised simulations (see Figure 5.14) make clear one of the major problems when dealing with two-dimensional architectural drawings. The partial original source data could easily be misinforming, for instance, the walkway linking the squash court to the gymnasium appeared to have a flat roof based on the two long elevations that were available. However, once the short elevation drawings became available, it was clear that the roof was formed of a series of curves along the building's width. A similar issue can be seen with the ramp leading up to the squash court, which was originally thought to be an external stair.

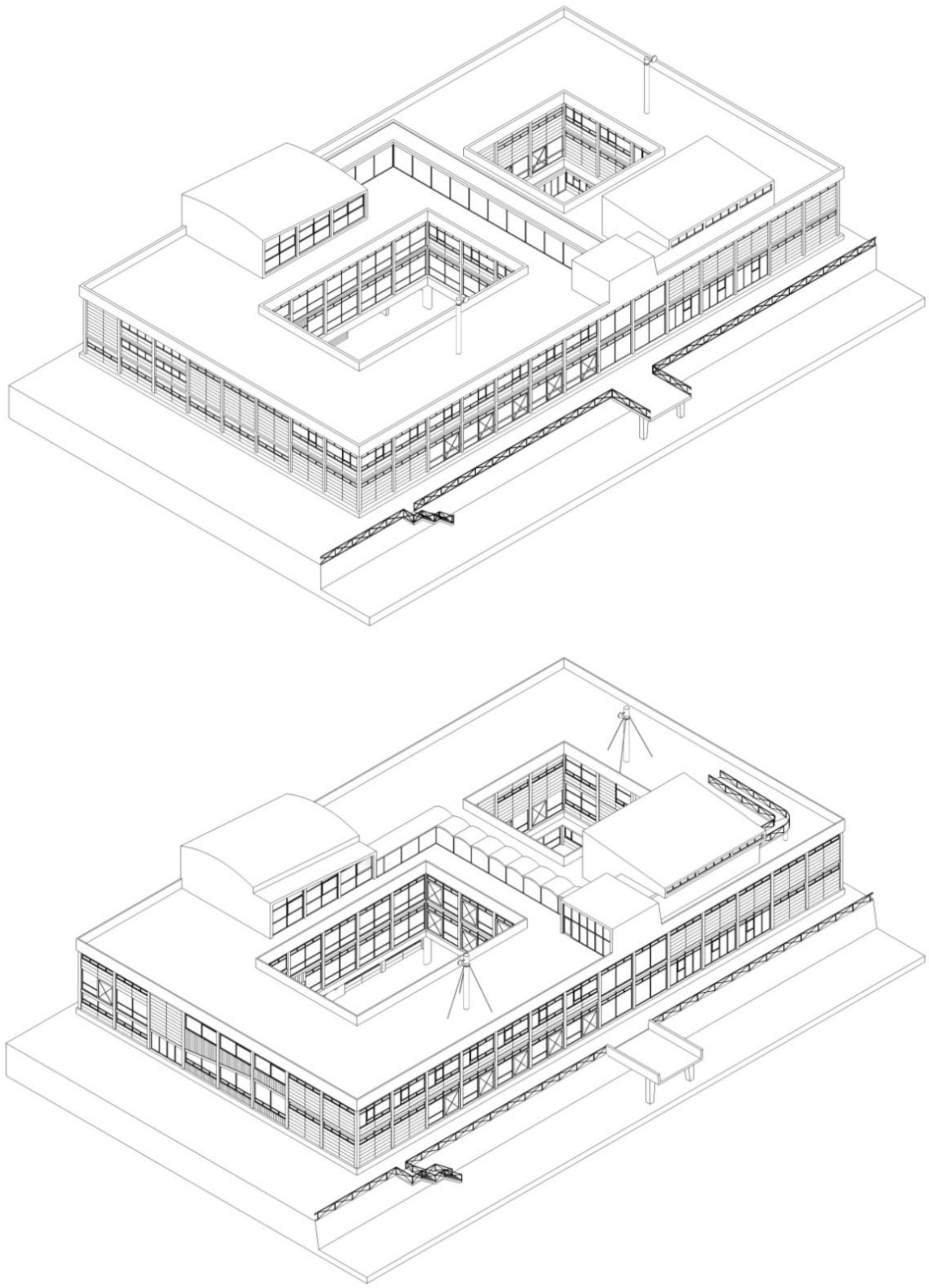


Figure 5.14: Isometric line drawings of the preliminary model (above) and reappraised model (below). The visible short elevation shows the raked seating of the lecture theatre breaking the structural grid in the reappraised model as well as the curved roof of the walkway between the gymnasium and squash court.

Although these errors are useful as a checking mechanism between the original simulation formed from partial data, and the reappraised simulation formed from a near full set of data, the fact that errors occurred is not crucial to the research. The main point of the pilot study was to demonstrate that in order to make inferences to fill in missing elements, a rigorous process has to be undertaken to fully understand the known elements of the design and its context. Therefore, it is this process that is the focus, rather than the resulting models themselves.

5.6 Lines of enquiry formed from additional information sourced

The publishing of Vidler's book in 2010 not only offers further primary source information, but also additional secondary information and commentary. In the text Vidler discusses Stirling's community centre in detail and comments on several issues that could be enhanced or explained further using digital techniques. These are listed below and will be discussed in detail in the following sub sections:

1) Use of the golden section
2) Use of colour and materials
3) Development of the column design

5.6.1 Use of the golden section

Stirling's experimentation with modernism can be seen in a fourth year project he competed at the Liverpool School of Architecture entitled a 'Community Centre for a Small Town in the Middle West USA'. Vidler (2010) discusses how the design is influenced by Le Corbusier's use of the golden section for proportioning, which is evident in the section drawing of the American community centre that includes a diagram of the golden section itself (see Figure 5.15). The golden section is a proportioning system that has been used since the days of antiquity for its apparent 'harmonious' relationship to the universe as well as the human body; a device that Le Corbusier utilised for his 'Modulor' system (Ching 1996).

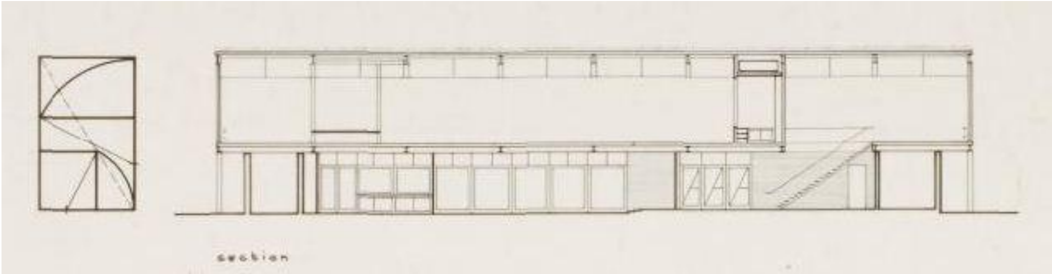


Figure 5.15: A fourth year student project by Stirling entitled a ‘Community Centre for a Small Town in the Middle West USA’, in which he displays the golden section to demonstrate the design’s relationship to it. Image credit: Vidler (2010, p.36).

In addition to the influence of Le Corbusier, Rowe may also have been persuasive in the use of such proportioning systems, which is particularly evident in his essay ‘the Mathematics of the Ideal Villa’ (Rowe 1974). This is important as Rowe tutored Stirling’s community centre thesis project. With this information available, the first line of enquiry is to test the extent of the use of the golden section in Stirling’s community centre thesis project. This would be possible without a digital representation (see Figure 5.15); however its use makes the process a lot simpler. This is because the three-dimensional digital model can be manipulated and rotated easily, as well as enabling quick scaling and repositioning of the golden section to test whether Stirling used it extensively. This can be seen in Figure 5.16 and Figure 5.17.

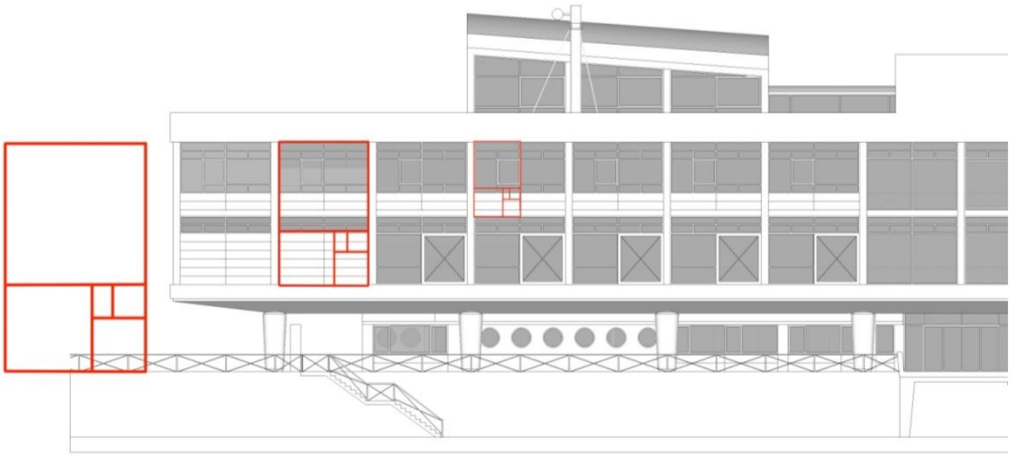


Figure 5.16: Reappraised digital model demonstrating the use of the golden section in elevation.

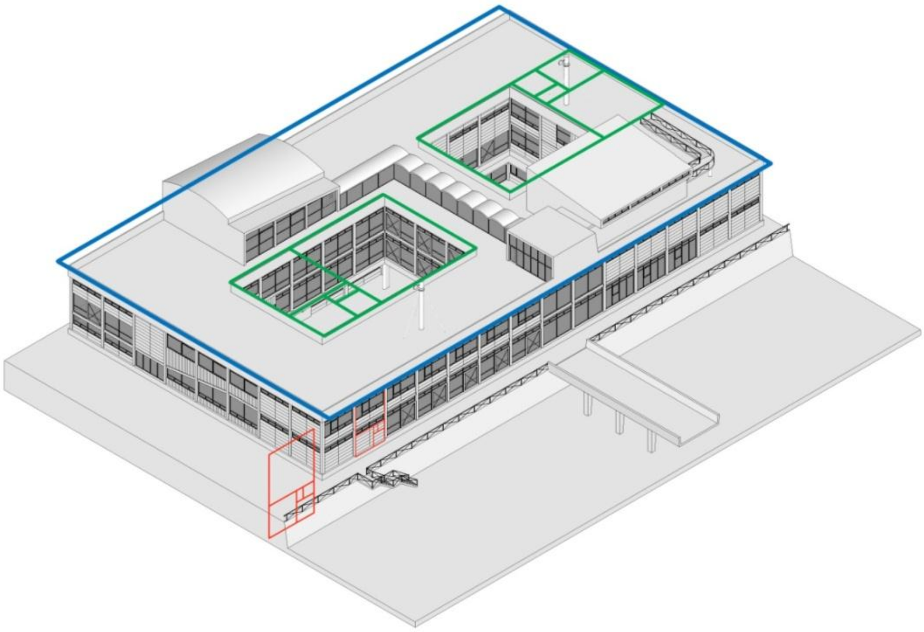


Figure 5.17: Reappraised digital model demonstrating the use of the golden section (green, blue and red) in isometric.

Figure 5.16 demonstrates that, in the same way as Stirling's American community centre (see Figure 5.15); the golden section heavily influences the façade design of the Newton Aycliffe community centre thesis. Initially, the golden section diagram was lined up against the height of the façade and shows that it relates to the design in terms of the distance between ground and first floor, as well as first floor to the roof floor. Additionally, the golden section diagram was placed along the façade, which demonstrates that it is almost exactly the same proportion to that of the two storey bays. Evidence that Stirling wanted to emphasise this can be seen in the way he designed the columns to span two storeys with the floor plate sitting further behind.

Figure 5.17 also demonstrates the use of the golden section in the community centre design; the diagram was rotated vertically to test its use in plan. This showed that the overall plan approximately equates to that of the golden section (see blue lines in Figure 5.17), as well as the large courtyard (see green lines in Figure 5.17). Additionally, it demonstrates that the smaller courtyard has the same relationship as the larger courtyard with the solid element of the design forming the remainder of the golden section. This line of enquiry enhances Vidler's comments about the use of the golden section by demonstrating digitally the various aspects of the design in which Stirling most likely utilised it.

5.6.2 Materiality and colour

A further line of enquiry based on the additional information discovered is to investigate the use of materiality and colour in the community centre design. Vidler states that Stirling's use of colour was 'a consistent preoccupation in his work, from the brightly coloured interiors he envisaged for the community centre thesis project, to Stirling's later equally bright coloured exteriors and interiors' (Vidler 2010, p.33). Firstly the exterior of the design will be investigated, followed by the interior.

Figure 5.18: Stirling's student project of a 'house for the architect'. Image credit: Canadian Centre for Architecture, reproduced in Vidler (2010, p.37).

The community centre thesis project marks a turning point in Stirling's early career, when compared to his early built work such as the Ham Common flats and earlier student projects such as his 'house for the architect'. The house for an architect (see Figure 5.18) utilises brightly coloured window frames and panels, as well as natural materials similar in style to architects such as Breuer (Vidler 2010). Evidence of such colour in the community centre design is suggested in the interior by Stirling, as well as indicated on the exterior with elements such as red frames around sliding doors (see Appendix A - 2). The elevation drawings also indicate infill panels coloured light blue with hatching that suggests they are made of precast concrete. They also indicate vertical panels of a darker blue colour that are more than likely made of timber. These assumptions were made based on standard architectural drawing, such as speckled hatching for concrete or render, and vertical hatching for vertically clad timber. However, the materiality of the design is not made explicit anywhere in the evidence available. The materiality of the design is questionable when compared to Stirling's earliest built works with Gowan such as Ham Common and the Cowes house on the Isle of Wight. These works use a palette of materials that is a lot more restrained, such as brickwork, exposed concrete and stained timber window frames. Ray traced digital renderings of the two materiality scenarios have been produced in order to enhance our understanding of what the community centre may have looked like externally (see Figure 5.19, Figure 5.20, Appendix A - 15 and Appendix A - 16).

Figure 5.19: Ray traced rendering of Stirling's community centre thesis with a material palette taken from the original drawings and earlier student projects.

Figure 5.20: Ray traced rendering of Stirling's community centre thesis with a material palette taken from early built designs such as Ham Common and the Cowes residence.

As already stated, Figure 5.19 is primarily based on Stirling's drawings for the project itself as well as analogies taken from his earlier student work. The rendering is bolder in its use of colour, for example window openings and the tops of chimney stacks are bright red in colour. This could be a very early indication of Stirling's use of colour much later in his career on projects such as No1 Poultry in London, or at least it may have been something he referred back to when designing these later projects. Figure 5.20 takes into account analogies from the precedent buildings that Stirling studied, such as Corbusier's St-Dié factory in France as discussed in section

5.2.3. It also acknowledges other likely analogies such as the exterior finish of works by Breuer, as discussed by Vidler (2010). The resulting rendering is therefore a lot more restrained in its use of materials with natural finishes. This reflects Stirling and Gowan's early built projects as already discussed. Another potential precedent that may have informed analogies for the materiality was Mies van der Rohe's unbuilt IIT library, which featured brick infill panels between the steel structural frames. Brick was considered as a possible material for Stirling's community centre; however, the evidence on the original drawings suggests the infill panels are made using timber formwork for concrete or simply vertically clad timber as previously discussed.

Again, whether or not either scenario rendered digitally is more likely than the other is not the highest priority. The different options highlight the potential materiality of the design and expose the thorough process that has to be undertaken to arrive at such representations. Therefore, the source information has been re-presented and re-analysed using digital forensic techniques.

These techniques were then repeated to investigate the interior spatial qualities and colour schemes of the community centre design. Pages of Stirling's thesis book are reprinted by Vidler (2010) and show five colour swatches for the proposed design which are dark red, ochre, green, yellow and purple, used in combination with grey and white. Vidler relates these swatches to a series of diagrammatic floor plans which indicate colour relating to different areas of the design in seven different colours of yellow, yellow brown, brown, green, emerald, blue, purple and red (see Figure 5.21). It is therefore questionable whether the two actually relate, as there are five colour swatches compared to the seven used on the plans. Stirling may have been using the colours on the floor plans primarily to highlight the different functions of the design, such as social spaces in yellow and the youth centre in purple. However, the two do loosely relate, especially when considering later built work by Stirling. For example, if we are to take yellow as the colour scheme for social areas in the community centre as suggested by Vidler, it emerges as a common choice in Stirling's later work also. This can be seen in the circulation routes at the Clore Gallery in London, the external stonework of the landscaped exteriors at the Staatsgalerie at Stuttgart as well as the circulation and social spaces at the Olivetti Training School in Surrey. This is again an example of how contentious issues resulting from conflicting source information can lead to enhanced understanding of a particular architect and their work.

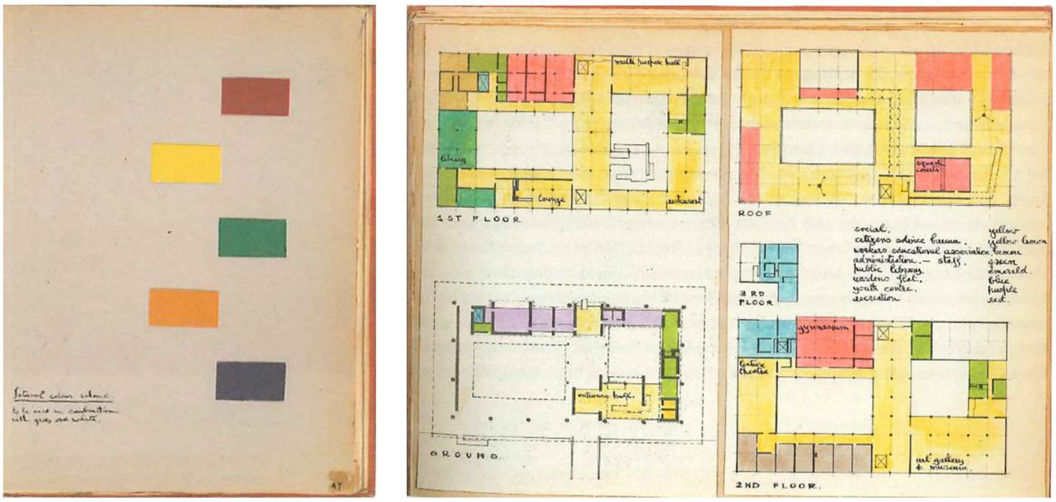


Figure 5.21: Stirling produces colour swatches for the interior of the community centre design (left) that Vidler (2010) believes relate to the functional floor plan (right). Image credit: Canadian Centre for Architecture, reproduced in Vidler (2010, p.56-57).

The decision was taken to make deductions from Stirling’s diagrammatic floor plans as a basis for the internal colour scheme. In addition to the confirmation of yellow in circulation and social areas of his other work, the plans were used because purple is the highlighted colour of the Warden’s flat in the community centre design, which directly links to precedent studies of Stirling such as the interior of Breuer’s houses. These show a similar use of dark blues and purple on a domestic scale.

Three scenes were chosen to show the colour and spatial qualities of the community centre design; the promenade deck on the first floor, the warden’s flat and the public library. Perspective views of each were created digitally using the model; however, the way in which to represent the spaces without misleading the viewer had to be considered. Consequently, three versions of each scene were created; a black and white line drawing, a black and white line drawing with greyscale infill and a colour ray traced representation (see Figure 5.22, Appendix A - 17 and Appendix A - 18). Black and white line drawings were chosen as they had already been used by Stirling for the exterior of the community centre; therefore it was an obvious choice in terms of continuity (see Appendix A - 13). Black and white line drawings with greyscale infill were chosen as this style was utilised by other students in the same year as Stirling when producing interior perspectives, therefore it was a good precedent to follow (see Appendix A - 14). The first two options avoid misleading the viewer, as they do not represent the contentious nature of the colour scheme; however, a third fully rendered image was produced in colour to give an indication of how the spaces may have realistically looked.

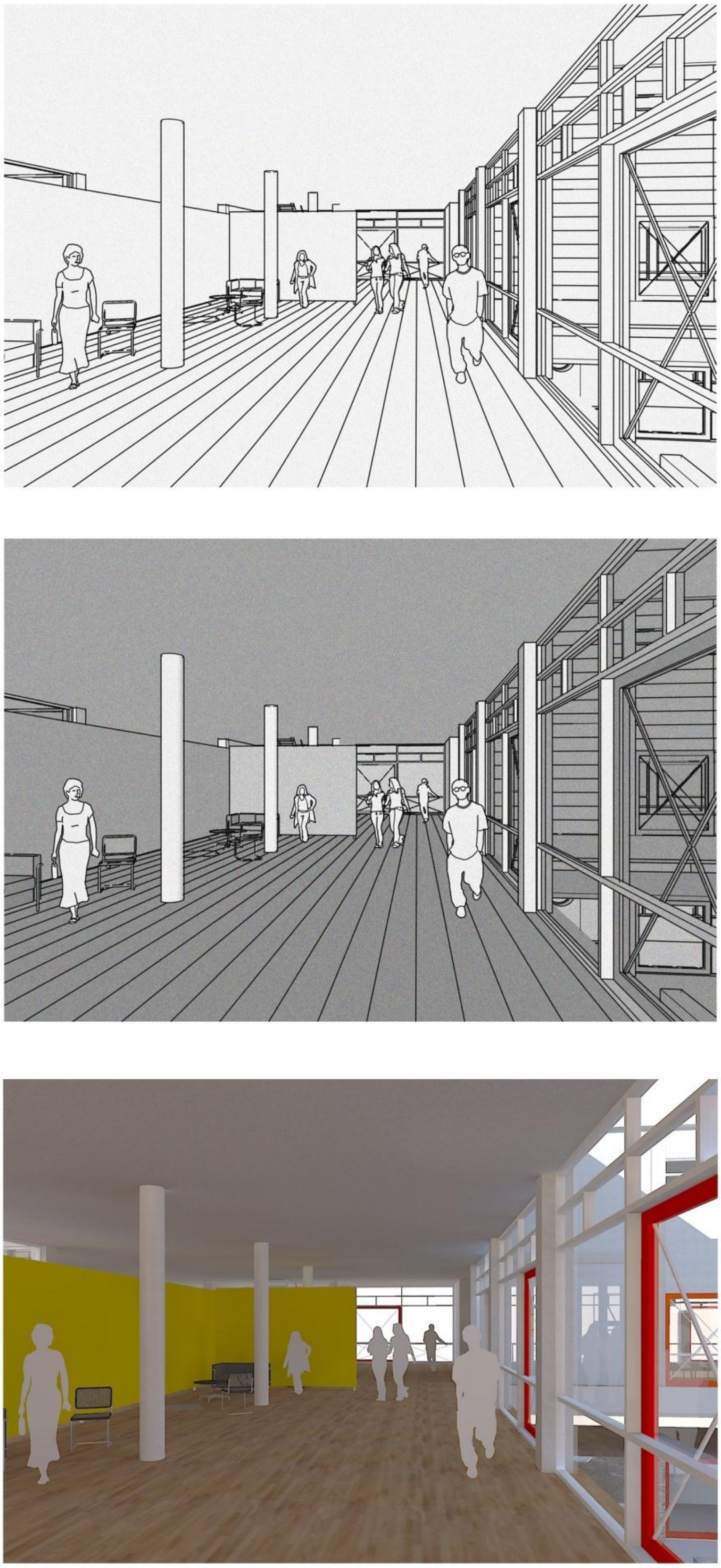


Figure 5.22: Visualisations of the promenade deck on the first floor of Stirling's Newton Aycliffe community centre. Three versions are produced; the first being a black and white line drawing, the second with added greyscale infill and the third a ray traced colour render. The third image represents the most probable colour scenario based on the evidence available; however, the use of three different image styles ensures that the coloured version is not taken as fact.

The use of colour visualised in the lowest image of Figure 5.22 also takes analogies from other precedents that Stirling studied, such as the brightly coloured interiors by Le Corbusier for the St-Dié factory in France. This, again, can be seen as an early iteration of Stirling's bold use of colour in his later work, especially in line with other studies he undertook whilst at university such as the house for the architect (see Figure 5.18). The three ray traced images are particularly useful in demonstrating the bold use of colour in contrast with the exterior of the design, which is much more reserved. This forms an important information source when researching the community centre design, as there is no original documents available directly showing the use of colour in the interior spaces.

5.6.3 Column location

Digital techniques can also be used to clearly demonstrate the development of the column structure underpinning the design of Stirling's community centre. This is again discussed by Vidler (2010) and shown using a combination of model photographs and architectural drawings in his book. The main feature of the community centre design is it being raised on columns to enable circulation to flow beneath. The column development can be shown using a series of images exported from the digital model; ideally these would be overlaid when presented digitally, however they are presented side by side here (see Figure 5.23).

Figure 5.23: The ground floor columns developed initially by following the pattern of the above floors (left). Next they became larger and circular (centre). Finally a combination of the two with additional rounded rectangular columns was used (right).

The digital imagery clearly shows how the column design was initiated by following the pattern of the columns on the floors above them, and then a major step was taken to redesign them with a greater mass in a conical circular shape. The final image of the three in Figure 5.23 shows a hybrid of the first two images which features additional rounded rectangular columns, suggesting this was a last minute refinement of the design process. This examination of the development process using digital techniques is important as it assists in identifying why there may have been issues with the column design between the courtyards, as discussed in section 5.2.2. Unlike other aspects of the design, the columns changed considerably during the development process, which helps to justify why mistakes may have been made in terms of their potential overhanging past the façade they were supporting.

5.7 Chapter summary

The chapter begins by discussing the preliminary study undertaken in 2008 that formed the starting point for the research presented here. This is acknowledged for its importance at demonstrating how digital techniques can be used to enhance our understanding of an unbuilt, damaged or destroyed work of architecture. These initial sections comment on the model making process, how inferences were made in order to fill in missing source information, as well as unexpected results that were found. This is discussed in order to express the importance of the process of using such techniques, above and over any resulting representation created.

The preliminary research was then reappraised based on additional information being sourced. This process was undertaken in order to test the accuracy of inferences made for the preliminary representations and highlight why aspects of these inferences may have been predicted incorrectly, for example problems of understanding two-dimensional source data. In section 5.6, lines of enquiry are considered based on the new information published. This offered a pilot study in terms of testing the methodology produced for the two major case studies (see Figure 1.1), which will be discussed further over the next two chapters. The use of the methodology in the Stirling case study is demonstrated in Figure 5.24.

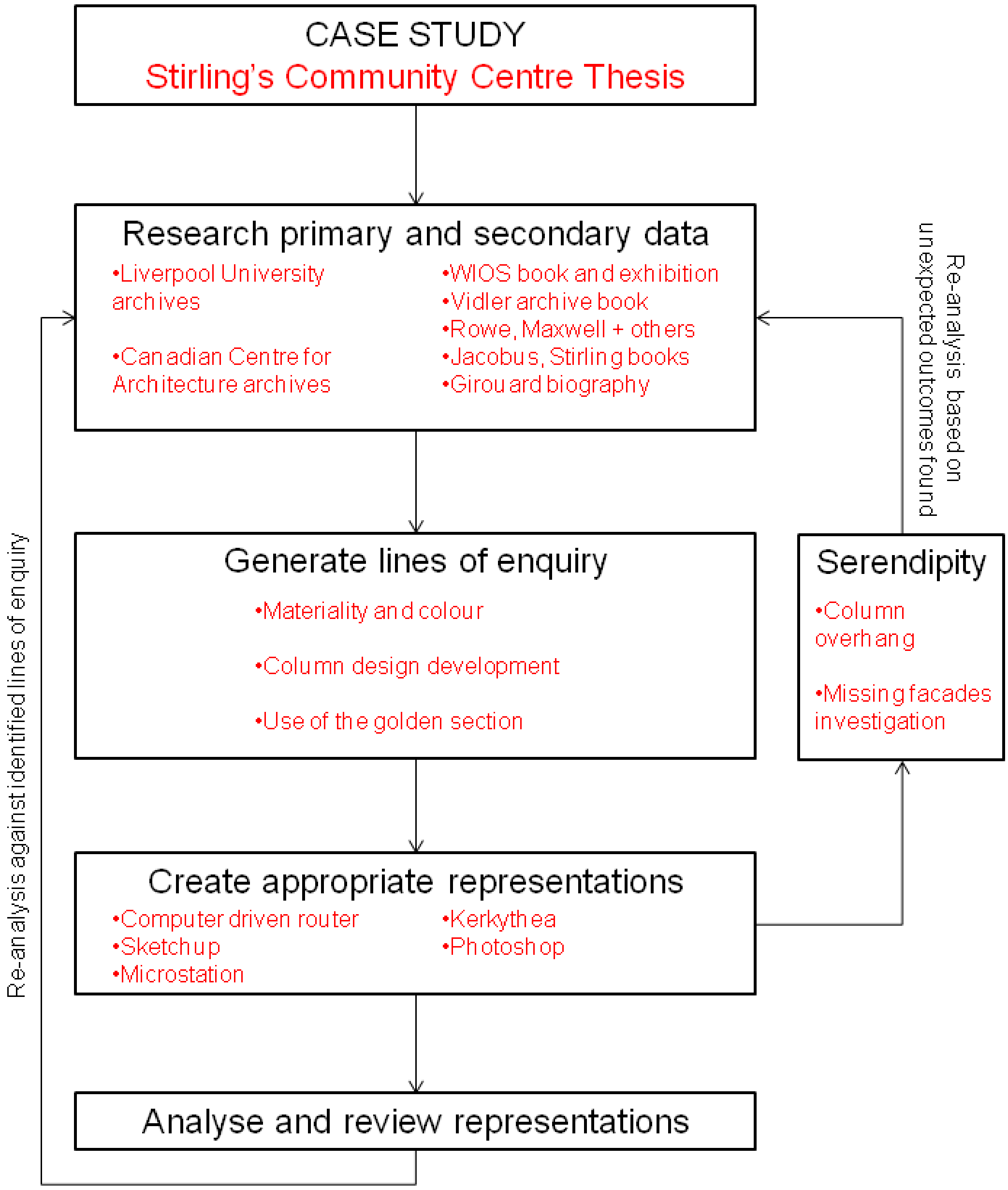


Figure 5.24: Sketch diagram demonstrating how the methodology was applied to the Stirling case study.

6 Perret case study

The second case study exploring the use of digital techniques to augment understanding of unbuilt, damaged or destroyed architecture consists of two unbuilt museum projects by the French architect Auguste Perret. Two projects were chosen, rather than one, for the potential comparatives that can be made between them. This is because the first of these, the Musée Moderne, was intentionally unbuilt and formed Perret's vision for an ideal museum. The second project, the Musée Bourdelle, was Perret's first opportunity to implement the ideas proposed in this ideal museum (see Figure 6.1). The Musée Bourdelle was unintentionally left unbuilt as it was proposed initially before being rejected for a different design solution. This case study research occurred in line with the development of the methodology, which is illustrated in Figure 1.1. Due to the developing nature of the methodology at the time, the case study presented here has a focus on the process of constructing the digital simulations and the unexpected results that were found based on this.

Figure 6.1: Perret's unbuilt design for the Musée Bourdelle in Paris, France. Image credit: Perret (1931)

The chapter will begin by examining in detail why Perret was chosen as an appropriate case study and how information was sourced. This then leads into an investigation of Perret as an architect and how he designed, which will then be used for inference purposes. The two museum projects will then be constructed using digital tools in which discoveries were made regarding techniques Perret utilised in order to design. Following this, comparisons will be made between the two museum projects using the simulations created. The two projects are discussed in reverse chronological order as there is more archival information available for the Musée Bourdelle than the Musée Moderne, therefore the information gathered to construct the Musée Bourdelle representation could subsequently be used for extrapolation purposes in unknowns of the Musée Moderne representation.

6.1 Why Perret?

Perret's museum projects were chosen to study for two particular reasons; firstly they share a common typology and secondly Perret had written in detail on his proposals for an ideal museum in 1929. At this time in the early twentieth century the architectural profession was undergoing radical change brought on by the arrival of the Modern Movement. One aspect of this was prominent architects expressing their theoretical propositions of how buildings should be designed, including typological ideals and new aesthetics (Bandini 1992). Perret producing a theoretical approach to his ideal museum can be seen as a direct response to this. His first major project of this type was the temporary Palais de Bois museum in Paris in 1924. He later went on to produce significant built museum designs in the city such as the Mobilier National and the Musée des Travaux Publics. In between this period Perret conceived projects that were intentionally unbuilt. One of these was described in an article he wrote about his ideal design for a museum; the Musée Moderne (Perret 1929a). In this, Perret proposed that the ideal museum should be planned on a single floor to allow natural lighting from above. In the narrative given by Perret, he states the museum has a central courtyard with access to galleries through a 'junction room' showing the main themes and exhibits of the gallery in question. Perret's article sets out specific requirements for the design and is accompanied by primary information in the form of a sketch plan and two perspective images (see Figure 6.22, Appendix B - 11 and Appendix B - 12). His narrative is sufficiently rich to produce a unique model of a design primarily based on text, enabling a visualisation of a scheme that has not been seen before.

In 1931 Perret designed a museum to house the works of his one time collaborator, the sculptor Bourdelle, who died in 1929. They worked together on the design of the Théâtre des Champs-Élysées in Paris; with Bourdelle contributing the friezes that are displayed on the front façade of the building as well as work on the interior (see Figure 6.2). The Musée Bourdelle was not built; however, we can identify in it elements of Perret's Musée Moderne such as being planned over one floor as far as possible. Quatremère de Quincy states in Dictionaire d'architecture Volume III that the use of typological ideals has to be amended when designing buildings to suit the requirements of the brief as well as the architect's imagination (Bandini 1992). This is evident in Perret's design for the Musée Bourdelle, with the site being far too small to facilitate all elements described in his ideal museum essay. This is not surprising considering Perret only wrote the essay two years previously and the Musée Bourdelle was his first chance to put his ideas into practice.

Figure 6.2: The Théâtre des Champs-Élysées in Paris was one of Perret's most significant designs in earning him recognition. The friezes on the external façade were designed by Bourdelle.

Britton (2001, p.7), who wrote a biography of Perret, describes her book as a historical account of the architect's career, rather than offering 'fresh scholarly discoveries'. By creating digital representations of the two unbuilt museums it is hoped that analysis will go beyond straight forward historical comment and enable a more rigorous and systematic review of the designs (El-Khoury et al. 2006).

6.2 Sourcing information on Perret

To assess the viability of the museum projects as a case study, the quantity and quality of primary archive material available had to be established. This was a relatively simple process as institutions holding archives are increasingly making their collections available online. It soon became apparent that the archives holding documentation on Perret were accessible on the Cité de l'architecture et du patrimoine website (Archiwebture 2010). The physical versions of these were located in Paris. The online catalogue indicated there was sufficient material relating to the two projects for a comprehensive analysis to be viable. The project required a visit to these archives in order to study the documentation in detail as the quality of the drawings published online was not satisfactory. Additionally, the archives held a wealth of paper records covering the majority of Perret's other designs, which could potentially be used for inference purposes.

Secondary information available for the study included biographies of Perret's work in English as well as further sources in French. These could be used to gain an understanding of the context that Perret's Musée Moderne and the Musée Bourdelle were set in. Again, this is crucial if inferences and analogies are required when constructing the digital representations. This meant researching his career, significant buildings and design principles. As well as reviewing the literature written about Perret, his built designs in Paris, Le Havre and Amiens were also visited to gain a clearer understanding of his work.

6.2.1 Career and significant buildings

Perret (1874-1954) is well known for his rationalist structures and pioneering use of reinforced concrete (Watkin 2000). He gained international recognition for buildings such as the apartment block at 25 Rue Benjamin Franklin, the Théâtre des Champs-Élysées, the Church of Notre Dame du Raincy as well as his urban planning for post-war Le Havre which was designated a UNESCO World Heritage site in 2005. In recognition of his work, he was awarded the Royal Gold Medal in 1948 (RIBA 2010).

Auguste Perret was born in Belgium in 1874, where his father was living in exile as a result of his involvement in the French uprising of 1871, closely followed by the birth of his two younger brothers, of which Gustave would later become his business partner (Collins 2004). Perret's father was a mason and on his return to Paris, after the government declared an amnesty for political offenders, he set up a construction company. Auguste and Gustave were sent to the Ecole des Beaux-Arts to study architecture whilst at the same time working for their father as draftsmen (Collins 2004). The Perret brothers did not complete their training as architects, a fact which Collins argues may have been because it would have legally prevented them from working as part of their father's company. The two sons were given an education into French Classical architecture by their father; who owned a copy of Viollet-le-Duc's 'Dictionnaire Raisonné de l'Architecture Française du XI au XVI'. The French academic discussed how historically, craftsmen in France would build using contemporary techniques of the period in which they were designed; which he believed was an appropriate method of construction;

> *"Viollet-le-Duc's influence on Auguste Perret was thus not to be traced to any specific guidance in the use of new materials, but rather to those ideas of structural integrity which his historical writings so passionately proclaimed."* (Collins 2004, p.158)

Perret's architectural influence from French Classicism was purely in terms of aesthetics; he was forward thinking in terms of structure (Britton 2001). He saw reinforced concrete as the perfect material for his classical forms. The Ancient Greeks used petrification of stone to imitate wood; therefore the wooden formwork used to cast concrete, and the texture it leaves behind, takes this analogy further. The combined use of classical forms and innovative structure led to Perret being labelled a Classical Rationalist (Frampton 1992). Although Auguste and Gustave Perret worked together, it was Auguste who took the lead as a designer at Perret frères; the company they ran together succeeding their father in the family business. Perret's education and working life as part of his father's construction company helps to explain why he was so particular with structure and how it hold such significance in his designs.

The building that brought Perret worldwide attention was the rue Franklin apartments in Paris, initiated in 1903. This was the first scheme in which he expressed the reinforced concrete frame; before this his father was against its use. This may have been because at the time the scheme required subcontractors to carry out the work in concrete, which would have resulted in work being taken away from the family business (Collins 2004). It took the death of Perret's father in 1905 before he could really begin experimenting with the material fully. The impact of the apartment scheme cannot be overestimated;

> *"The rue Franklin building is considered by virtually every historical account of modern architecture to be the first building constructed of reinforced concrete to expose its frame deliberately, thereby conferring on it a canonical status in the development of the Modern Movement."* (Britton 2001, p.142)

The design clearly expresses the concrete frame in contrast to the infill panels (see Figure 6.3). The structural elements were clad in plain ceramic tiles as it was thought at the time that moisture could penetrate into the concrete and cause the reinforcement to rust. The infill panels feature a leaf pattern by Alexandre Bigot which distinguishes them from the plain ceramic structure (Britton 2001). Internally, slender columns replace load bearing walls meaning partitions could be placed more freely, rather than having to be placed in order to support a load. This had a knock on effect to Modernist architecture of which the free plan became a defining element.

Figure 6.3: Ceramic tiles designed by Alexandre Bigot on Perret's rue Franklin apartment scheme. The leaf pattern is used to show non structural elements whereas the plain tiles indicate the concrete frame.

Located close to the rue Franklin apartments are the rue Raynourd apartments which were built around 25 years later in 1929. This building demonstrates how Perret's use of the structural concrete frame developed over this time period of his career; the use of ceramic tiles to protect the concrete is long gone.

After the rue Franklin apartments and another important commission, the rue de Ponthieu garage, the Perret brothers received few commissions as architects; although they were not officially recognised as architects for several years to come. Instead they worked as building contractors and became renowned for their use of reinforced concrete as a skeletal system (Collins 2004). Part way through this period, the Perret brothers were asked by the Art Nouveau architect Henri van de

Velde to work on his scheme for the Théâtre des Champs-Élysées in Paris in 1913. This was because van de Velde realised that reinforced concrete was the most appropriate material for the site and design (Frampton 1992). Unfortunately for van de Velde, Perret said that his design was structurally unfeasible, leading to arguments that would prove to be fundamentally divisive. Six months later van de Velde resigned leaving the Perret brothers in charge. In Perret's version of the theatre design little concrete was expressed externally; the majority of it being faced with stone. However, the structure comprised of a monolithic concrete frame rising from a raft foundation which took exceptional technical ability to achieve on such a confined site (Frampton 1992). The low reliefs and friezes were designed by Bourdelle (see Figure 6.4).

Figure 6.4: The Théâtre des Champs-Élysées showing Bourdelle's friezes.

The interior expressed the reinforced concrete structure, and was criticised by many at the time as being stark and brutal (Britton, 2001). There is a story which states that Bourdelle's panels did not fit properly, and rather than having the spaces amended, Perret had them stored in the cellar and replaced with canvas screens (Collins 2004). This gives an indication of how particular Perret was with architectural proportions and classical forms. The friezes are especially important to the digital representations as two of them are replicated on the perspective drawings of Perret's design for the Bourdelle museum (see Figure 6.1 and Figure 6.4).

Another significant scheme by Perret is the Church of Notre Dame du Raincy designed in 1922 on the outskirts of Paris. The design for the church was commissioned immediately following the First World War and consequently had a tight budget. Perret was seen to be the ideal person for the job due to his knowledge of the economy of concrete construction (Kostof 1995). The design exposed the reinforced concrete frame both externally and internally. It featured round columns for the first time in Perret's career and utilised visual illusions such as entasis as prescribed in Classical architecture (Frampton 1992). The structure comprises of columns supporting a barrel vaulted ceiling with a tower at one end. The design gives an insight of how Perret dealt with non structural elements such as the spaces between columns and beams; these infill panels form the façade. At the church Perret designed the infill panels using a series of concrete blocks with geometric shaped openings filled with stained glass (see Figure 6.5). This technique of making concrete blocks unique to each scheme was something that Perret developed in later designs. The church highlights the competing elements of innovation and tradition that has regularly been spoken of regarding his career; Perret translated traditional classical forms using innovative reinforced concrete techniques (Britton 2001).

Figure 6.5: Interior of the Church of Notre Dame du Raincy. The stained glass windows are all based on standard dimensions designed by Perret.

Perret went on to design several significant schemes such as the temporary Palais de Bois in 1924, the Ecole Normale de Musique in 1928, the Mobilier National in 1935, the Musée des Travaux Publics in 1938 and finally major elements in the rebuilding of the city of Le Havre from 1945 onwards. These schemes will be discussed in relation to his detailed design principles to assist in producing the digital reconstructions.

6.2.2 Perret's design principles for inferences purposes

Once Perret's significant buildings had been researched, his detailed design principles were investigated in order to further understand his design philosophy. This would become especially important when examining the Musée Moderne, as the process of creating a digital simulation relied heavily on inferences. The architect's detailed design principles were researched firstly by reviewing 'Concrete' by Collins first published in 1959, which gives a detailed history of concrete architecture, primarily relating to Perret. His buildings, mainly located in Paris, were then visited.

The first aspect of design in which Perret attached major importance to was columns. Through their use, he strived to create rhythm and unity in the overall design (Collins 2004). Innovative development of the use of reinforced concrete in France also came from Hennebique. Interesting comparisons can be made between Perret and Hennebique, as Perret effectively turned Hennebique's pioneering structural system on its side. Whereas Hennebique cast reinforced columns to the whole height of the building and then cast floor beams in between; Perret cast the columns up to the underside of the floor beams, which then had the whole floor, comprising of beam and slab, cast over them (see Figure 6.6).

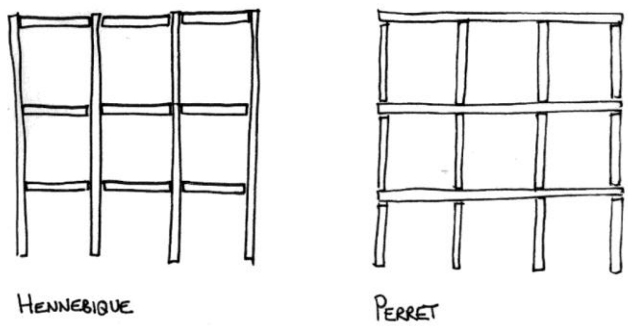


Figure 6.6: In the Hennebique system, columns are cast the height of the building whereas Perret turned this on its side casting the beams across the width of the building.

Perret's earlier column designs mimicked entasis principles of Classical stone columns; being narrower at the top than the bottom, with a slight outward bulge towards the centre. This can be seen in his earlier designs such as the Church of Notre Dame du Raincy (see Figure 6.5). However, he reversed this principle by making the columns thicker at the top than the bottom, beginning with a design for the 1933 Paris exposition (see Figure 6.7). Perret's analogy of this was a timber table or chair leg which is always thicker at the joint with the seat of the chair as it is the part which requires most strength. Therefore he saw this as also being true with a reinforced concrete frame; by thickening the top of the column it improves the structural rigidity and its ability to resist moments. Perret believed, righty, the base of the column could therefore be much thinner, especially if it was a single storey building (Collins 2004).

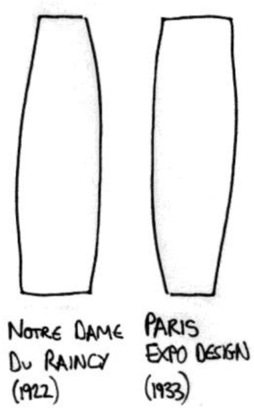


Figure 6.7: Perret reversed the direction of the entasis around 1933.

The columns were polygonal as a result of the way they were cast; wooden plank formwork was used which resulted in each plank having a straight surface. To create entasis, the formwork was constructed in the same way as a wooden barrel; stiffening rings with various circumferences gave the desired thicknesses as the column changed shape. Finally, Perret created fluting on the columns by removing elements of the cement film from the surface. Although this reversal of the column design occurred after the two museum projects were conceived, it indicates how Perret was constantly redesigning his principles striving towards more efficient designs and structures.

Perret also placed great emphasis on the design of beams. Many of his contemporaries wanted to prevent them from being on show, however, Perret believed that building elements should not be used solely for ornament; rather the structure of the building should provide the ornamentation. This is especially important as the column and beam, or structural frame, formed the basis of Perret's significant works of architecture (see Figure 6.8). Instead of casting beams truly horizontally, he used a slight arch on the beams to correct the illusion of sagging. In Perret's method of structural frame, the beams were cast directly into reinforcement bars left protruding from the columns, which then created a rigid system.

Figure 6.8: Detail of the column and beam structural system at Amiens train station, France. The beam system is made up of two smaller beams running parallel to each other.

One of the major factors that defined Perret apart from architects and designers of the Modern Movement was window design. He believed that non load bearing walls should not be entirely glazed, if the design permitted it. Instead he used traditional methods of creating a rhythm of solid and void to punctuate a façade (Collins 2004). On a trip to America, Britton (2001) discusses how Philip Johnson gave Perret a tour of his glass house. Perret summed up the experience in three words; 'too much glass.' The window openings he used generally spanned from floor to ceiling with proportions of a 'human' scale; or rather they were tall and thin (see Figure 6.9).

As Perret was insistent on showing the structure of his buildings and generally used tall and thin windows, this left areas blank which needed to be filled somehow. Perret designed a system of precast blocks which were unique to each scheme he worked on; seemingly fitting perfectly into the areas required. In this sense he was working in the opposite way to masonry construction today, where it is seen as good practice to design using standard brick dimensions. Instead Perret worked out the appropriate size of the structural frame regardless of standard block dimensions and then made his own custom blocks to fit the frame utilising classical proportions. Another technique Perret used was infill posts; adding these between long beam spans to create reinforcement. This can be seen in his design for the Mobilier National in Paris in 1935 (see Figure 6.9).

Figure 6.9: The Mobilier National demonstrates the tall and thin windows spanning floor to floor that Perret regularly used. It also shows the secondary columns punctuating the blank façades.

6.3 Musée Bourdelle

As already discussed, the digital representations were constructed in reverse chronological order. It was logical to work backwards in time and begin with the Musée Bourdelle from 1931, and then return to the Musée Moderne from 1929, as there was a large amount of original drawings available for the Musée Bourdelle making the process of creating the digital representation a lot simpler in terms of access to reference material. After this, the Musée Moderne digital representation could be constructed utilising the research carried out for the Musée Bourdelle as a starting point. The following text records the process of constructing the Musée Bourdelle model, focusing on problems that arose and inconsistencies in the evidence that the analysis revealed.

6.3.1 Sorting the archive material in terms of relevancy

As an initial task, the original Musée Bourdelle drawings from the Paris archives had to be arranged in chronological order. They are likely to have been at a planning stage but are still formal drawings rather than sketch designs. A particular problem here was that there were several variations of similar designs, for instance, five different plans and four different sections were available (see Appendix B). Many of the drawings were stamped with a ‘Perret Frères’ logo including the date they were completed, which simplified the process. If undated, the latest versions were found by comparing features in plan, elevation and section to check whether they correlated. The following text records the process of digital construction, focusing on problems that arose and inconsistencies in the evidence that the initial study of Perret's work revealed.

6.3.2 Tracing over the original drawings digitally

The archive material indicated a metric scale of 1/50, which made tracing the drawings digitally a simple task. There was also a survey drawing of the site which included dimensions; this acted as a method for checking the measurements were correct in the digital model. The first step when tracing the drawings was to establish the location and spacing of the structural grid as this forms the basis of the majority of Perret's schemes; 'the composition of the framework is very important because it is to the building what the skeleton is to the animal' (Perret 1929b, p.230). This was measured from the archive plan as 5720mm square and enabled the rest of the design to be built with this structural grid as the framework. Other standard dimensions then had to be found, such as external and internal wall thicknesses, depths of floors and column and beam sizes. Digital drafting allows us to design at a 1/1 scale, whereas the Musée Bourdelle drawings were hand drawn at a scale of 1/50. This led to inaccuracies regarding the standard dimensions, as measurements taken at 1/50 could not give definitive results. For example, the thickness of pen lines drawn to represent thinner columns in plan measured between 300mm and 400mm. Therefore, detailed drawings in the archives of two of Perret's built museums; the Musée des Travaux Publics and Mobilier National, were used to accurately check the dimensions. This was because they provided construction drawings at a larger scale with annotation of dimensions and materials. These ensured analogies could be made giving a process of informed extrapolation, of which these dimensions were rechecked against the original 1/50 drawings for clarity.

Once these basic dimensions were established, the lower ground floor plan was traced followed by the upper ground floor plan. This process revealed a discrepancy in the vestibule area of the design; on the lower ground plan the columns sit in front of the wall but on the upper ground plan they sit within the wall (see Figure 6.10). For this initial stage of analysis it was decided to place the columns in front of the wall, as this is how they appear on the only interior perspective of the space (see Appendix B - 9). This discrepancy offers an opportunity to present alternative scenarios in the model for different interpretations of the design; the first scenario presumes the interior perspective is correct whereas the second scenario adheres to the plans. This issue could have arisen as a result of the nature of the drawings, which suggest an unfinished development of the design (Novitski 1998).

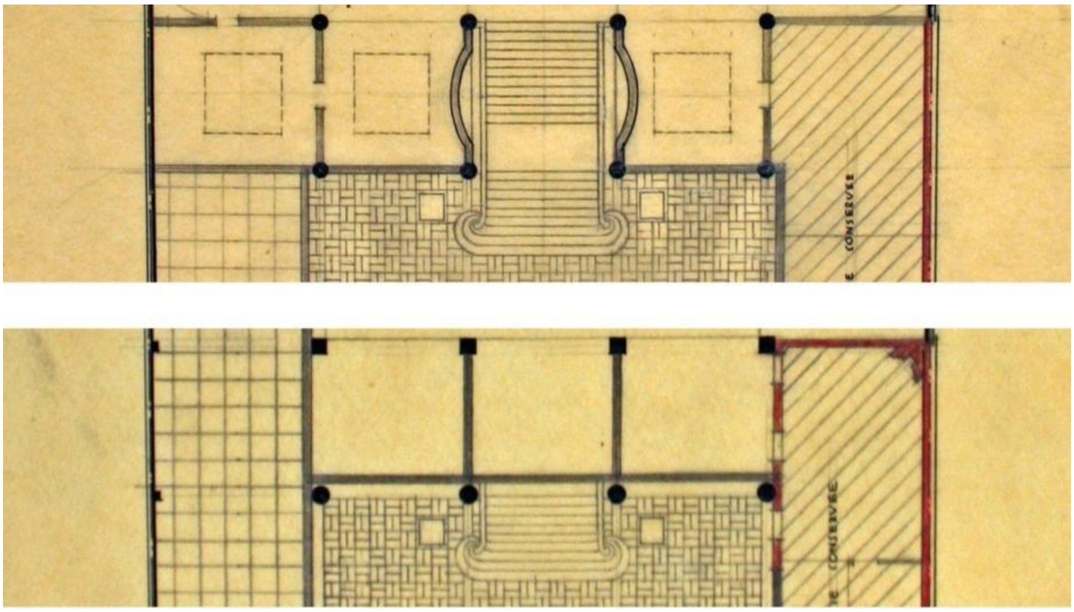


Figure 6.10: On the lower ground plan the columns sit in front of the wall (bottom image). On the upper ground plan they sit within the wall (top image). On the original internal perspective the columns sit in front of the wall. Image credit: Perret (1931)

Tracing the drawings also revealed useful information confirming Perret’s employment of the classical orders. When constructing the curvature of the main staircase in the vestibule it became apparent that they were designed using the Fibonacci spiral. The curvature was made of a series of quarter-circles which become smaller with every segment suggesting the use of the Fibbonaci spiral; this was then laid over the top of the original drawings for confirmation.

Tracing the front elevation proved a challenge, as a perspective image of the façade prepared after the elevation drawing was available (see Figure 6.1). Therefore the elevation drawing was used as a guide for basic dimensions, as it matched those of the available section and plans, and detail was deduced from the later perspective image such as lettering on the main entrance door, and the friezes designed by Bourdelle. This revealed inconsistencies with the drawings; the perspective image shows the lower section constructed of seven square infill panels vertically. In reality, only five square panels could fit into the space when drawing the area digitally (see Figure 6.11). This raises the question of whether the later design was raised in height, or whether the perspective was exaggerated, possibly to suggest the design was taller. It was presumed that exaggerated perspective was the cause, as the height between Bourdelle's original house and the cornice of the front elevation were compared in elevation and perspective and appeared to be the same. Once complete, the two-dimensional digital drawings were exported to a three-dimensional modelling program to begin creating the digital simulation.

Figure 6.11: Digitally traced drawing of the front elevation. Only five square infill panels fit height wise on the drawing whereas seven are indicated on the archive perspective.

6.3.3 Constructing the digital representation

The process of constructing the three-dimensional digital model occurred in a similar fashion to that of the two-dimensional drafting; first the structural frame was modelled then detail was added. Constructing the digital model requires one to acknowledge elements which may not be apparent from studying the archive drawings alone. For instance, when the beams were modelled the dimensions of 650mm x 650mm made them look oversized. By studying other buildings such as Perret's train station at Amiens, it revealed that these large beams were in fact split down the centre to give the appearance of two smaller beams (see Figure 6.8). This detail was also apparent on a surviving interior perspective drawing of the Musée Bourdelle, which provided sufficient evidence to make deductions and reproduce the detail for the digital model (see Appendix B - 9). This demonstrates how creating a digital representation leads to enhanced understanding of an architect's work.

The three-dimensional model is explicit in demonstrating the structure of the building. For example, it clearly shows how the beams and columns are thicker around the central area that supports an octagonal dome (see Figure 6.12). In contrast, the two-dimensional nature of the original drawings do not express this well; particularly the beams.

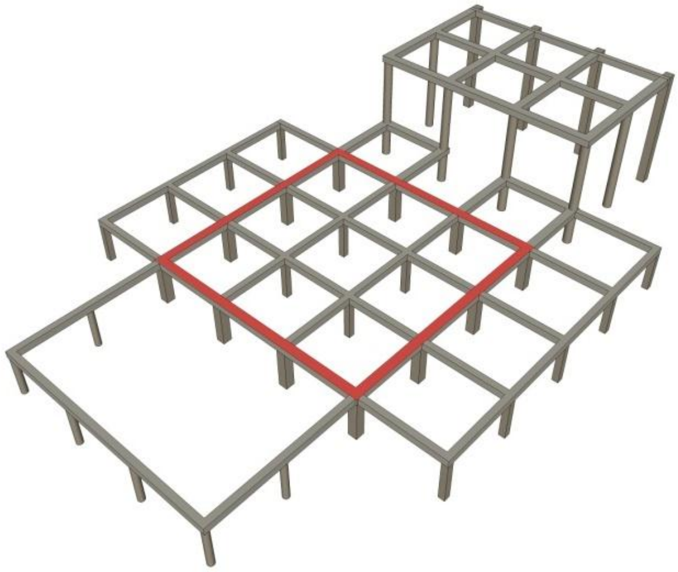


Figure 6.12: The digital model clearly expresses that the structure of the lower ground frame has thicker columns and beams in the area where it supports the dome (beams shown in red).

The layout of the columns in the garden area to the rear of the building proved a divisive issue to resolve. Bearing in mind Perret's doctrine on the structure of his buildings, it seemed unusual that the columns around the perimeter of the garden area disappear from the archive plans after the initial lower ground plan (see Appendix B - 7). The only explanation for this is that the perimeter wall becomes load bearing in the later designs rather than a series of columns with infill panels. Further study of the archive drawings confirmed this, as they all show that columns were used around the internal edge of the courtyard space and not on the perimeter wall. The absence of an initial upper ground plan may also suggest that Perret would have used this method if he had continued with the initial design.

In constructing the model and adding detail to the existing Bourdelle house that was retained as part of the design, it was noticed that the height of the lower ground floor plan was determined by the height of the existing building.

Once the basic model was built, openings were added such as the skylights indicated in plan by dotted squares (see Appendix B - 8). Windows were also added above the doors to the private areas above the garden courtyard. The archive drawings do not show any windows to these rooms, except to indicate what at first was simply thought to be door openings. It was decided these must have been windows at higher level due to the height of the openings and lack of indication of windows anywhere else on the drawings. However, evidence of this type of combined window and door design was not found in Perret's built works of architecture, therefore the inference must be treated as an assumption (Masuch et al. 1999).

The process of constructing the digital representation of the Musée Bourdelle has shown how questions have to be resolved by investigating the design in detail. The more significant of these, which required additional sources for inference purposes, will be reported in section 6.3.5 dealing with serendipitous results.

6.3.4 Applying materiality for visualisation purposes

Once the form of the model was complete, material could be added in order to generate a near photorealistic interpretation of the design. The issue of adding materiality to digital representations is open to debate; as it is important not to mislead the viewer into believing what they see is real as discussed in section 3.5. In other words, one has to acknowledge that a near photorealistic interpretation is based on inferences from other designs. However, it was felt this was an appropriate representation technique because of the overwhelming use of concrete in Perret's built schemes, as well as the indication of the material on the original drawings meaning deductions could be made with relative confidence. Perret's Musée des Travaux Publics in Paris was used as a material swatch. This was an appropriate source as it contains all of the elements that are apparent in the Musée Bourdelle design, such as square and round columns, infill panels and a high level of detail on finishes. Photographs were taken of the building then digitally ortho-rectified to form the correct sizes for the digital construction (see Figure 6.13). These were then used as analogies and applied to the digital model.

Figure 6.13: Ortho-rectified material swatches taken from the Musée des Travaux Publics ready to be applied to the digital model.

A key element of the Musée Bourdelle design is the inclusion of friezes designed by Bourdelle himself forming part of the front façade, which were originally designed for the Théâtre des Champs-Élysées (see Figure 6.2). Copies exist of the friezes in the current Bourdelle museum in Paris, which were photographed so they could be included in the digital model. Of the five original friezes, it is possible to determine from the archive perspective drawing exactly which two Perret decided to include on the front façade (see Figure 6.1).

6.3.5 Serendipitous results

The process of constructing the digital representation of Perret's Musée Bourdelle was particularly productive in generating results that occurred serendipitously. The first of these was found in relation to the beam and column design in the central area supporting the dome; the corner columns did not meet the beam they were intended to support above. This was because Perret offsets the beams inwards enabling the columns to be expressed internally, which can be seen in his original section drawing (see Appendix B-6). This arrangement is acceptable in most circumstances, as the columns simply shift inwards along the structural grid in a single direction. However, the corner columns need to shift along the structural grid in two directions, hence becoming unaligned (see Figure 6.14). Studying the archive drawings did not offer a resolution; therefore it was decided to look at Perret's built works. At the Church of St Joseph in Le Havre, the city Perret helped to rebuild after the Second World War, it was noticed that a similar offset arrangement of column and beam occurred. Perret resolved this by adding an extra section internally to the beam structure (see Figure 6.15). It is arguable that at Le Havre this was for aesthetic rather than structural qualities; however it gave enough justification to provide an analogy for inference purposes using the Church of St Joseph (see Figure 6.14).

Figure 6.14: Digital model based on the original drawings (left). An extra section was added to the beam taking inspiration from the Church of St Joseph at Le Havre (right).

Figure 6.15: Church of St Joseph at Le Havre. Perret adds structure at the corners of the beams as a method of ending the columns.

This raises an interesting question regarding Perret's work; the thicker column and beam design around the octagonal dome area emphasises stability in the scheme. However, similar to the Church of St Joseph, it was realised that the corner columns do not have to carry as much load as the rest as they do not directly support the dome. This suggests that in a minority of cases, Perret's strict structural grid is primarily used for aesthetic purposes with the structural qualities becoming secondary.

When adding the infill blocks based on Perret's standard dimensions to the digital model, it became clear that this method does not always create such a neat design as suggested by Collins (2004) and Britton (2001). For instance, the column widths are either 450mm or 650mm depending on the load they are supporting. Bearing in mind that the structural grid of the Musée Bourdelle is 5720mm square, this meant that the infill area was 5070mm between two 650mm columns, 5170mm between a 650mm and 450mm column and 5270mm between two 450mm columns (see Figure 6.16).

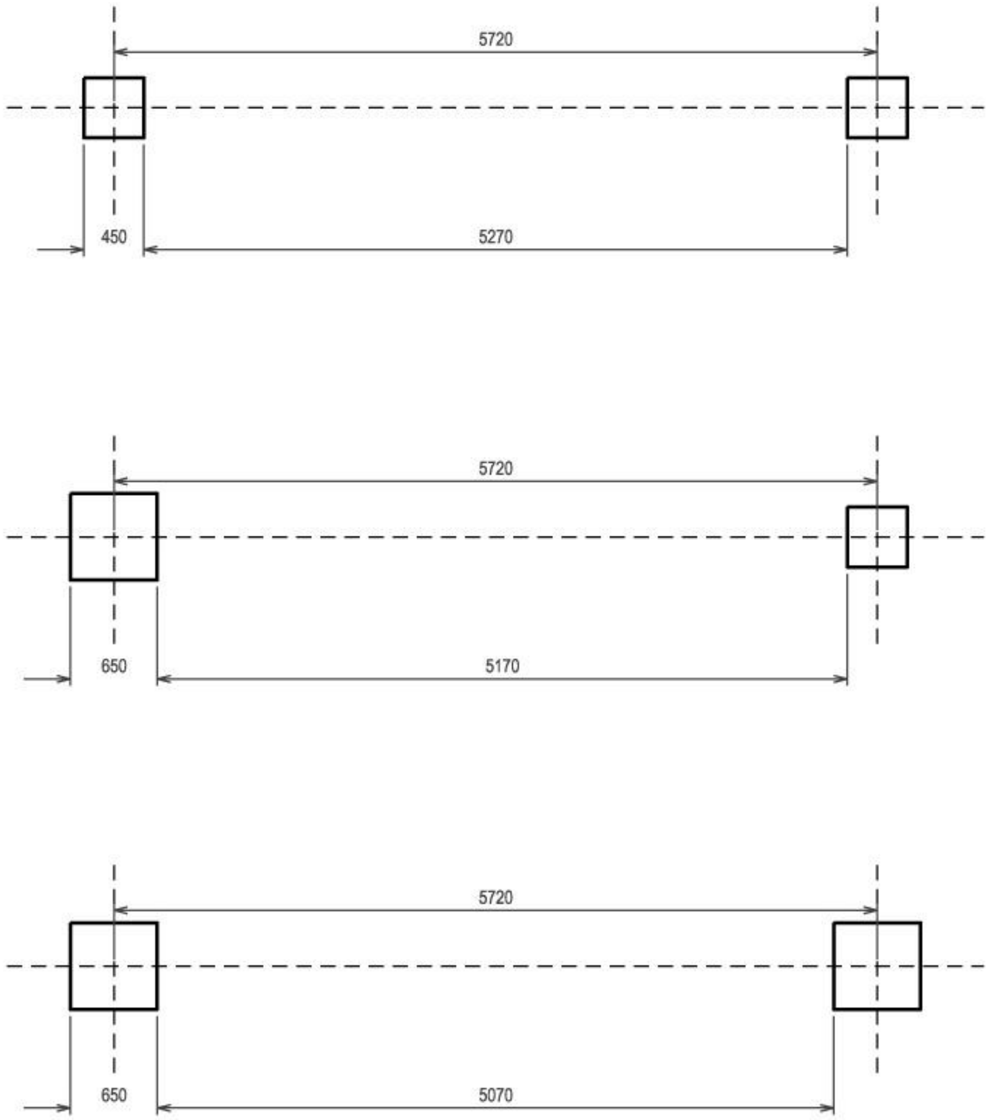


Figure 6.16: Three scenarios of different infill areas for the Musée Bourdelle design based on the structural grid of 5720mm square compared with different column widths.

As the infill blocks were based on the 5070mm width between two 650mm columns, this resulted in an extra gap of up to 200mm. This could have been resolved by making the corner columns wider to compensate for the gap where possible; however this would contradict Perret's drawings considering he places most importance on structure. Another solution would be to redesign the infill blocks, as Perret utilised a custom system anyway. However, this would mean amending dimensions that were crucial to his design philosophy, for example panels based on a perfect square or the golden section. Therefore, the issue was resolved by investigating whether this situation occurred in the design of Perret's other built work. Again, the Church of Saint Joseph at Le Havre provided an analogy. Here a similar relationship could be seen between differing column widths, and Perret resolved the matter by increasing the mortar joint between the infill blocks to compensate for the extra width (see Figure 6.17). Therefore this technique was replicated for the Musée Bourdelle digital representation (see Figure 6.18).

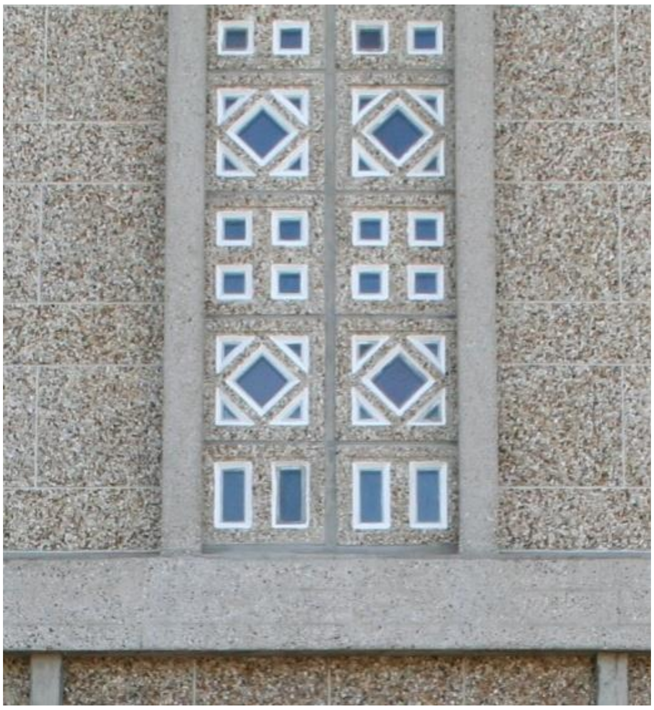


Figure 6.17: The mortar between the infill blocks at the Church of St Joseph has a greater vertical width than horizontal width. This retains the overall dimensions of the structural framework as well as the square design of the infill blocks.

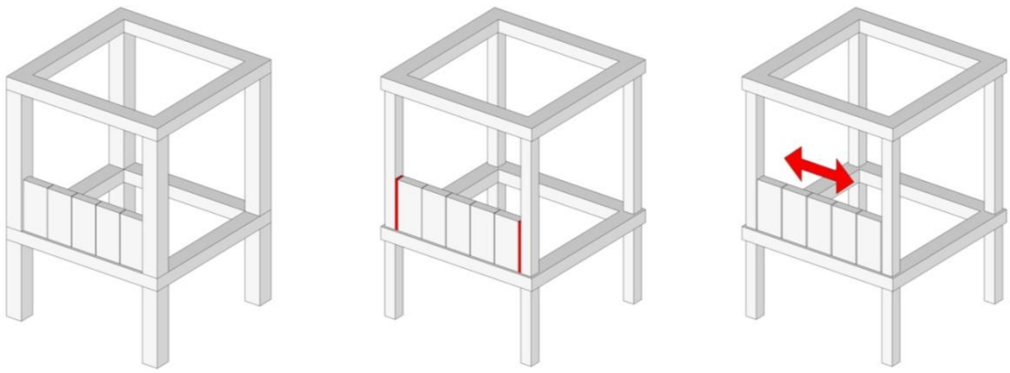


Figure 6.18: Diagrams demonstrating the construction of Perret's non-load bearing blocks. Their classical proportions fit within Perret's structural grid perfectly (left), however, once the column width changes shape (centre) a gap is left. Therefore the solution seen in Perret's other built works was to increase the mortar joint to compensate (right).

6.3.6 Additional observations made from the digital representation

The previous sections demonstrate how the use of digital techniques and consequent investigation required, creates a rigorous analysis of a design. The resulting digital representation enables a visualisation of an unbuilt scheme which can be used to further aid understanding and share the results with a wider audience. The ray traced images created of the digital model offer an opportunity of direct comparison to the original perspective images drawn. Figure 6.19 shows the front façade rendering is very similar to the original perspective except for the original seeming taller and thinner than the digital representation as discussed in section 6.3.2, which may have been due to exaggerated perspective.

Figure 6.19: Original perspective drawing (left) and a ray tracing of the digital equivalent (right). Left image credit: Perret (1931)

The interior perspective image (see Appendix B - 9) was difficult to reproduce because of whether or not it should be presented based on information from the original perspective or the original plans. Therefore, visualisations of both were ray traced in order to make clear there is more than one likely solution based on the entire information available (see Figure 6.20 and Figure 6.21). The digital images give a better spatial understanding of the design, for example the scale of the interior is a lot greater than first anticipated once a human figure is added next to Bourdelle’s sculptures.

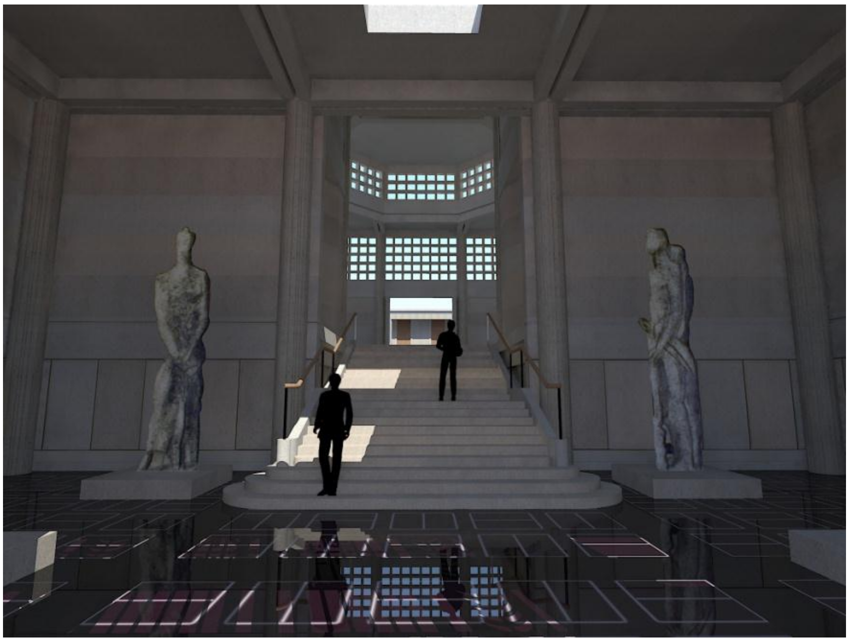


Figure 6.20: Interior perspective of the vestibule which aimed to match the original perspective.

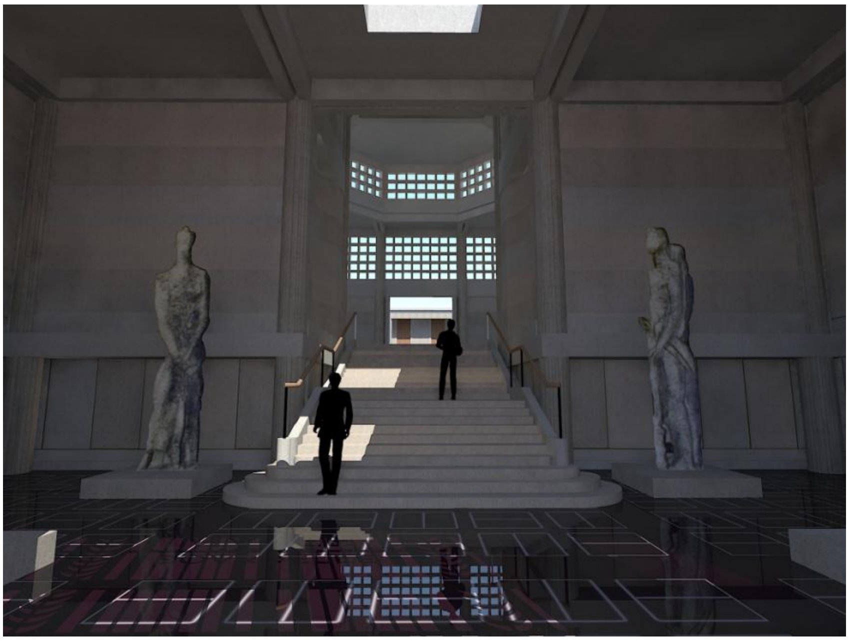


Figure 6.21: Interior perspective of the vestibule based on plan drawings. Notice the columns sitting on the beams between upper and lower ground floors.

6.4 Musée Moderne

Once the Musée Bourdelle had been researched, constructed digitally and analysed, this process could begin for Perret's theoretical ideal museum; the Musée Moderne (see Figure 6.22). This section of the case study is based on an article Perret wrote for Mouseion, which is a written piece with three accompanying sketches (Perret 1929b). Again, the investigation into the Musée Moderne occurred after that of the Musée Bourdelle as there was a larger amount of information for the latter, meaning it had the potential to be utilised to make inferences for unknown elements of the Musée Moderne narrative. This included information already gathered such as basic measurements, material swatches and patterns. The study of the Musée Moderne differed from the Musée Bourdelle as it provided more of an exercise into visualising an intentionally unbuilt design based on written sources. In this sense, the primary line of enquiry became the production of such images based on the text. Therefore, the main task was to analyse the original article and translate the written information into a three-dimensional digital model.

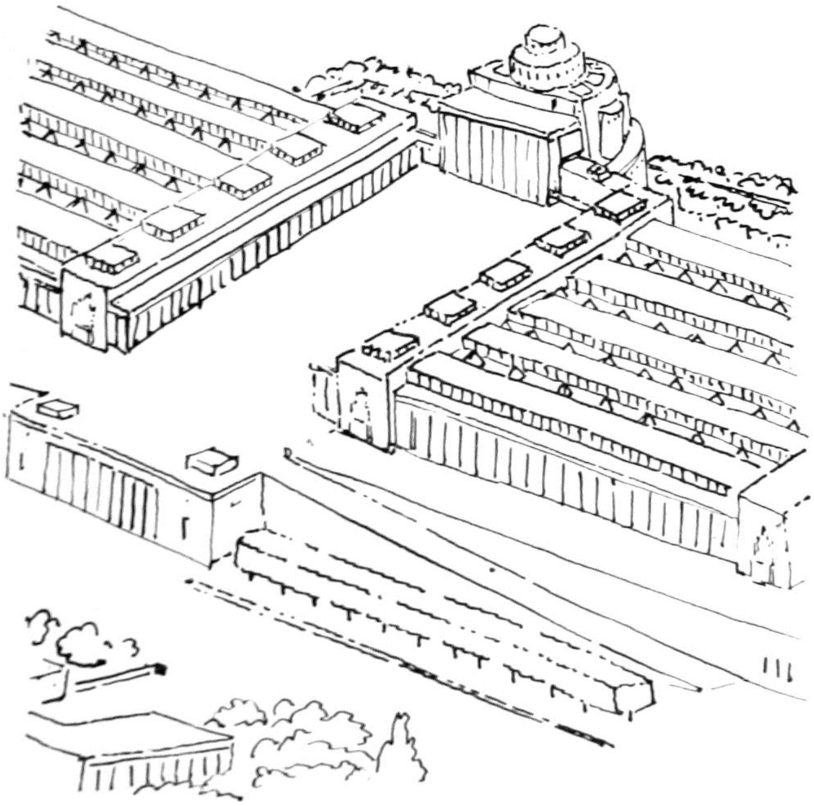


Figure 6.22: Perret's sketch of the Musée Moderne. Image credit: Perret (1929b, p.227).

6.4.1 Inferences required to construct the digital representation

The initial construction process was similar to that of the Musée Bourdelle, as Perret included a sketch plan as part of the Musée Moderne essay. However, this did not indicate dimensions or scale, therefore a series of inferences had to be made. On the other hand, Perret's article sets out strict requirements for the design which could be used to guide the process of constructing the digital representation;

> *"Our museum would be framed reinforced concrete; that is to say, it would be made of widely spaced columns that would support beams and slabs; it is this whole system we call the backbone."* (Perret 1929b, p.230)

Therefore, the first task was to make inferences to decide upon an appropriate set of dimensions forming the structural grid, or backbone of the whole design, as Perret does not give measurable values for this in the text. Using the Musée Bourdelle's structural grid of 5270mm square as an analogy, as well as one of his built museum designs, the Mobilier National with a grid of 5800mm square, an inferred average of 5500mm square was decided upon. This was because similar sized components such as columns and beams were also utilised, hence it makes certain that they could be structurally supporting as the grid is similar. Again, the Musée Bourdelle thicker column and beam dimensions of 650mm square were used as an analogy, as the Musée Moderne is on a larger scale with high ceilings and large loads.

Perret sets out very specific requirements for the external wall thicknesses to regulate heat. He states they 'will be made of five separate walls with four vacuums 4cm wide separating them' (Perret 1929b, p.234). The detailed drawings of the Mobilier National, used previously to confirm dimensions for the Musée Bourdelle model, were used as a guide to assist in constructing the external walls. These drawings showed that the facing concrete of the infill walls is 80mm wide with an inner leaf of 50mm wide. Based on Perret's instructions of three inner walls and two external ones, this resulted in a 470mm wide wall (80 + 40 + 50 + 40 + 50 + 40 + 50 + 40 + 80). Assumptions had to be made to determine the heights of the museum galleries; the golden section was used as classical orders and proportions influenced Perret. This was double-checked by looking at heights on his sketch which also suggests this ratio was more than likely used (see Figure 6.22).

In his article Perret states that the framework of the building should provide rhythm, balance and symmetry (Perret 1929b). The sketch plan he drew is symmetrical and the rhythm is defined by the layout of the columns and beams (see Appendix B - 12). This framework and symmetry meant that only half of the model had to be built, which was then mirrored to form the remaining half. It is likely that there would be differences in each side of the museum if it were a real project; however, as it is a theoretical scheme this seemed appropriate for the digital model.

In terms of materiality the design is perhaps unsurprisingly made of reinforced concrete. Perret believed that the building should not take attention away from the exhibits;

> *"...the floors will be painted in dark, neutral tones. Finally all polished surfaces are removed... should the museum be decorated? We think not. The appearance of the rooms should not fight with the art."* (Perret 1929b, p.235)

The patterns of the infill panels seen at the Musée des Travaux Publics and on the Musée Bourdelle drawings were again used as material swatches and applied in line with Perret's principles (see Figure 6.13).

6.4.2 Interpreting textual information as visual information

Perret provides a descriptive account of the various features of his ideal museum, and once the digital representation was complete, a walkthrough of the scheme was available giving a more thorough understanding of what the Musée Moderne would have looked like. The initial isometric is used to highlight areas of interest in relation to Perret's narrative (see Figure 6.23).

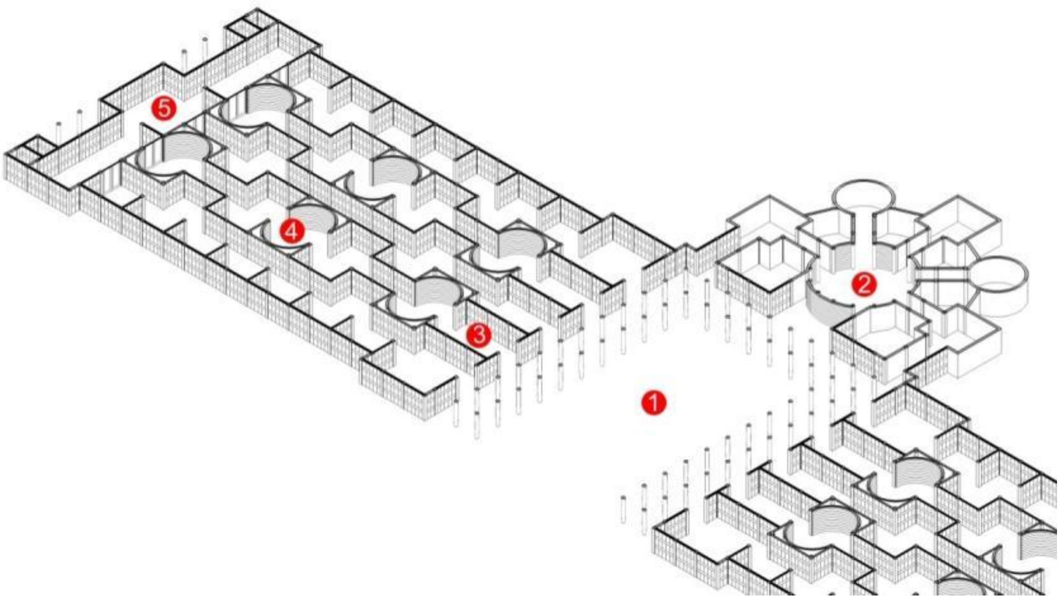


Figure 6.23: Isometric view of Perret's Museé Moderne taken from the digital representation showing the courtyard (1), dome area (2), junction room (3), main galleries (4) and workshops (5).

Perret describes the central courtyard area, junction rooms and galleries as follows;

> *"The central area is a large rectangular courtyard surrounded by a double portico–the first one open and the second one closed; it is through the second one that the junction rooms and galleries of study would be ...the galleries consist of two straight walls containing a range of different cells in their surface."* (Perret 1929b, p.226)

Perret also describes the main gallery spaces as having a junction room nearest the central courtyard in order to show the major works of the gallery's theme. He also states that the central dome '...would be the heart of the museum and contain the rarest and most unique items' (Perret 1929b, p.226). These descriptions offer an opportunity to create digital scenarios, for example Perret states that the courtyard area would be a place of enjoyment. Consequently the rendered image shown in Figure 6.24 indicates people occupying the space.

Figure 6.24: Representation of the occupied courtyard space in front of the Musée Moderne.

The junction rooms off the external courtyard have an important part to play in the design and are described by Perret as a place where the key items relating to the gallery can be seen. Consequently, the visual representation for this space has been created and is shown in Figure 6.25. The layout meant that a visitor could walk around the courtyard space and visit the junction rooms to decide whether they wanted to visit the whole gallery for a more comprehensive coverage of the artists work, or simply have an overview of the works. In the rendered image, Picasso's work is used as an example of art on display.

Figure 6.25: Visualisation of the junction room. For this image Picasso has been used as an example.

The representations have been deliberately rendered to be indicative rather than fully photorealistic. The representations are created to help better understand the proportions, nature and quality of the spaces represented. In the case of the Musée Moderne aspects such as proportion, element colour and texture, and lighting are most important.

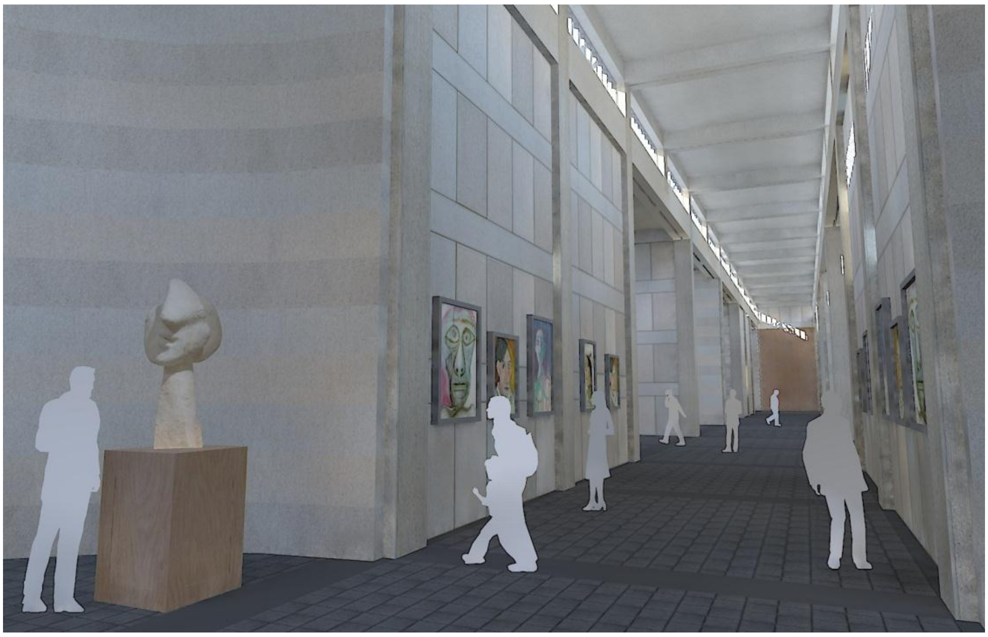


Figure 6.26: Visualisation of the linear galleries.

The final area of the Musée Moderne of importance is the galleries themselves (see Figure 6.26). These are long and thin with niches to hold further art work or sculptures. The rendered image demonstrates how this helps to break the linear nature of the galleries. Perret states that this would give the viewer unique reference points to navigate by in the gallery. Actually Figure 6.25 and Figure 6.26 demonstrate that the route is a simple journey along the left hand side to the far end then back down the right hand side to the central courtyard once again. The images lend support to Perret’s design intention, that the architecture should not ‘fight for attention’ with the art. The building is simple and rational placing the focus on the art.

6.4.3 Counterfactual scenario building

In terms of developing a counterfactual scenario, the digital simulation can be used to create a fake scene. Therefore, a ‘what-if?’ scenario enables the consequences of placing the digital simulation in a postulated context to be considered. In the context of this case study, the Musée Moderne is situated in the modern context of the Bois de Boulogne in Paris, as Perret states in his article that this would be an ideal site for his theoretical design (Perret 1929b). This is due to the vast scale of the building, which has an approximate length, back-calculated from the digital reconstruction, of 300 metres. Perret wanted it to rival the Louvre in this sense (Perret 1929b). The image in Figure 6.27 takes the digitally constructed design and places the building in the modern context of the Bois de Boulogne at the end of Avenue Henri Martin.

Figure 6.27: Counterfactual representation of the Musée Moderne in the Bois de Boulogne, Paris.

The location was decided upon due to its transport links with the centre of Paris. It is almost certain that the surrounding road layout would also have been different had the museum been built. Placing the building on this site begins to show the massive scale envisaged by Perret. If this theoretical scheme had been built, it is likely to have become one of the largest and most important museums in Europe.

6.5 Comparisons between the two museum projects

The digital representations of the two projects provide a new perspective when investigating the work of Perret. In the broadest sense, it allows his unbuilt designs to be visualised in three dimensions. This provides a far better spatial understanding of the two museums than simply reviewing the text and two-dimensional images.

Comparing the two projects, there are several similarities which suggest that the Musée Bourdelle was influenced by the Musée Moderne essay written two years previously. The first major comparative is that the ideal situation according to Perret is to have the museum all across one level. Although the Musée Bourdelle is designed over two levels, the lower floor is used for storage space. When investigating the digital representation produced, a clear distinction between public and private areas could be seen between these areas. Even though Perret does not have enough space on the site to include the various accommodations across one level, he ensures that the main gallery spaces are on the upper level so they have direct light via roof lights and windows, as proposed in his ideal museum. The pyramid shaped roof lights discussed in the Musée Moderne essay can also be seen in the earliest Musée Bourdelle section drawing (see Appendix B - 3), confirming that Perret must have been conscious of using the principles he theorised two years previously. These give an indication of how theorising typology in architecture has to be amended when dealing with real problems such as site, requirements of the brief and aesthetics (Bandini 1992). It must be pointed out that this information was confirmed using the digital representations, however, it may also have been discovered by studying the archive drawings. The point here is the rigorous process of investigation in order to produce the digital representations leads to the odds of the potential discovery of such observations becoming a lot greater.

What is apparent in both projects is the sense of scale that Perret strived for. The digital representations show what a vast building the Musée Moderne would have been. Rapid prototyping has been used to produce three-dimensional prints of both projects at the same scale to emphasise the vast scale of the Musée Moderne (see Figure 6.28). This is also made apparent using the counterfactual image placing the museum in the context of the Bois de Boulogne discussed in section 6.4.3. The use of rapid prototyping was particularly useful for the study, as the results were presented to the Franco British Union of Architects' reunion in Le Havre in which the physical models formed a key part of the presentation giving enhanced explanation of the research.

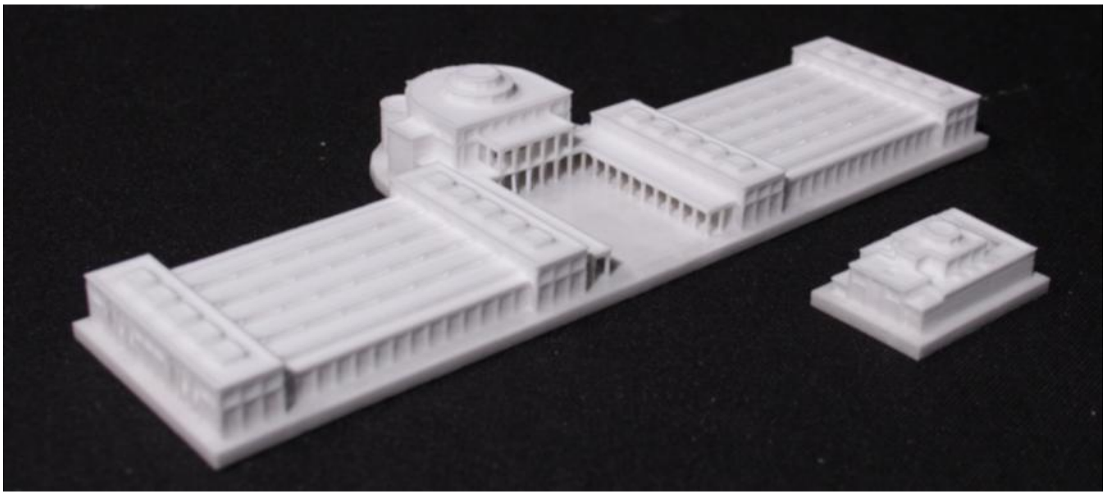


Figure 6.28: 3D print of Perret's Musée Moderne (left) and Musée Bourdelle (bottom right). The prints are both at a scale of 1:1250 and emphasise how large the Musée Moderne would have been.

As mentioned, the original interior perspective of the Musée Bourdelle is misleading as the sculptures in the drawings could be read as representing human scale; consequently they lead the viewer to underestimate considerably the size of the internal spaces. Adding a human figure to the digital representation gives a better impression of the true scale of the Musée Bourdelle (see Figure 6.20 and Figure 6.21). The simplicity of the design also reflects Perret's museum ideal of an uncomplicated journey; walking through the spaces is a straightforward route from the vestibule into the main gallery space, outside into the garden area then back again.

6.6 Lessons learned

Overall, the investigation of the Musée Bourdelle was much more fruitful in finding new information than that of the Musée Moderne. This was mainly due to the process of construction and digital forensic investigation, which required an understanding of Perret's design principles and both precedents and antecedents. The case study clearly shows how digital techniques can be used to enhance our understanding of a particular architect or building. Its use has enabled challenges to be made of previous studies of Perret's work; for example, to give a clearer understanding of his use of standard sized blocks. This would not be possible without the use of digital modelling techniques, in which the process of construction reveals inconsistencies and geometric relationships that can easily missed though inspection of the original drawings. The resulting digital representations are also particularly useful at enhancing spatial understanding of the two museum projects. This enables the viewer an insight into designs that have not been seen before in three dimensions, but, importantly, what we can also show are alternative possibilities where the evidence does not point to a single answer (see Figure 6.20 and Figure 6.21).

6.7 Chapter summary

The chapter begins by discussing the work of Perret, his architectural background, significant buildings as well as his design philosophy. This is covered in order to fully understand the architect for inference purposes when constructing the two digital representations of the unbuilt museum projects. The Musée Bourdelle is investigated first due to the large amount of source data available to construct the digital representation. The process of construction revealed several serendipitous results, which became the focus of the study rather than results found from generating specific lines of enquiry. The Musée Moderne was investigated next, which demonstrated the visual and spatial qualities of a scheme that had previously been primarily understood based on textual description.

The fact that the case study reveals that in some instances, more results can be found by chance as part of the process of constructing a digital model, rather than results from specific lines of enquiry, is important as it may affect the methodology proposed in Figure 1.1. However, the final case study will have to be undertaken before this is fully considered. The use of the methodological process in relation to the Perret case study is demonstrated in Figure 6.29.

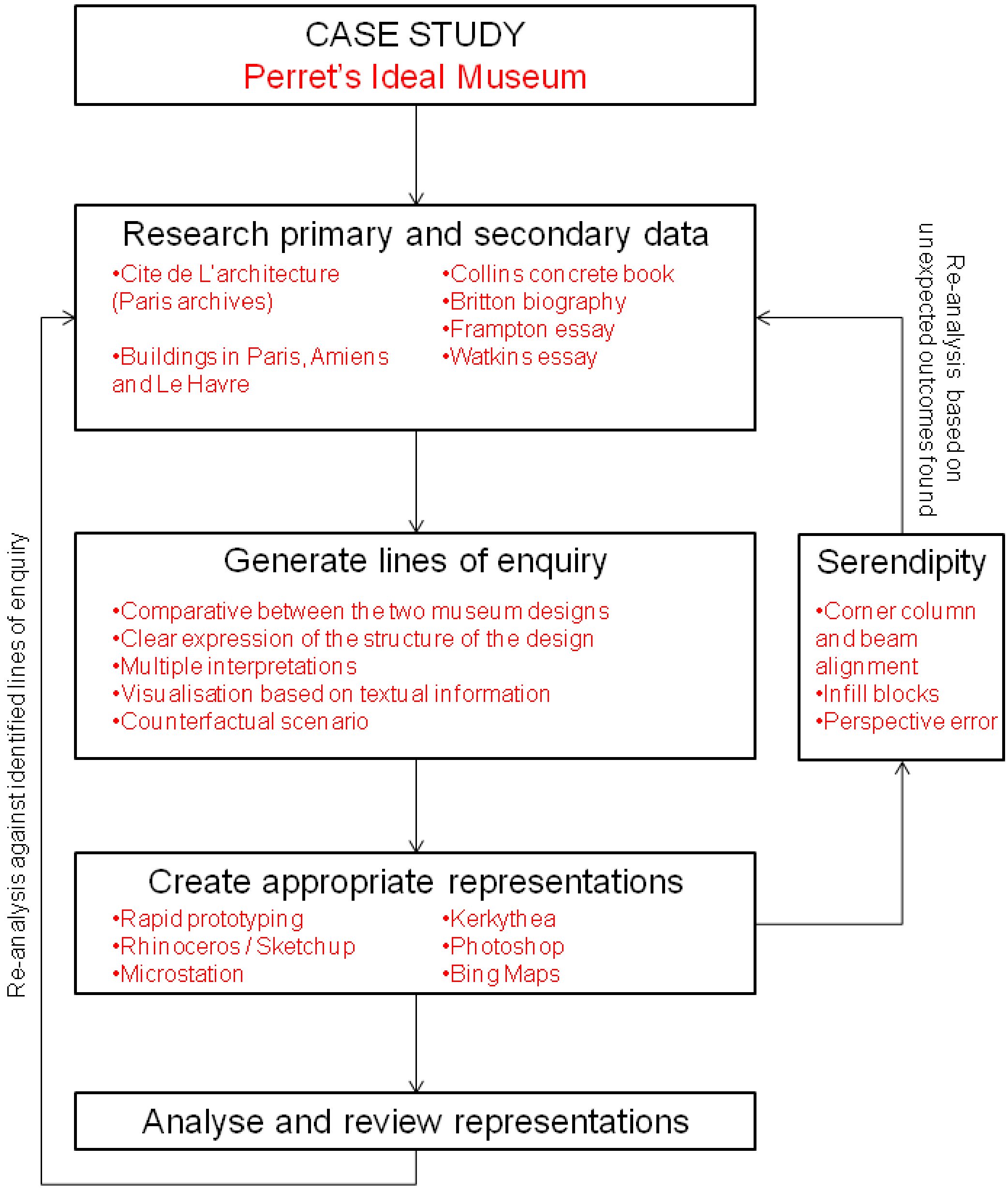


Figure 6.29: Sketch diagram demonstrating how the methodology was applied to the Perret case study.

7 Lutyens case study

> *"The question whether a building can assume a place of authority in the world of architecture without actually being built is a curious one; but the answer is not in doubt… It will survive as an architectural creation of the highest order."* (Summerson 1981, p.52)

The final, most comprehensive, case study is an investigation of the unintentionally left unbuilt design for Liverpool Metropolitan Cathedral (see Figure 7.1). The building on the site today was designed by Sir Frederick Gibberd, which sits beside and above the crypt of an earlier design by Sir Edwin Lutyens. Although Gibberd's design represents a significant achievement in modern architecture for the city of Liverpool, Lutyens' crypt offers a glimpse into the design of what would have been one of the largest cathedrals in the world if built beyond its base. This case study offers an opportunity to fully explore the methodology proposed in Figure 1.1. Consequently, considerably more focus is placed on the methodological process of generating specific lines of enquiry.

Figure 7.1: Cecil Farey perspective of Lutyens' early design for the Liverpool Metropolitan Cathedral in September 1930. The buttressing around the dome is a lot less substantial than the later scheme. Image credit: Farey (1930).

The case study initially discusses why the cathedral design was chosen, followed by an investigation of the source data available and the architecture of Lutyens. By looking at the entire source data available, opportunities were initiated to generate lines of enquiry. The process of constructing the digital representation, along with the techniques this involved, are then discussed. Lines of enquiry were then pursued, which revealed enhanced information about the design such as its geometric relationship to the Thiepval Memorial to the Missing of the Somme as well as conflicting scenarios of how the interior would have been lit. After the various lines of enquiry are investigated, a significant serendipitous result based on the model construction process is documented, which reveals that the design would have needed revising if it had been built.

7.1 Why Lutyens?

Lutyens' unbuilt design for Liverpool Metropolitan Cathedral was chosen as a case study for several reasons. Firstly, the design holds a significant place in the history of the city, which can be seen in its discussion as a work of architecture alongside that of the built (Sharples 2004, Hughes 1964). The logistics of the project also added to its viability as a large amount of source data is located in the city of Liverpool, meaning that it was easier to evaluate than other case studies located further away. In addition to the cathedral being included in several books on the city's architecture, it also forms a significant design in Lutyens' body of work. Therefore there are numerous discussions and accounts written on the design, giving strong potential in terms of generating lines of enquiry to investigate.

7.2 Sourcing information on Lutyens and the cathedral design

A wide range of historical sources were used to formulate the background investigation into the Liverpool Metropolitan Cathedral. Firstly, secondary sources were studied to look for initial lines of enquiry to form when augmenting knowledge of the design using digital techniques. This began by investigating various biographies of the architect such as those written by Hussey (1950), Amery et al. (1981) and Mary Lutyens (1980). This was followed by looking at more specific secondary sources such as Snead (1979) and Butler (1950) as well as documentation relating to Liverpool; notably Hughes (1964) and Sharples (2004).

Once this was completed, various primary sources of information were investigated. These included newspaper cuttings from the Liverpool Record Office and drawings by Lutyens in the RIBA Drawings Collection. However, the most substantial sources of primary information were from the Liverpool Metropolitan Cathedral Archives, which included detailed correspondence on the cathedral design as well as a variety of drawings. In addition to this an extensive set of the most resolved drawings were published as part of the Lutyens Memorial (Butler 1950). A key supplementary point of reference was the physical model of the design exhibited in the Museum of Liverpool. Studying all of the sources resulted in specific lines of enquiry emerging; of which a three-dimensional digital model of the design became the primary tool. Before a description of the detailed analytical process using digital techniques is given, it is salutatory to begin with a historical account of the Liverpool Metropolitan Cathedral and Lutyens' work as an architect.

7.2.1 Cathedral architect: Lutyens

Sir Edwin Lutyens was a leading English architect of the early twentieth century with architectural historians going so far as to say he was 'the greatest artist in building that this country has produced' (Hussey 1950, p.xviii). For his contribution to architecture he was knighted in 1918 and received the Royal Gold Medal in 1921 (RIBA 2010). Born in 1869, Lutyens began has architectural career working for Sir Ernest George, in the office of which he met Herbert Baker who later worked alongside Lutyens at New Delhi. Lutyens was described as a 'society' architect due to his connections with the upper classes; even so, this was seen as a stroke of luck as his architecture was highly regarded rather than him getting by on good connections alone (Amery et al. 1981). One of his connections was Gertrude Jekyll, a garden designer he met through a client. Lutyens and Jekyll worked together on many country houses in Surrey with Lutyens designing the buildings and Jekyll the gardens; if either received a commission they would recommend the other where possible. This was the formative period of his career where he became known for designing country houses in the 'Surrey Vernacular' style. This included Munstead Wood, a house designed for Jekyll between 1893-1897, which incorporates all of the ideas of the 'Surrey Vernacular,' particularly looking to the domestic architecture of the sixteenth to eighteenth centuries for precedent as well as using local materials (see Figure 7.2).

Figure 7.2: Lutyens' design for Jekyll's house at Munstead Wood. Image credit: Amery et al. (1981, p.87).

Lutyens' style evolved from the 'Surrey Vernacular' of the late nineteenth century towards Neo-Georgian designs in the first decades of the twentieth century. This can be seen in his houses such as Heathcoate in Ilkley (1905-1907), The Salutation in Kent (1911) and Ednaston Manor in Derbyshire (1911-1914). The evolution of his architecture continued beyond country houses following the First World War into more abstract forms such as war graves and monuments, the most well known being the Cenotaph in London (1919-1920); a design that was replicated all over the world. This was a development of the Neo-Georgian language into Neo-Classical designs, notably other war memorials such as those at Leicester (1923) and Thiepval (1927-1932) which took the form of triumphant arches. Another important aspect of Lutyens' career was his work in New Delhi, particularly the Viceroy's House (Rashtrapati Bhavan) between 1912 and 1931 (see Figure 7.3). His war memorial architecture can also be seen in New Delhi in the form of the All India Gate (1917 - 1931). His influence there was so great that the area is known to this day as Lutyens' Delhi.

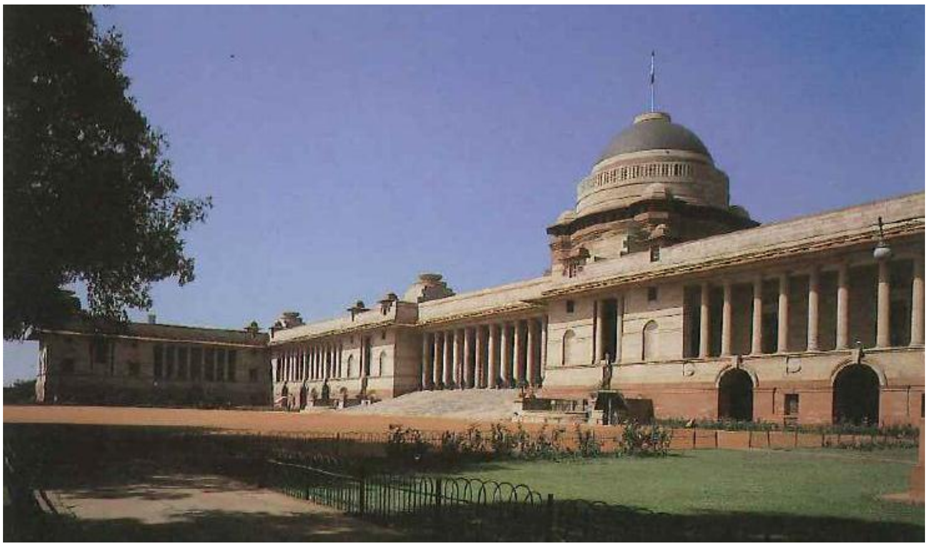


Figure 7.3: Rashtrapati Bhavan, formerly Viceroy's House, was designed by Lutyens in India (1912-1931). Image credit: Amery et al. (1981, p.167).

In 1929 Lutyens began his design for the Liverpool Metropolitan Cathedral which would arguably have been his most significant building had it been completed. It is of particular interest in his body of work as it overlaps the periods in which he was designing in New Delhi as well as his war memorials such as that at Thiepval; both of which can be seen in elements of the cathedral design (Butler 1950). Although Lutyens worked on other projects, the cathedral at Liverpool became his primary focus for the rest of his life.

7.2.2 Original Pugin cathedral design

A catholic cathedral was first proposed in Liverpool in the mid 19th century, with a design reportedly prepared by A. W. N. Pugin (Sharples 2004). However, it was not until 1856 that a design by his son, E. W. Pugin, was accepted and construction began on a site in St Domingo Road, Everton (see Figure 7.4). The gothic design featured a 300 feet (91 metre) high spire of which only the Lady Chapel was completed due to funding being reallocated to more pressing buildings such as schools, parish churches and orphanages (Liverpool Metropolitan Cathedral 2007).

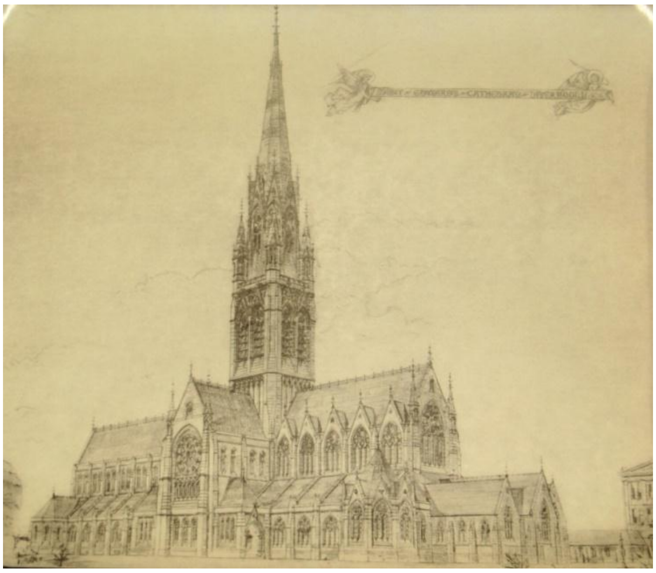


Figure 7.4: E. W. Pugin design. Image credit: (Pugin, n.d).

7.2.3 Lutyens' 1929 design

In 1911 Liverpool became an Archdiocese, and Bishop Whiteside was promoted to Archbishop. He died in 1921 and was succeeded by Archbishop Keating. A suitable memorial for Whiteside was discussed and the idea of a catholic cathedral in Liverpool was reborn for the first time since Pugin's abandoned design. Keating pursued the idea and set up a cathedral committee in 1922 which began to raise funds for its construction. However, he died in 1928 without securing a site or design for the scheme. His successor, Dr Richard Downey, became the key figure in progressing efforts to build a cathedral.

Downey and Lutyens first met in 1929 at the Garrick Club in London through a mutual friend, Alfred Sutro. Downey recalls the event in an article written for the laying of the foundation stone:

> *"We plunged into the subject (of the cathedral) immediately. I outlined my idea and tried to explain what we wanted. Sitting there at the table he drew a rough sketch. It was enough; he had seen our ideal. That rough sketch has been little altered."* (Swarbrick 1933, p.2)

Shortly afterwards, the pair met in Liverpool and Lutyens was confirmed as the architect for the cathedral, with him stating that '(Downey's) more than kind letter gave me the moment of my life' (Lutyens 1929b). The pair worked closely together and it would take the death of both men before the design was eventually abandoned (Snead 1979).

Lutyens unveiled his initial design, a Neo-Classical domed building formed of interlocking arches, to the cathedral committee in a visit to the proposed Brownlow Hill site in November 1929 (see Appendix C - 1). Drawings he unveiled included a plan, sections and elevations (Lutyens 1929a). Reilly, the Head of the Liverpool School of Architecture, was allowed to see the drawings in February 1930 and commented positively on them in local papers such as the Daily Post and Liverpool Echo (Reilly 1930).

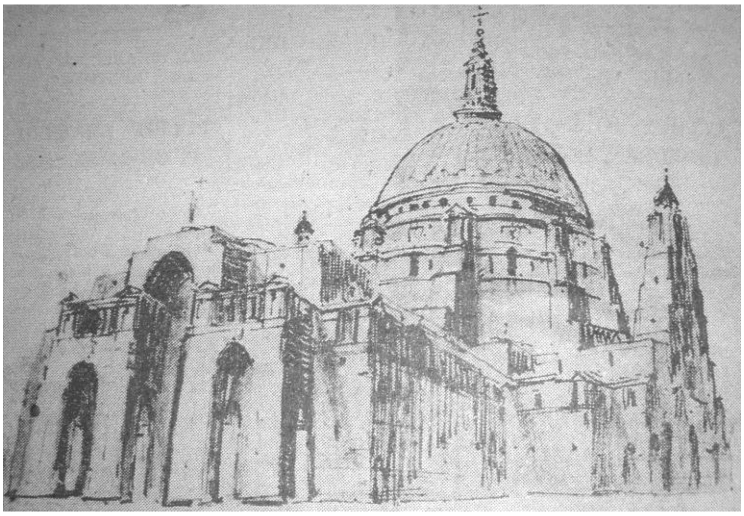


Figure 7.5: A sketch of the 1929 design by Lutyens published in the local newspaper the Liverpool Echo. Image credit: Liverpool Echo, (1930b, p.29)

In 1930 the cathedral authorities negotiated the terms and price of purchasing the Brownlow Hill site. Protestant leaders reacted strongly against the idea of a catholic cathedral in the city, with Reverend Longbottom being particularly outspoken stating that he ‘would sooner have a poison germ factory than a Roman Catholic Cathedral on that site’ (Longbottom 1930). After much correspondence and negotiation, the City Council agreed to sell the land to the Catholic Church on 5th June 1930 (Liverpool Echo 1930a). This was followed the next week by the release of the first images of the design to the press (see Figure 7.1 and Figure 7.5), notably including the perspectives by Farey. However, it was not until November of that year that all of the legalities of buying the site were confirmed (Yates 1930).

7.2.4 Description of the design

The design of the cathedral featured a series of interlocking arches at different sizes, all with a ratio of 1:3. The smallest 15 by 45 feet high arches (4.57 by 13.7 metres) intersect 22 by 66 feet high arches (6.71 by 20.12 metres), which in turn intersect 32 by 96 feet high arches (9.75 by 22.96 metres) and finally these intersect 46 by 138 feet high arches (14.02 by 42.06 metres). This is capped with a 300 feet (91.44 metres) high dome internally (Lutyens 1933). Comparisons have been made between Lutyens' design of the cathedral and his war memorial at Thiepval; featuring a similar arrangement of interlocking arches at a monumental scale. The materiality of the cathedral consists of pinky-brown coloured Roman bricks with contrasting granite detailing which is used in bands as the elevation rises as well as on the crypt. The main feature of the design is the dome that would have been one of the largest in the world; bigger than that of St Peter's Basilica in Rome and St Paul's Cathedral in London. Lutyens used comparative plans and sections to demonstrate the size of the cathedral (see Figure 7.6 and Figure 7.7).

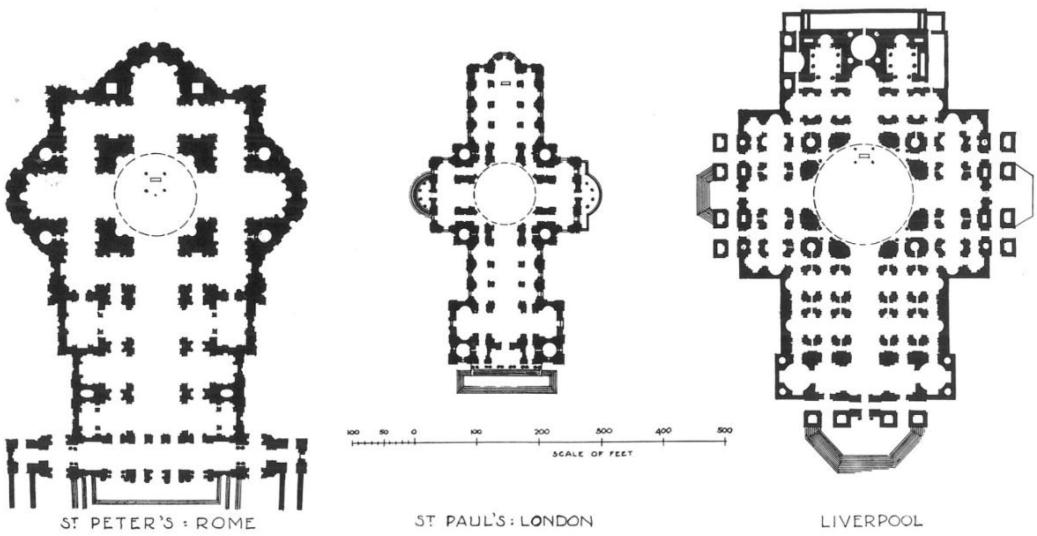


Figure 7.6: Comparative plans. Image credit: Butler (1950, plate XC).

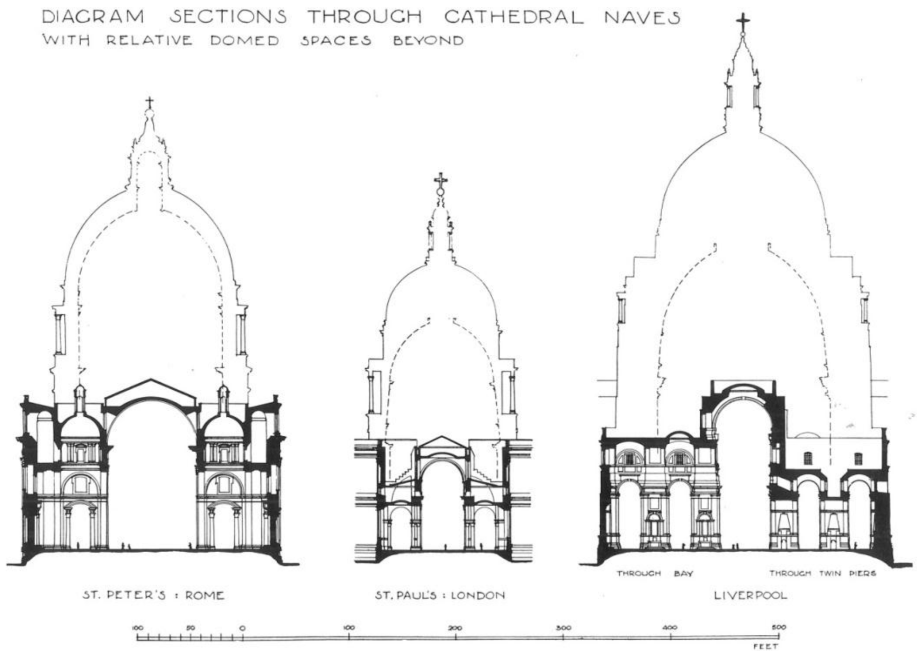


Figure 7.7: Comparative sections through the dome spaces. Image credit: Butler (1950, plate XCI).

7.2.5 Lutyens' 1932 design and 1934 model

Lutyens worked on developing the initial 1929 design and produced more detailed drawings over the next few years. These were exhibited at the Royal Academy in 1932. Hussey comments that;

> *"...although the plan has remained essentially unchanged, comparison of the sketch perspectives then published with the model exhibited at the Royal Academy in 1934 reveals that above all the main roof level in the 1930 design had been provisional – as Lutyens emphasised at the time was the case – and was fundamentally redesigned."* (Hussey 1950, p.529)

After 1934, the design was more or less complete. The most comprehensive set of drawings available are published in Butler's Lutyens Memorial (Butler 1950) which are post 1934. These were redrawn by Stewart, who worked for Lutyens, and based them on a complete set of ¼ inch scale drawings (i.e. 1/48) prepared by the architect before he died (Hussey 1950). The main change between the 1932 scheme and post 1934 scheme is the design of the altar below the dome. In the earlier scheme steps lead up to the altar whereas in the later scheme they disappear. Lutyens discusses the original altar in an article he wrote for the Liverpool Echo when the initial drawings were made public;

> *"(The high altar) is 12ft above the level of the floor of the nave and approached by a flight of steps. If you walk with me to the right or the left*

> *you can still see the high altar, as you can from any other part of the building."* (Liverpool Echo 1930b, p.29)

The change of design must have occurred between 1932 and 1934 as the interior of the 1/48 model shows that the altar is that of the later design compared to the earlier version shown in drawings exhibited at the Royal Academy in 1932 (Mezzo Films 2009).

Figure 7.8: Still from an endoscopic film of the restored 1934 model interior showing the later design of the altar. Image credit: Limehouse Heritage (2010).

In addition to the built crypt, the physical model forms the best surviving piece that describes the design. First shown at the Royal Academy in 1934, it is 11 by 17 feet (3.35 by 5.18 metres) in size. The model was made by Messrs John B Thorp, and after falling into a poor condition it has now been restored and is on permanent display at the Museum of Liverpool (see Figure 7.9). An endoscopic film of which an image was captured of in Figure 7.8 gives a basic indication of what the interior space would have been like, however, the credibility of the model must be treated with caution as the restoration team state that they had to make inferences using various conflicting drawings in order to complete the model (Limehouse Heritage 2011). In addition to changes in the dome design, buttressing, bell towers and altar, the area to the east of the sanctuary was also significantly redesigned between 1929 and 1934.

Figure 7.9: Renovated Lutyens model exhibited in 2007. Image credit: Liverpool Museums (2011).

7.2.6 Construction of the Crypt and death of Lutyens

On Whit Monday, June 5th 1933, an outdoor ceremony was held to lay the foundation stone of the cathedral. By this date the former workhouse site had been cleared of the majority of existing buildings. The ceremony was attended by over thirty thousand people (Snead 1979). It was estimated that the cathedral would cost three million pounds, which Lutyens suggested could be achieved largely from the charity of the congregation;

> *If we were to get 3d a week from the parishioners I could do it in twenty years. If we get 2d a week from them it will take thirty years."* (Liverpool Echo 1930b, p.29)

Work on the crypt commenced over the coming years until the outbreak of World War Two meant that there were labour shortages. Only one apprentice remained working until 1941 when work stopped completely and the site was used as an air raid shelter.

Lutyens continued to work on the designs until he became ill. He died on New Year's Day 1944 surrounded by drawings of the cathedral. This meant that all building work – design and construction – ceased. The project would not continue until after the war when building restrictions were lifted.

7.2.7 Crypt completion and Scott redesign

After Lutyens' death, Downey stated that the design would continue when building permission would allow, however Downey died in 1953. By this point Adrian Gilbert Scott, the brother of Giles Gilbert Scott who designed the Liverpool Anglican Cathedral, had been appointed as continuator on the scheme. Downey's successor was Archbishop William Godfrey. He considered that the Lutyens scheme was too expensive and should be abandoned;

> *"Now the decision is taken and we have resolved that the changed circumstances and the lowered value of money, added to the present cost of building and material, make it imperative to plan afresh and to invite our architect, Mr Adrian Gilbert Scott, to prepare a simpler and reduced version of Sir Edwin Lutyens' design... We are assured that to continue with the original Lutyens' design would mean an outlay of over 27 million pounds and that hundreds of years would pass before the cathedral was completed."* (Godfrey 1955)

Figure 7.10: Scott's 'reduced' design for the Cathedral. Image credit: Liverpool Metropolitan Cathedral (2007).

Scott's 'reduced' design bore little resemblance to the Lutyens scheme and was widely criticised (see Figure 7.10). The Royal Fine Art Commission stated that if the scheme was to be abandoned, the crypt should be completed and a new cathedral design sought altogether, as 'it would be deplorable if a mere caricature of the Lutyens design were erected' (Liverpool Daily Post 1957). In the meantime, from 1956 onwards work continued on the crypt under the supervision of Scott. It was finished in 1958. In 1957 John Heenan took over as Archbishop and in 1959 he announced a competition to design a new cathedral incorporating Lutyens' crypt.

> *"Not only by reason of its majestic beauty but because it has already cost over half-a-million pounds the crypt must not be abandoned. In some way it will have to be incorporated into the new cathedral."* (Heenan 1959)

The competition was won by Sir Frederick Gibberd, designing a smaller, modernist building, circular in plan with a large crown that was much smaller than Lutyens' dome. The design utilised the roof of the crypt as a piazza. Gibberd's design was built and still stands on the site today (see Figure 7.11).

Figure 7.11: Gibberd's completed design of the Liverpool Metropolitan Cathedral that sits above Lutyens' crypt.

7.3 Issues arising from the digital representation construction

In creating the digital model of Lutyens' design for the Liverpool Metropolitan Cathedral, the archive drawings first had to be sorted in date order. These ranged from an initial set produced in 1929 to a final set produced after 1934; which are published in the Lutyens Memorial (Butler 1950). Between these two sets various other development drawings emerged. The key changes between the initial and final design were noted and would form a line of enquiry investigating the design development to be discussed in section 7.5. As a strategy, a digital representation of the 1934 design was constructed first as it forms the most complete account of the design in terms of both quality and quantity of drawings. In addition to this, the majority of the design below roof level remained unchanged, meaning development would be easier to document once the main body of the cathedral was modelled digitally using the higher quality 1934 drawings. Following this, changes were modelled digitally in reverse chronological order back to the initial 1929 design. Although Lutyens completed a set of drawings at ¼ inch scale (i.e. 1/48), these do not include any details of construction. For example the sections through walls do not show where the brick skeleton ends and stonework begins. Therefore, the design can only be considered in detail on a planning level (see Figure 7.12 and Appendix C - 2).

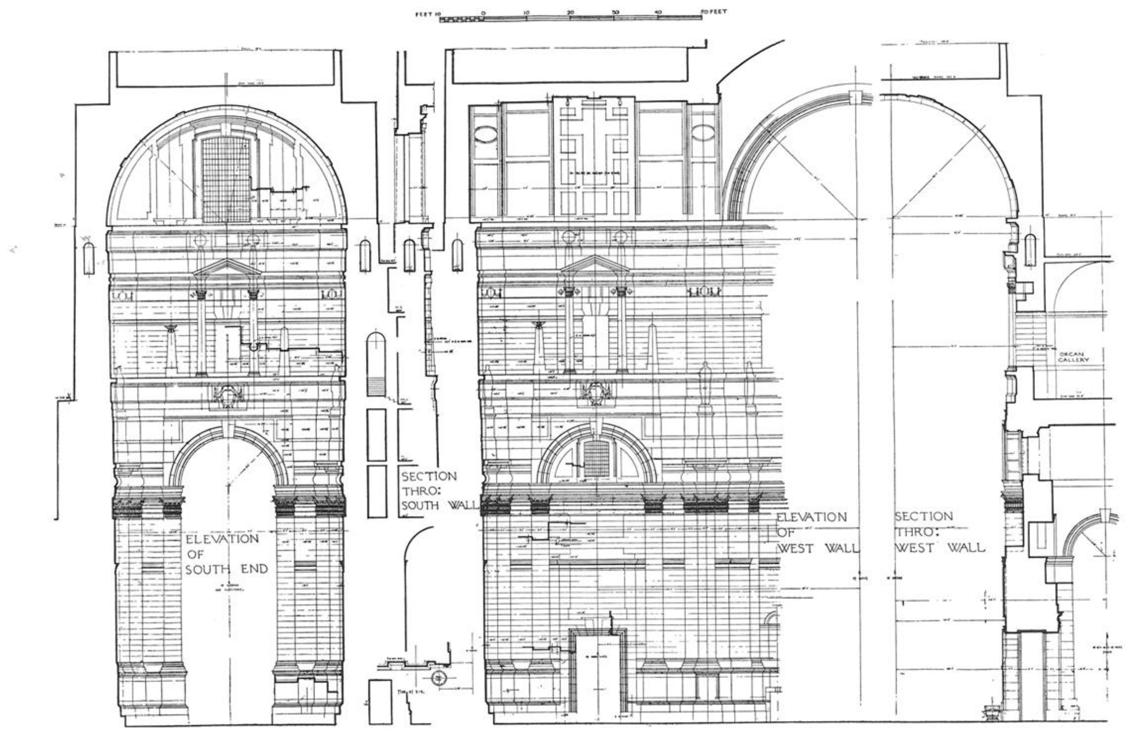


Figure 7.12: Section through the south end of the Narthex. The drawings give no indication of the inner wall materiality. Image credit: Butler (1950b, plate C).

7.3.1 Choice of computer aided design software

Once the drawings were in order, the process of creating the digital model could begin. SketchUp 8 was chosen as the modelling software (@Last Software 2000). SketchUp is designed for ease of use with tools such as 'push/pull' which extrudes a surface into a three-dimensional shape. A more complex version of this is the 'follow me' tool allowing surfaces to be extruded along a given path. These two features, combined with the simple to use interface, meant that the software was ideal for modelling the cathedral as the design is primarily based on simple geometry which are ideal for the 'push/pull' and 'follow me' tools. The software also features a number of plug-ins to enhance its capabilities, for example, Kerkythea can be used to ray trace SketchUp models rather than relying on image captures alone. Additionally, the digital model can be exported in many file formats such as 3DS enabling it to be imported into other programs such as games engines and rapid prototyping software. One of the main disadvantages of SketchUp is its poor capabilities when working with freeform geometry or double curved surfaces, however, in the case of the cathedral design, this type of geometry occurs little. The only exception to this being the domed areas which have a very simple relationship between the curved surfaces in each direction, therefore SketchUp is still an appropriate tool to use. The latest version eight of the software also includes solid modelling tools, increasing its modelling capabilities even further whilst maintaining the simple interface. The uncomplicated nature of the software also meant that the design could be produced as quickly and efficiently as possible given the vast size of the cathedral; a process that would still take more than twelve weeks. If the design had included more complex freeform geometry, such as the Sagrada Familia church by Gaudi, software such as Rhinoceros 3D or 3DS Max would have been better suited. However, the only areas besides the domes featuring very complex freeform shapes were the statues placed within the design; objects which will not have a high impact on the study of the architecture and therefore will not be modelled.

7.3.2 Constructing the digital representation

The modelling process began by digitally scanning the 1934 set of drawings then placing them in SketchUp using the ‘drag and drop’ command. The images had to be rescaled to 1:1 within the model to act as a direct reference; a process that was relatively simple as the majority of the drawings included a scale bar. Any drawings without a scale bar could then be scaled using those with a scale bar, for instance comparing plan to elevation. The construction process utilised a grid system that Lutyens indicates on his drawings; simplifying the process into manageable areas whilst adhering to an overall design (see Appendix C - 3). This helped to identify common parts, such as the bases of the nave piers; which could be modelled as components and duplicated as necessary within the model (see Figure 7.13). The symmetry of the design along its length also meant that only half of the cathedral had to be modelled, which could then be mirrored to form the other half. There were a few exceptions to this such as differences in detailed design between the Lady Chapel and the Blessed Sacrament Chapel; however, the basic geometry of each was still very similar.

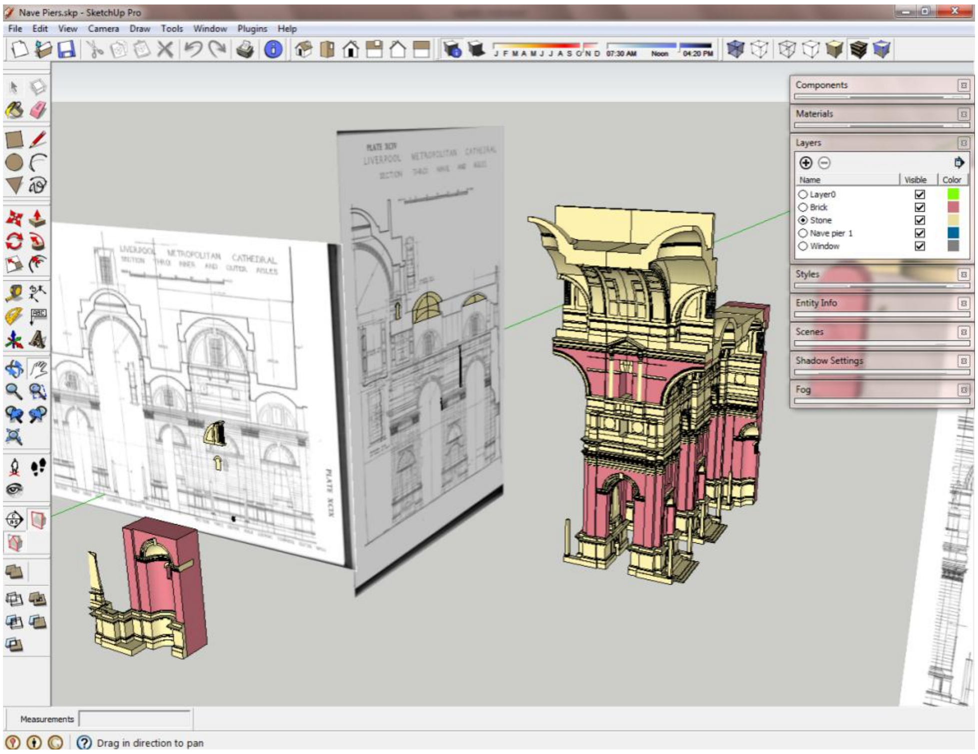


Figure 7.13: Screen capture of the part built Nave Piers in SketchUp. The jpeg images can be seen rescaled to 1:1 within the model acting as the key reference to construct the model. The banding of material is also clearly expressed which follows the same pattern throughout the design.

7.3.3 Representing materiality in the digital model

In terms of modelling the design beyond the geometry, materiality formed a key aspect of the investigation; particularly for lines of enquiry such as the interior lighting of the cathedral, upon which the materials used has a direct affect. The process of applying materials to the model was relatively simple as Lutyens specifies the type of brick used would be a ‘pinky-brown’ Roman design, of which he also specifies at the Thiepval Memorial to the Missing of the Somme (see Figure 7.14). Therefore, photographs were taken of the brick at Thiepval and ortho-rectified digitally then added to the digital modelling program as a texture (see Figure 7.14). It must be noted that the bricks used for the cathedral may have differed if the design had been built; however, the description of the proposed bricks matches that of those at Thiepval closely, especially considering the two schemes were designed at a similar time in Lutyens’ career. This procedure of deduction was repeated for the granite and was a relatively simple process as the material had already been used for the crypt; the only part of the cathedral to be built, which therefore offered direct primary evidence in terms of materiality (see Figure 7.11).

Figure 7.14: The Thiepval Memorial to the Missing of the Somme was a key reference of informing the materiality of the cathedral digital model (left). An ortho-rectified photograph of the 'pinky-brown' Roman bricks at Thiepval were used as a material swatch for the cathedral model (right).

7.4 Avoiding ambiguity in the digital representation

When constructing a digital representation of a design that was destroyed or not built at all, it is highly likely that the source material used as a reference for its construction will be incomplete. This can lead to ‘inferences, educated guesses, and just plain wild speculation’ making their way into a digital representation in order to fill in the missing elements (Kensek 2005, p.640). Such ambiguity should be avoided; something that can be achieved by making clear to the viewer that what they are seeing is based on incomplete information and consequently inferences have been made to give a complete picture of the design in question for the sake of analysis. This was previously discussed in detail in section 3.5.

Compared to previous cases, the cathedral investigation has been relatively straight forward in avoiding ambiguity, as the Lutyens Memorial provides a near complete set of drawings with additional sources filling in many of the gaps. However, there were still areas of the design that were not represented in the drawings and inferences consequently had to be made. The cathedral design is very systematically laid out; granite footings sit below brick piers followed by another band of granite, then another band of brick and finally the vaulted arch granite-clad ceilings in the higher levels of the building (see Figure 7.13). This pattern, including the cornice and architrave details, repeats itself throughout the design so a general rule could be deduced that any unknown elements should adopt the basic principles outlined above without any additional detail being added based on assumptions and analogies. This avoids the situation of relying on educated guesses whilst being confident that the basic design elements are represented as correctly as possible.

Areas with drawings missing, such as the chapels flanking the lateral transepts, had to be inferred based on the pattern of materials described above. As the drawing of the ground floor plan of the design was available, the banding was deduced based on that. In addition to this, other drawings could be used to ascertain the internal height of the space; a section through the lateral transept indicated an additional room on top of the chapels which was confirmed by the presence of a second row of windows on the external elevations. However, this upper room is not directly drawn anywhere in the archive material studied, therefore it was decided not to model the space in detail as the unknown internal area does not affect the lines of enquiry pursued.

Another section of the internal design that had to be inferred was the main entrance of the west elevation; again, the basic pattern of the design was used as a template. Additionally, the long section indicating the elevations of the internal entrances in the lateral transepts could be used as a source of evidence (see Appendix C - 2), as the entrances are of a very similar design on all three main entrances (west, north and south). The external entrance of the west elevation could also be used as a template to ascertain what was happening on the inside of the cathedral. Again, this ensured that inferences were well informed to reduce the margin for errors.

To clarify the level of inference in the design, a version of the digital model has been created suggesting various levels of confidence based on the amount of source data available to create it (Kensek et al. 2002). This enables the viewer to gain a clearer view of exactly what they are seeing and acts as an additional reference point when trying to enhance understanding of the cathedral design. Based on the methodology of Kensek et al. (2002), green suggests areas of greater confidence whereas red indicates less confidence. Also, darker hues imply greater confidence and lighter hues imply less confidence (see Figure 7.15).

Figure 7.15: Snapshot of the narthex of the digital model indicating confidence levels in the source data based on Kensek et al (2002). Bright green represents greater confidence and bright red represents less confidence. Darker hues represent greater confidence than lighter hues giving a four tier system of confidence.

Figure 7.15 is a digital representation of the main west entrance of the cathedral; one of the areas requiring inferred modelling. The bright green areas are levels of high confidence in the source data as there are drawings directly available for them. The lighter green areas have fragmented drawings available and follow the general pattern of the design, therefore having a medium level of confidence in their accuracy. The bright red areas, such as the columns, have a lower level of confidence as there are no elevation drawings indicating their form, however based on the plan and external elevation available they can be seen as an educated guess. The curved geometry over the columns is purely based on what occurs on the external elevation and therefore has the lowest level of confidence; light red.

7.5 Lines of enquiry and results

Upon reading the source information, specific lines of enquiry emerged. These were formulated by ascertaining whether digital techniques could be used to answer questions that would not have been possible in a pre-digital era, as well as aiming to enhance knowledge and explanation of particular aspects of the design. The specific lines of enquiry that emerged are as follows:

1) Development of design from 1929 to 1934
2) Internal geometry of the cathedral
3) Lighting of the cathedral

4) Geometric comparisons to the Thiepval Memorial to the Missing of the Somme
5) Lutyens' original crypt design compared to Scott's version
6) Auralisation of the cathedral organ
7) Counterfactual history

The use of virtual reality enables an environment to be created in which the viewer has the ability to walk around, inside and out, a design. This could result in a far better understanding of the spatial qualities of the building as traditional perspective images in which the creator decides the view do not take into account the 'sequential movement of the viewer's angle of vision over time' (Labrousse 1997, p.32). This ability is arguably second only to walking around the cathedral itself had it been built. Opportunities such as creating a timeline of events in the form of digital models layered on top of each other offer a much clearer understanding of the development of the site and untangle all of the traditional forms of representation into a concise graphic language. The process of constructing the models also results in many questions being asked, such as how missing elements may have looked. This method results in a far more rigorous investigation into the building.

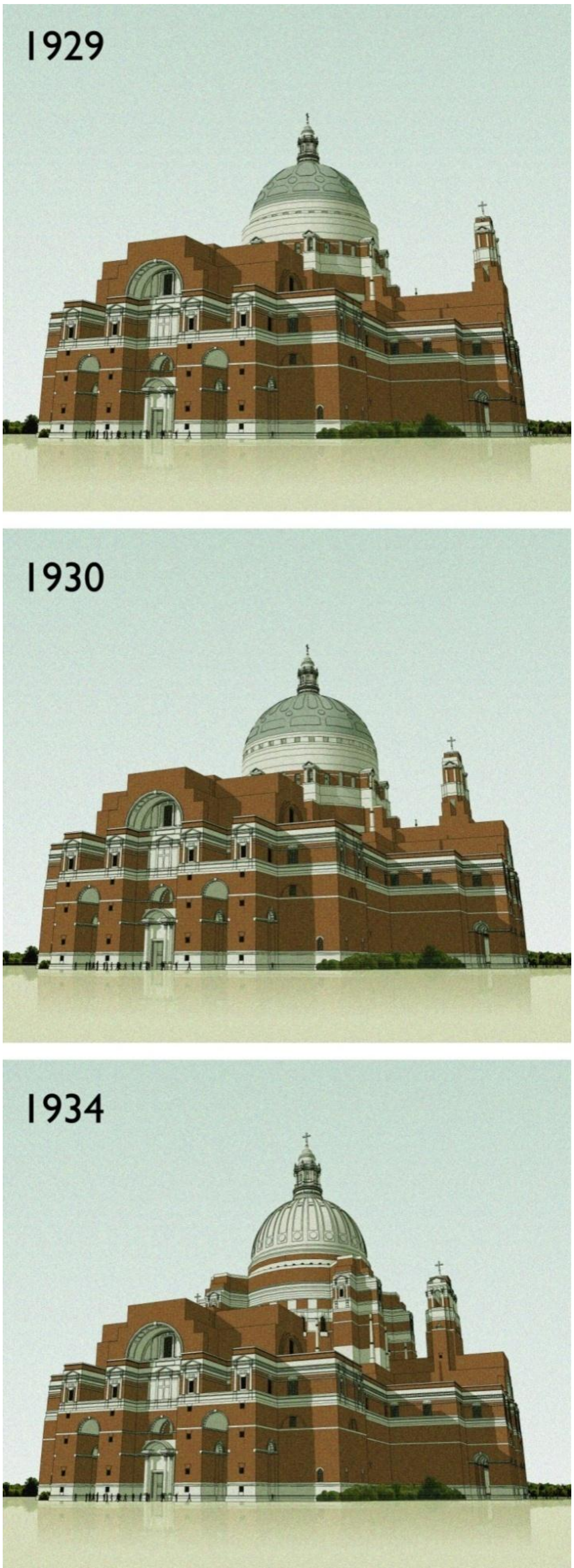
This section investigates the various lines of enquiry formulated from studying the existing primary and secondary sources and presents augmented critique of Lutyens' cathedral using digital techniques.

7.5.1 Development of the design from 1929 to 1934

The documentation of how the cathedral developed from 1929 onwards is complex. Key dates of development are 1929 when the initial design was unveiled to the cathedral committee, 1930 when Farey's perspectives of the scheme were released to the press, 1932 when the drawings were displayed at the Royal Academy and further to this, the display of the physical model in 1934. Over this time, changes occurred primarily in the design of the dome and buttressing, bell towers, altar, sanctuary and areas east of the sanctuary. However, with no built design to act as a reference, the various sources have become intertwined. For example, Farey's perspectives (see Figure 7.1) are commonly used to illustrate how the exterior of the cathedral would have looked, however, it is not made explicit that these were produced in 1930 and that the dome design developed considerably afterwards. This subsequent development can be seen in the drawings published in the Lutyens

Memorial, as well as the physical model. The use of digital techniques enables the various stages of the design development to be dissected and displayed separately; something that was not viable in the restoration of the physical model which had to be seen as a ‘best guess’ between the various iterations (Limehouse Heritage 2011).

Farey’s perspectives were taken as a template to enhance understanding of the external design of the cathedral using digital techniques. The view shown in Figure 7.1 was replicated, as well as introducing an additional viewpoint to highlight changes to the east of the sanctuary. Farey’s perspectives were purposely imitated to highlight the fact that they are illustrating an iteration of the design from the development process, not those which Lutyens developed to ¼ inch scale (1/48) akin to the 1934 design. This enables the various stages of external development to be visualised using the same graphic language (see Figure 7.16 and Figure 7.17).

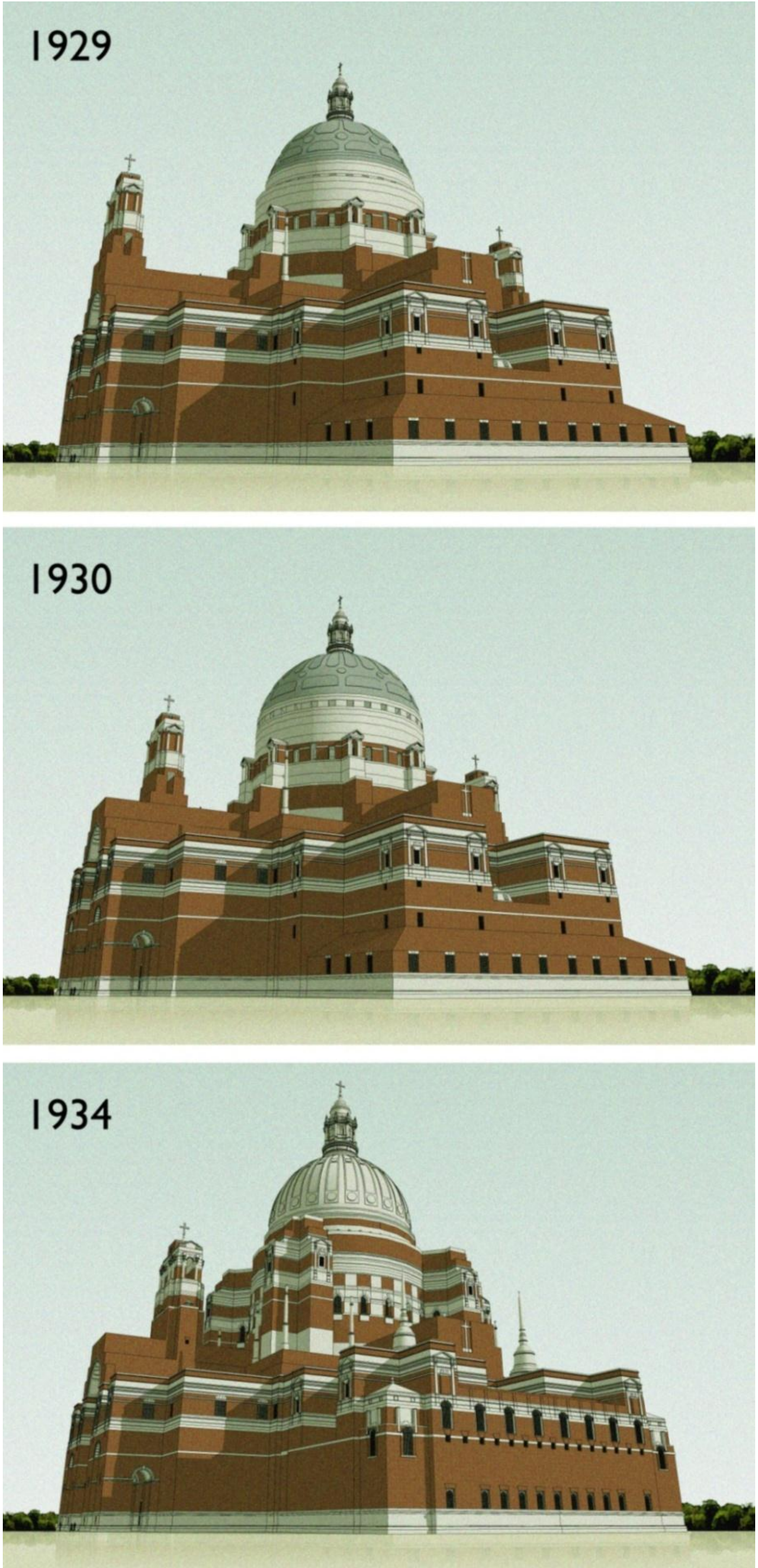


The 1929 design features a smaller stainless steel external dome and the bell towers are located above the porches.

The 1930 design is a direct copy of Farey's perspective (see Figure 7.1) in which the dome size increases and the bell towers move above the lateral transepts.

The 1934 design (bottom) sees the dome, buttressing and bell towers redesigned.

Figure 7.16: Digital renderings replicating Farey's perspective of the front of the cathedral.



In addition to the changes noted in Figure 7.16, the design to the east of the sanctuary changes considerably from 1929 (top) and 1930 (centre) to the 1934 design (bottom).

Figure 7.17: Digital renderings replicating the style of Farey's perspectives and applying them to the rear of the cathedral design.

The bottom images of Figure 7.16 and Figure 7.17 show the 1934 version of the design whereas the version normally portrayed is the centre image from 1930. Working backwards to the 1929 design from the 1930 design displays how the dome developed becoming slightly wider in diameter externally, however, it must be acknowledged that this may have been an error in Farey's perspective as there are no architectural drawings available of the 1930 design, for instance plans or elevations. In addition to this the images of the 1929 and 1930 designs displays how the bell towers move from above the porches to above the lateral transepts. Moving forwards from the 1930 design to the 1934 design illustrates how the dome supports change from eight small buttresses to four large buttresses. It also shows how Lutyens amended the dome design from stainless steel cladding to granite matching the rest of the design. The dome becomes taller in the later design as well as the bell towers and lantern increasing in size. Finally the digital images show how the area to the east of the sanctuary developed considerably between 1929 and 1934; notably with the addition of another storey housing a library and the spires of the two chapels emerging. It is hoped that as a resource, these images will make the development of the cathedral design a lot clearer.

In addition to the external development, changes also occurred internally. As discussed previously, the existing drawings and model show different versions of the design which have become intertwined. Therefore an isometric section cut has been taken through the different iterations of the digital model in order to demonstrate the development in a concise graphic language (see Figure 7.18). The digital sections show that major development occurred between 1929 and 1932, especially in redesigning the dome and areas east of the sanctuary. They also highlight the fact that one of the last changes to occur was the design of the altar between 1932 and 1934, in which the central steps leading to the sanctuary are removed and a domed canopy added.

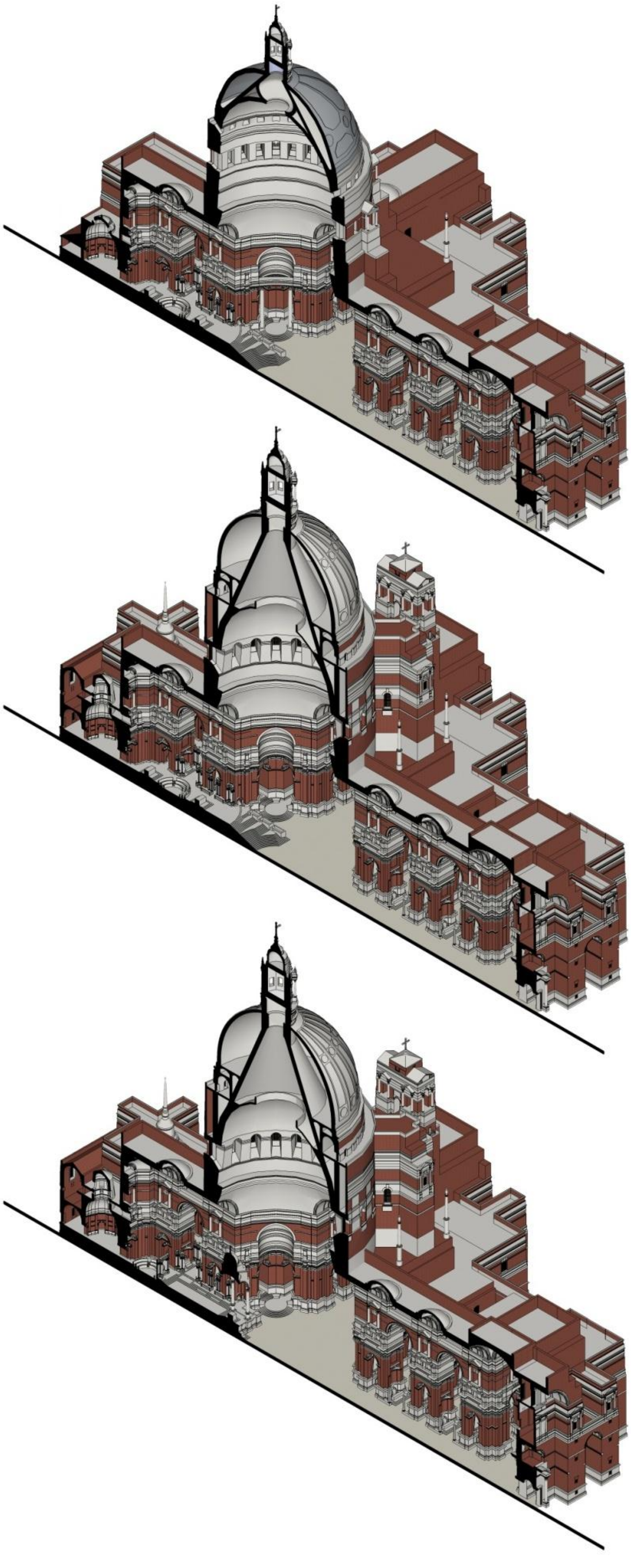


Figure 7.18: Isometric section cuts taken through the digital model showing the initial design from 1929 (top), 1932 revision (centre) and final 1934 design (bottom).

7.5.2 Internal geometry of the cathedral

Summerson's 'Arches of Triumph' essay (1981) describes in detail the geometry of the cathedral and how it is formed by a series of arches that interlock with each other. This internal geometry forms the basis of the design and is described by Lutyens in his address to Liverpool City Council:

> *"The organisation of the design consists of a sequence of barrel arches intercepted with adventures in their various lengths. Arches 15 feet wide and 45 feet high carry at right angles, arches 22 feet wide and 66 feet high, which in turn carry arches 32 feet wide and 96 feet high, and these carry the main vaults 46 feet wide and 138 feet high, rising incidentally to 150 feet; the whole converging to carry the great dome, 168 feet in diameter, covering a height of some 300 feet."* (Swarbrick 1933, p.5)

Summerson (1981, p.46) acknowledges that 'to set all this up in one's mind as a real-life experience is far from easy' and states that at the time of writing the only guides to comprehend the geometry were sketches of the interior by William Walcot. What is particularly revealing about the text is that Summerson describes the arches as a series of tunnels, which gives the impression that they are carved from a large mass resulting in the cathedral having a cavernous feel. This analogy begins to explain how the geometry of the design could be generated as a series of Boolean operations as used in solid modelling. This process works by taking a number of solid models and applying operations to them to change their form. For example, a sphere and a cube could be joined into one object using a Boolean union, or a tunnel could be formed by removing the volume of a cylinder from a square using a Boolean subtraction. Further to the Boolean operation analogy, Butler (1950 p.49) stated that the design should be 'thought out in solid geometrical relationships' and seems to pre-empt the use of digital techniques to describe the cathedral.

> *"It's lucidity is difficult to convey in words and really requires a model for its explanation – a model, that is, which could be taken to pieces and built up again."* (Butler 1950, p.49)

Boolean operations are used to precisely explain how the arches are seemingly carved from a large mass to form 'tunnels' within the design. Each arch size described by Lutyens is modelled digitally, colour coded and located on top of a plan of the cathedral that has been digitally scanned. This enables a build up of the definitive elements making up the cathedral design from the series of arches to the dome (see Figure 7.19).

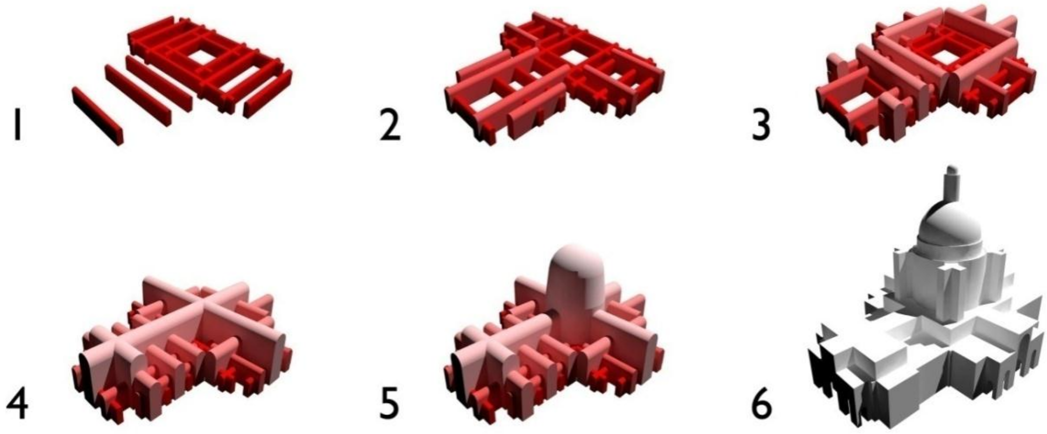


Figure 7.19: Boolean operations are used to describe the internal geometry of the cathedral. 1) 15 by 45 feet high arches. 2) 22 by 66 feet high arches. 3) 32 by 96 feet high arches. 4) 46 by 138 feet high arches. 5) 300 feet high dome. 6) The geometry is subtracted from a massing model of the cathedral to form the interior.

By way of a Boolean subtraction, these solid elements are then taken away from a simple massing model of the cathedral design to give a geometrically simple model of the interior (see Figure 7.20).

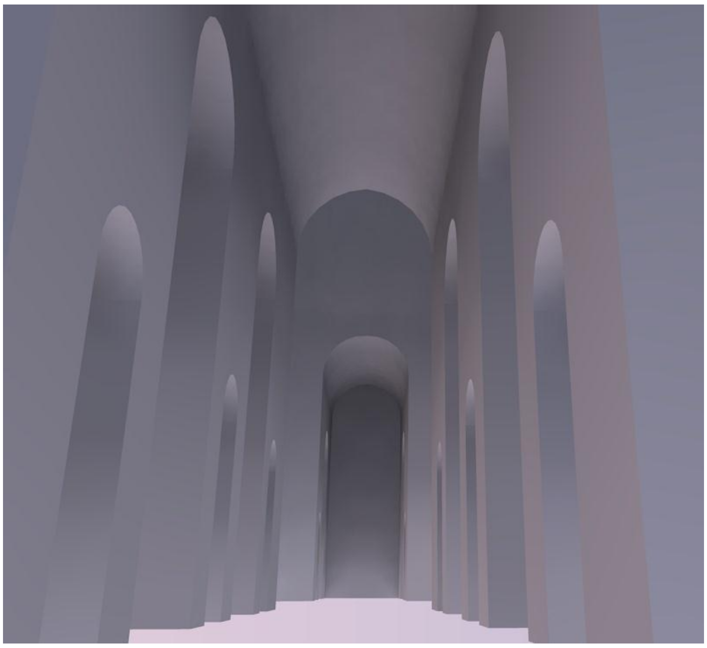


Figure 7.20: By subtracting the geometry produced in figure 16 from a massing model of the cathedral, the simplified geometry of the internal space can be visualised.

This simple model explains the basic geometric principles of the design and shows graphically how it would have looked in its most primitive form along the length of the nave. The model could then be developed to a higher degree of detail to assist with additional lines of enquiry into the design.

7.5.3 Lighting of the cathedral

The previous section demonstrates how the design can be seen as interior spaces carved from a solid, giving the cathedral a cavernous feel. Summerson (1981) discusses in detail how natural light would affect the interior, stating that the openings high up in the dome space would be a main source of light, however the nave and narthex would supply little light from the sparse openings above. Summerson also suggests there would perhaps be a greater amount of light in the aisles than the nave and narthex as the number of openings increases here; Lutyens punches openings through the outer walls as well as high up looking out onto areas hidden from the external elevations.

> *"Certainly there would not be over-much illumination and what there was would come from small, bright inlets, high up in the structure. St. Paul's Cathedral would by comparison, be radiant. Liverpool would be altogether more mysterious, more evocative than Wren's cathedral."* (Summerson 1981, p.47)

Existing sources of information do not give a clear indication of how the interior would have been lit. This is due to the methods of representation available at the time; as a series of pencil sketches, Lutyens' interior sketches as well as those by Walcot (1981) indicate the geometry of the space but do not demonstrate the lighting. The closest indication available of how the interior may have been lit comes from the physical model as seen in the endoscopic film (Mezzo Films 2009), however, the model lets in light through the saucer domes along the nave which does not occur in Lutyens' design, therefore the lighting displayed in the interior does not accurately visualise what would have been (see Figure 7.21).

Figure 7.21: Interior photograph of the model showing light entering from the saucer domes which does not occur in Lutyens' design. Image credit: Liverpool Museums (2011).

Therefore, the digitally created model can be utilised to simulate more accurate lighting predictions using ray tracing. As a starting point, a view was taken from the main entrance porch along the nave towards the dome and ray traced to get a near photo real image of what the scene would have looked like (see Figure 7.22). This meant that materials had to be applied to the model as discussed in section 7.3.3; as the design was only partially built material samples had to be taken from another of Lutyens' designs for the brickwork but the stonework of the crypt could be directly used as a material swatch for the unbuilt elements.

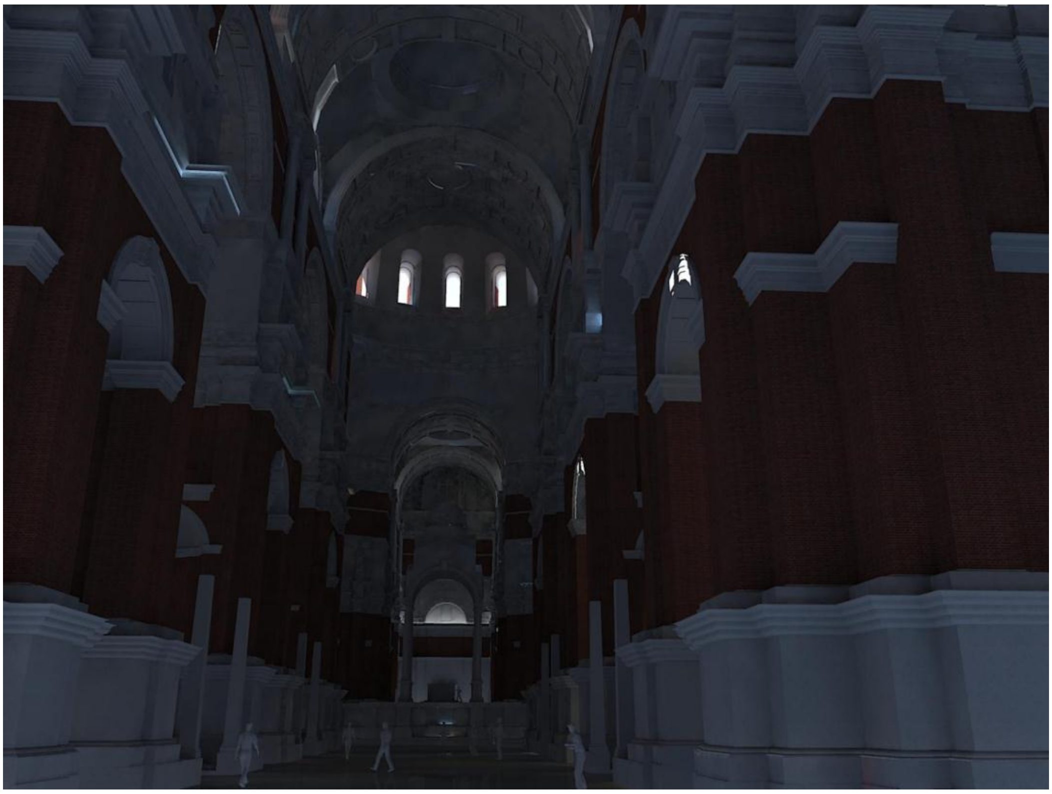


Figure 7.22: Ray traced view of the cathedral interior along the nave with daylight only.

The interior lighting along the nave is somewhat gloomy and would have required additional lighting to supplement it; an issue which was a point of debate between Lutyens and the cathedral committee;

> *"I want my Cathedral to be lit entirely by candles. You need wondrous few. The big Nave at St. John's College is lit by four candles and isn't it glorious and mysterious! The choir is alone well lit in that every chorister has a candle.*
>
> *But they want electric light, and flood-lighting at that."* (Hussey 1950, p.575)

Again, the interior image can be simulated to show the difference between what the design would have looked like in both scenarios; candlelit and floodlit. Kerkythea, the rendering system used to create the ray traced images, enables lights to be placed directly in the SketchUp model, and then exported to Kerkythea and finally ray traced (see Figure 7.23 and Figure 7.24). For the candlelit render, point lights with a Kerkythea light power value of 0.32, which equates to 12.5 lumens, were placed throughout the model. For the floodlit render the process was repeated using a light power equating to floodlighting with the lights placed on the shelf created between the bases of the piers and brickwork above. This seemed like an obvious area to place the floodlighting due to its ease of access for maintenance purposes had the design been built, as well as the shelf hiding the lighting unit itself, therefore being advantageous aesthetically.

Figure 7.23: Ray traced view of the cathedral interior along the nave with natural lighting and candle lighting.

Figure 7.24: Ray traced view of the cathedral interior along the nave with natural lighting and flood lighting.

The two alternative lighting conditions contrast each other greatly. The digitally created images indicate that Lutyens' preference for candlelight would have been evocative and mysterious, especially as the upper levels of the design have very low lighting levels. In contrast, the floodlit version makes the architecture of the cathedral very apparent but loses some of the mystery of the unlit or candlelit renders. The digital images provide visualisations of how the cathedral could have been lit in a much more accurate way than has been achieved in previous representations of the design, such as hand drawings and the physical model. However, although the digitally created views provide more accurate representations, they are still subjective in the sense that it is the decision of the viewer which lighting style they prefer.

Besides the representations shown above, a quantitative method could be used to re-analyse the lighting of the cathedral. This was attempted using Autodesk Ecotect Analysis software; however, as the validity of the results is questionable, they are discussed in Appendix D as an illustrative study.

7.5.4 Geometric comparisons to his memorial design at Thiepval

Lutyens' Memorial to the Missing of the Somme at Thiepval, France, has often been compared to the cathedral design at Liverpool in terms of its geometry and materiality (see Figure 7.14). It includes the same barrel arches that Lutyens describes in the design for the cathedral. The main difference between the two designs is that the arches at Thiepval have a ratio of 2:5, whereas at the cathedral they have a ratio of 1:3 to give a loftier feel. In fact, the main arch of Thiepval is exactly the same width of the Transept arches in the cathedral. By overlaying the two designs digitally this could be demonstrated effectively. The materiality of the schemes are also very similar; red brick and grey stone. It is also worth noting that Thiepval was designed and constructed from 1927 to 1932, which directly overlaps the time when Lutyens was commissioned to design the cathedral. Therefore it is very likely that his ideas in France influenced his design in Liverpool.

Questioning the extent of similarities between the geometry of the Cathedral in comparison to Thiepval can be demonstrated using a series of comparative snapshots taken from digital models of the two designs. This involved creating a digital model of Thiepval in order to directly compare it with the cathedral model. The digital model of Thiepval was produced using a set of drawings published in the Lutyens Memorial (Butler 1950), as well as through visiting the monument itself, which enabled key features to be checked and material snapshots to be taken. Critically, the drawings of the base of the design were different from what was actually built, for example the paving patterns. This acts as an important reminder when investigating unbuilt or destroyed works of architecture; the surviving documentation used to form the basis of a digital simulation is unlikely to be exactly the same as what would have been built. Once complete, the digital models were overlaid at the same scale using graphics editing software to begin the process of investigating the extent of their similarities (see Figure 7.25).

Figure 7.25: Digital overlay showing a section of the cathedral nave compared to the Thiepval Memorial at the same scale. The image demonstrates how the arches of the two intersect at the same point.

The overlay shows how the arches connect at exactly the same point along the nave transept and aisles. In addition to this, the geometry created in section 7.5.2 to explain the shapes of the cathedral interior with Boolean operations has been utilised to make explicit how the arches cross at exactly the same point (see Figure 7.26).

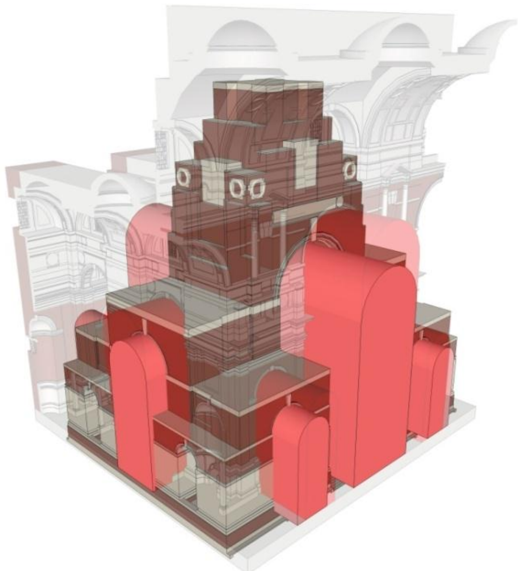


Figure 7.26: Digital overlay showing a section of the cathedral nave compared to the Thiepval Memorial at the same scale. The geometry of the arches used for the Boolean operations shows that they are the same width but have a different height ratio.

The image also demonstrates that the main difference between the two designs is that they have different arch heights and same arch widths; Thiepval has a ratio of 2:5 whereas the cathedral has a loftier ratio of 1:3. For example at Thiepval the largest arch is 32 feet wide and 80 feet high (9.75 by 24.38 metres) whereas at the cathedral the equivalent arch is 32 feet wide and 96 feet high (9.75 by 29.26 metres). Using digital overlays of the models enables views to be created from exactly the same perspective to show the models from the same position of intersection; something that would be much more difficult to achieve if physical versions of both schemes existed. Views of each design taken from a human perspective at the same position have been compared (see Figure 7.27 and Figure 7.28).

Figure 7.27: Digital line drawing of the cathedral (left) taken from the same position as Thiepval (right) looking through the 32 foot (9.75 metre) wide arch.

Figure 7.28: Digital line drawing of the cathedral (left) taken from the same position as Thiepval (right) looking through the 22 foot (6.71 metre) wide arch.

The overlays clearly demonstrate that the overall geometry of the two designs is very similar. On the other hand, they also show how different the two are in their level of detail; Thiepval is simpler and restrained in terms of decoration, whereas the cathedral has a high level of detail especially in areas such as caps of columns and spandrels. To say that the two designs are similar would be an understatement; the nave aisles and transepts of the cathedral are in essence the Thiepval arch repeated a total of ten times (see Figure 7.29).

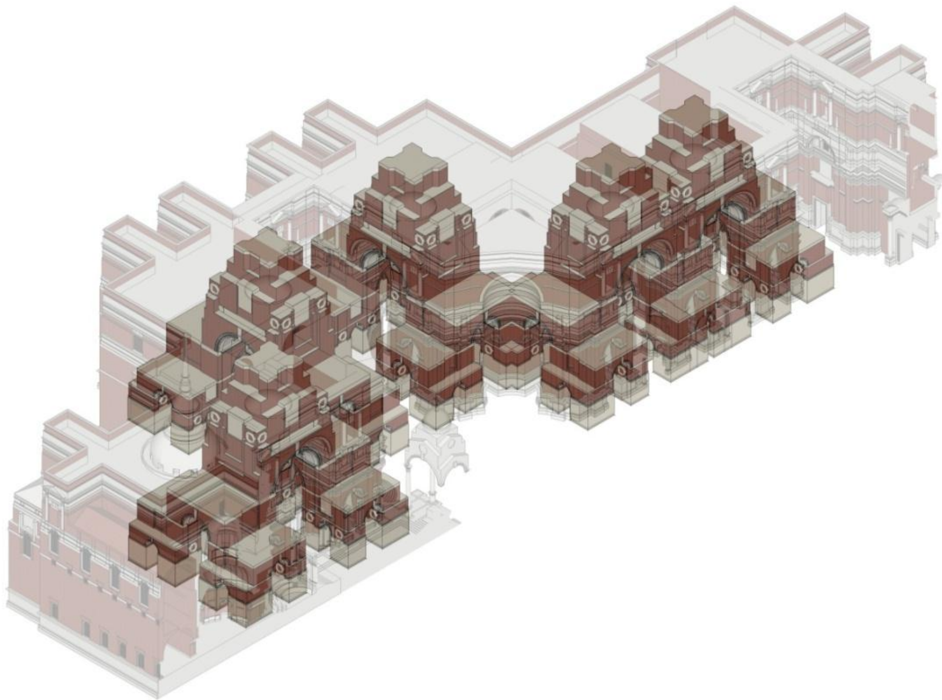


Figure 7.29: Overlaying the lower levels of half of the cathedral with the Thiepval model repeated a total of five times; twice in the nave, twice in the lateral transept and once in the sanctuary. This is then mirrored in the other half of the cathedral design.

7.5.5 Lutyens' original crypt design compared to Scott's version

Following Lutyens' death on New Year's Day 1944, a continuator had to be found to oversee the construction of the cathedral, of which completion was still deemed a realistic possibility. Lutyens completed all of the drawings necessary to build the cathedral, however an architect was still needed to oversee building work and deal with the detailed design. Sir Charles Reilly suggested Stewart to the cathedral committee, who worked with Lutyens and drafted many of the design drawings of the cathedral. However, they decided on Adrian Gilbert Scott, brother of Giles Gilbert Scott who designed the Liverpool Anglican Cathedral. In completing the crypt, Scott made decisions that countered Lutyens' design intentions, notably using marble for the crypt floor and not plastering the brick walls (Snead 1979). An essay in the Lutyens Memorial comments that 'the brick walls and vaults will, of course, be plastered, thus reducing the present too strong projection of the granite surfaces' (Butler 1950). In addition to this, Lutyens discusses the crypt in a letter to the cathedral committee:

> *"The Chapel should be plastered, otherwise it will look little better than a coal cellar. It will save your electric light bill, and apart from this, it is not fair to the Cathedral to present it to the public in that way."* Lutyens (1937) cited in Snead (1979, p.90)

Lutyens goes on to say that if the crypt is not plastered it will look like a workhouse, be depressing and psychologically wrong (Snead 1979). This, another contrasting view between Lutyens and the cathedral committee, offers an opportunity to visualise what the cathedral crypt would have looked like had it been plastered. The crypt hall was modelled using SketchUp and then materials were added to match Scott's completed design for the crypt (see Figure 7.31). This was then repeated using Lutyens' original intention to have the walls plastered (see Figure 7.32). The two scenarios were ray traced in Kerkythea and a photograph of the crypt was also used to gauge how close it was to the rendered image (see Figure 7.30). The renderings were based purely on daylight rather than studying the effects of electric lighting.

Figure 7.30: Photograph of the crypt hall as built to Scott's detailed design. Image credit: Harris (2010)

Figure 7.31: Ray traced image mimicking the conditions of Scott's detailed design of the crypt as seen in Figure 7.30.

Figure 7.32: Ray traced image amending the materials of the crypt to Lutyens' original intentions.

The visual similarities between the photograph and Scott version are close enough to ensure the comparative study has a satisfactory level of accuracy. Comparing Lutyens' original intentions to the built reality of Scott's detailed design demonstrates how different the crypt would have been in terms of brightness. However, Lutyens' statement that without plastering the brickwork the crypt would be little better than a coal cellar seems extreme, especially considering how the stonework details help to divide the space in the built design. It is worth noting how Scott's version is closer to that of the main cathedral space that would have been built above, as demonstrated in the previous lighting study of the nave (see Figure 7.22). The light rendered walls of Lutyens' proposal would have had a different atmosphere to Scott's built design, offering a contrasting environment in terms of materiality to that of the proposed main cathedral. One speculates whether the decision not to render the walls was in part decided upon to gain a feel for what the main cathedral spaces would have looked like.

As with the lighting of the main cathedral space discussed in section 7.5.3, an illustrative study has also been undertaken for the lighting of the crypt and is included in Appendix D.

7.5.6 Auralisation of the cathedral organ

One of the most unique aspects of Lutyens' cathedral design is the organ. He places it in the crypt with the sound travelling upwards through a grill into the sanctuary with the choir stand located around the grill so that, in the words of the architect, 'sound and song could come out together' (Butler 1950, p.50). This is a design that Lutyens had used earlier in the Temple of Music at Tyringham and formed an example which he was able to show to Archbishop Downey to illustrate how the organ might sound (The Organ 1935). The design was novel for a cathedral and therefore created a lot of interest;

> *"...were the organ to be placed cellarwise in the basement, its tones would perforce have to be voiced louder than normal if it is going to lead congregational song. The Clergy at the Altar would then get more than they would like of heavy organ tone, and yet the people at the back of the Nave might only be getting a weak and indecisive lead from it."* (Dixon 1930)

Because it generated interest in the music press, as well as the fact that Lutyens had to convince Downey it would work by showing him the example at Tyringham, this generates a line of enquiry to ascertain what the organ would have sounded like within the internal space of the cathedral. To answer this question, digital auralisation could be used. However, the techniques used cannot be validated for this study and auralisation techniques are therefore discussed illustratively in Appendix D.

7.5.7 Counterfactual history

The use of counterfactual scenarios in architecture is 'slippery' (Mitchell 1998). However, digital modelling can be used to form the starting point of 'what if?' scenarios to investigate what a design would have been like if it was built. Mitchell (1998) continues to say that counterfactual scenarios are only plausible if a juncture in history suggests that an alternative building would have been constructed. This is true of Lutyens' design for the cathedral; the most significant evidence of this juncture being the construction of the crypt. As a line of enquiry, counterfactual scenarios differ from those discussed previously as they specifically investigate situations had the design been built. For instance, how would the building influence and compare to that of the surrounding city of Liverpool?

A previous study by River Media, commissioned by the Liverpool Metropolitan Cathedral, provides an insight into what the cathedral would have looked like in the modern context of the city of Liverpool (see Figure 7.33). This took the form of digital images giving a realistic impression of how the design would have looked in the context of the Liverpool cityscape.

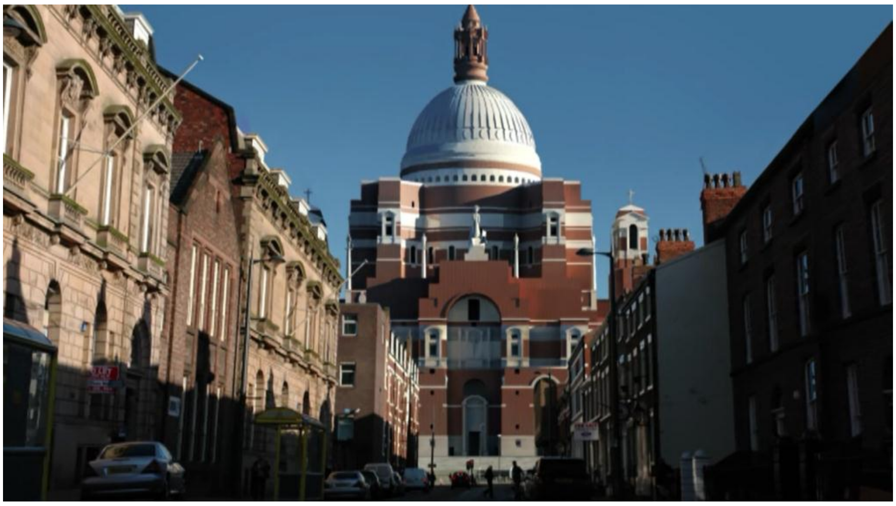


Figure 7.33: Digital montage of Lutyens' cathedral in the modern context of Liverpool had it been built. The image is credited to a film by River Media, which was commissioned by the Liverpool Metropolitan Cathedral.

Hussey (1950, p.530) describes what different aspects of the building would have been like had the design been completed:

> *"But first we may imagine ourselves ascending Brownlow Hill a century, it may be, hence and the vision realised, though now the fabric of a dream."*

He continues to discuss the design as a narrative moving around the exterior of the cathedral after ascending Brownlow Hill. Such text-based narratives can be enhanced by providing a visual depiction of the scene described using digital representations such as those by River Media. The main difference with the digital images created here is they specifically replicate elements from Hussey's text. He begins by stating that on ascending Brownlow Hill, a 'cliff-like mass of pinkish buff brick laced with grey granite looms before us. In the centre of its south end confronting us, a portal arch 145 ft' (Hussey 1950, p.530). Based on the fact that the true south end of the design forms the main entrance porch, Hussey mistakenly states that the street leading up to this is Brownlow Hill when it is in fact Mount Pleasant. A counterfactual image of this scene is demonstrated alongside the current built environment in Figure 7.34. This utilised the digital model created for the previous lines of enquiry; photographs were taken at the different points around the cathedral site in line with Hussey's text, then their position was replicated in the digital model using digitised maps. This ensured that the images rendered of the digital model matched the location of the photographs as closely as possible.

Figure 7.34: Current built environment (left) compared to what would have been if Lutyens' design had been built (right). Notice the exclusion of the Liverpool Science Park on the counterfactual image.

When composing the digital images using a graphics editing program, decisions had to be made over which buildings to maintain in the immediate vicinity of the cathedral design. For example, the Liverpool Science Park was excluded as it sits on the site of what was once a church; a building that was set to be demolished to make way for Lutyens' cathedral design anyway. This gives justification in excluding it from the counterfactual digital images. A further two images have been created based on Hussey's text which can be found in Appendix C - 4 and Appendix C - 5. By juxtaposing the current cityscape with Lutyens' cathedral design, the vast scale of the design is made more apparent. It also suggests that the surrounding streetscape would have been designed differently due to the impact of such a significant building. This issue of the surrounding context was addressed by Lutyens as he prepared a sketch scheme to master plan the area surrounding the cathedral; therefore similar questions can be asked investigating how it would have influenced the city with the alternative surrounding designs (see Appendix C - 6).

Another method of counterfactually enhancing understanding of the cathedral design would be to create a walkthrough or flythrough of the area. The Google 3D Warehouse in conjunction with Google SketchUp and Google Earth was proposed for this. Users can model the built environment in SketchUp and add them to Google Earth, which combines satellite images and GIS (geographic information system) data enabling terrain to be visualised. The aim is to encourage entire city models to be produced digitally. Google state that models to be included permanently as part of Google Earth should only be real-world buildings; however, proposed, historic or unbuilt designs can be uploaded by the user for private use (SketchUp 2011). Although cities such as New York have been modelled using this method extensively, Liverpool only includes significant buildings such as the Liver Building, Cathedrals and Beetham Tower. Consequently there were not enough digital models of buildings in the city to create a visually rich walkthrough or flythrough (see Appendix C - 7). The amount of time it would take to model a large portion of the city, compared to the potential research benefits this would bring for this study, was not justifiable.

However, the scale of the design can be further demonstrated using the significant buildings that have been modelled digitally and publicly included in Google Earth. This is a method that was used to advertise the cathedral design in the 1930s, as demonstrated against the 'Three Graces' of the Royal Liver Building, the Port of Liverpool Building and the Cunard Building (see Appendix C - 8). Juxtaposing the design digitally results in much more accurate representations than those used in Appendix C - 8, as well as enabling the cathedral design to be compared to other Liverpool landmarks via the Google 3D warehouse. Views were formed in SketchUp using a parallel projection which removes perspective, therefore creating images akin to elevations.

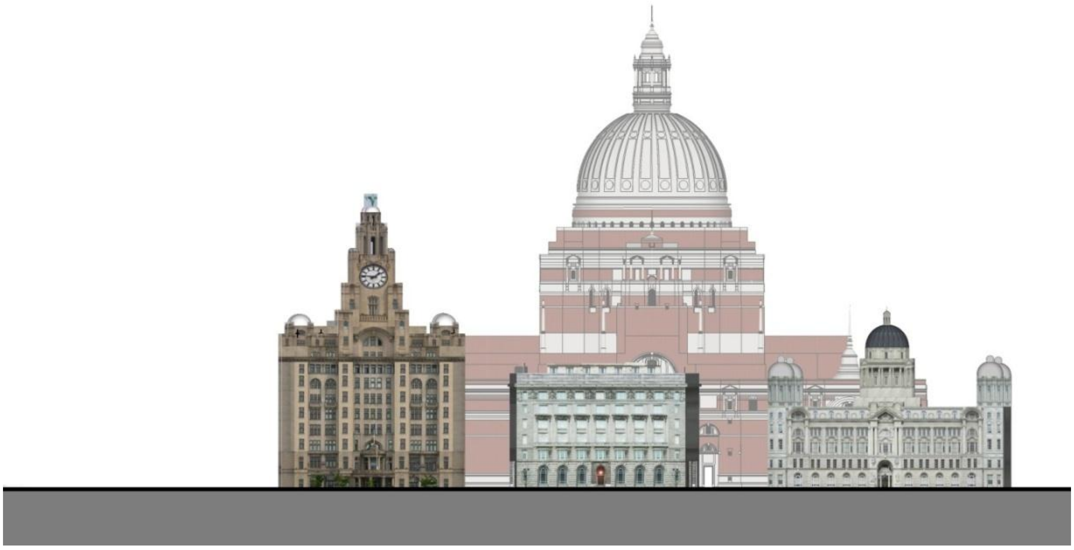


Figure 7.35: Lutyens' cathedral design juxtaposed against the Three Graces.

Figure 7.36: Lutyens' cathedral design juxtaposed against the Liverpool Anglican Cathedral and Gibberd's built design for the Liverpool Metropolitan Cathedral.

The first image (Figure 7.35) demonstrates the vast scale of the design compared to the Three Graces, of which the Liver Building is regarded as Britain's first skyscraper. The second image (Figure 7.36) demonstrates the colossal size of the design compared to the two current cathedrals in Liverpool; considering how the two cathedrals already dominate the Liverpool skyline makes their juxtaposition against the Lutyens design even more astounding. Finally, the design is compared to some of Liverpool's tallest modern buildings. Liverpool's current tallest building, Beetham West Tower, is 140 metres tall compared to Lutyens' cathedral which is 158 metres tall; this can clearly be seen in Appendix C - 9. In addition to Liverpool landmarks, digital models of St Peter's Basilica in Rome and St Paul's Cathedral in London can be utilised in the same way. Lutyens used comparisons to these two churches in plan and section to demonstrate the scale of the design (Figure 7.6 and Figure 7.7); however, the digital models offer the opportunity to juxtapose the external elevations. Again, these demonstrate the vast scale of the Lutyens design (see Appendix C - 10).

The digital images and use of the Google 3D warehouse provide a technique of rapidly comparing the cathedral design to other landmarks and counterfactually offer the opportunity to compare it to buildings that did not exist at the time. This is particularly useful as people are aware of the city they live in and being able to compare the unbuilt design, for example, to the Radio City Tower or Gibberd Metropolitan Cathedral, increases the ability to relate to the digital comparatives.

7.6 Serendipitous results

Constructing a model digitally is the chief method of answering lines of enquiry as part of the methodology used. This process of investigating specific themes using modelling as the main technique has the advantage of providing results that are unexpected, and in addition to the lines of enquiry generated. These unexpected results are partly due to the nature of architectural models, whether physical or digital, which are required to co-ordinate the plan, section and elevation. When these drawings are viewed as separate entities, the margin for error increases.

Studying the primary sources of information between the initial design in 1929 and the near-final version of the design represented through the physical model of 1934 reveals that in addition to the dome, the area which also developed considerably was the liturgical east of the cathedral. This area is behind the altar and houses the sanctuary transept, chapels and sacristies. In the process of constructing the digital representation of the design, it became apparent that the cross section drawing through the east of the sanctuary is not a straight cut through the cathedral, but is in fact staggered (see Figure 7.37 and Figure 7.38). Two sections have been taken with straight cuts through the digital model to demonstrate that the original drawing is staggered (see Figure 7.39 and Figure 7.40).

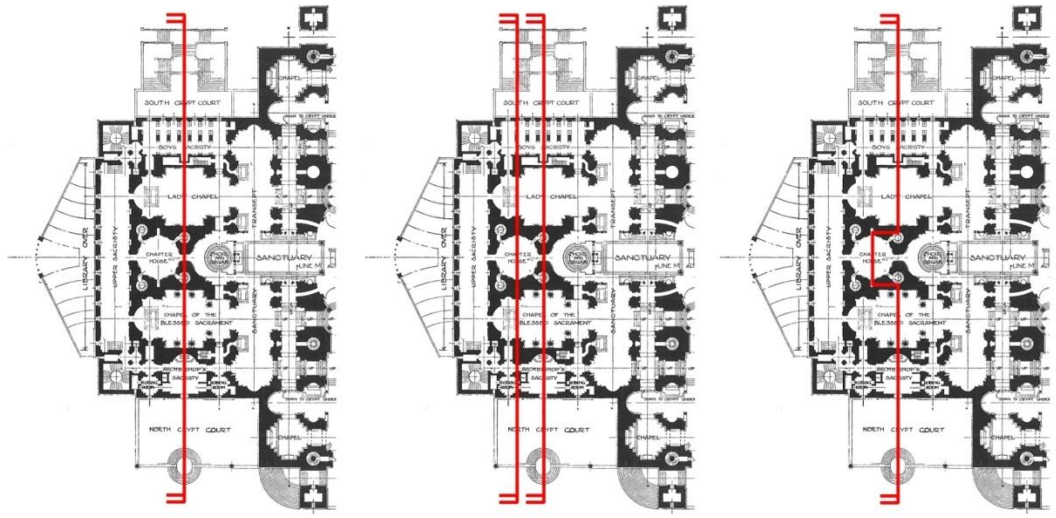


Figure 7.37: Assumed section cut (left) compared to digital section cuts taken (centre) revealed that the actual section cut (right) is staggered. Original plan taken from Butler (1950, plate LXXXIX).

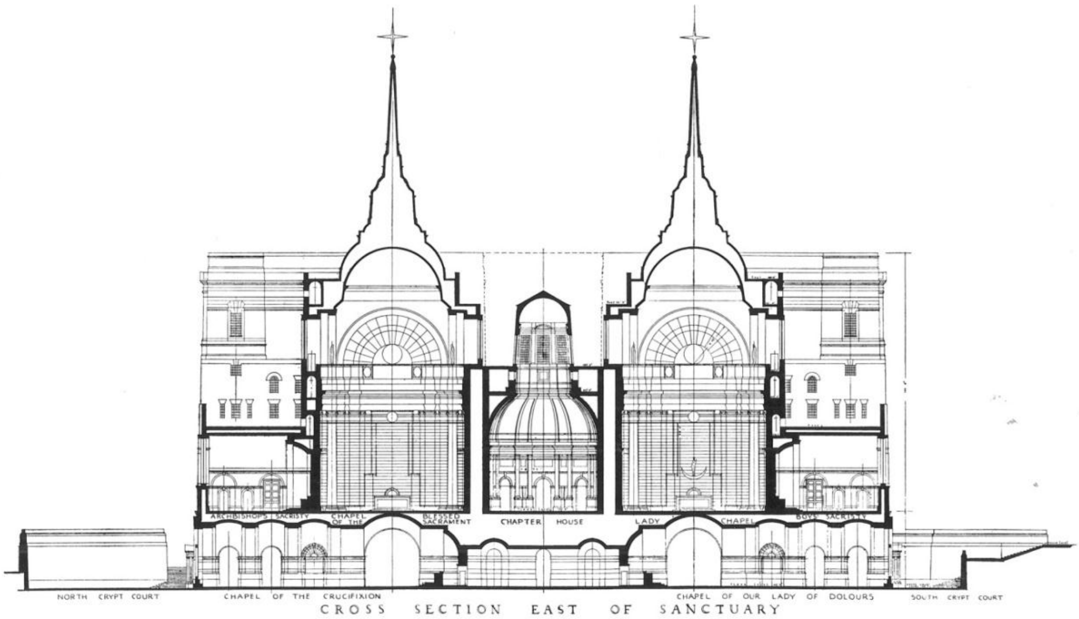


Figure 7.38: Original cross section drawing to the east of the Sanctuary is presumed to be a straight section cut as there is no indication of a stagger on the plan. Image credit: Butler (1950, plate CI).

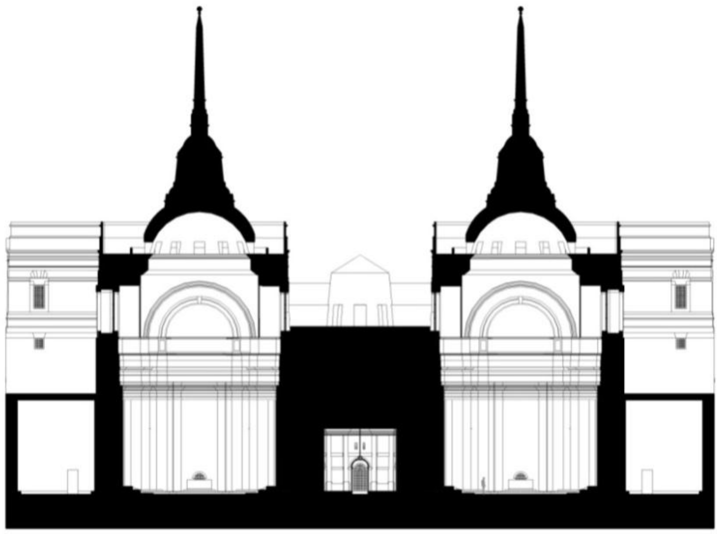


Figure 7.39: A section taken through the assumed cut demonstrates how the chapter house sits behind the cut rather than in the centre of it.

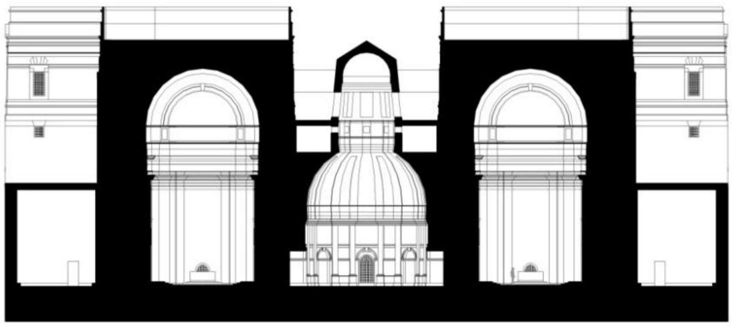


Figure 7.40: A section cut through the centre of the chapter house demonstrates, in conjunction with figure 39, that the original section cut is staggered.

The lack of clarity over the precise location of the section cut resulted in an error in the more detailed drawings that followed. It is likely that Lutyens or one of his employees used the cross section (see Figure 7.38) as a basis for the more detailed Blessed Sacrament Chapel and Lady Chapel sections (see Appendix C - 11). These clearly show window openings on each side of the room at a high level which, according to the original cross section, open out to an external area around the dome of the chapter house. The process of constructing the digital model revealed that the cross sections of the Blessed Sacrament Chapel and Lady Chapel, which are of the same basic design, are incorrect (see Appendix C - 11). This is because the windows which open out to the dome of the chapter house intersect the line of the sanctuary wall; a fact that is difficult to ascertain from the drawings alone, especially due to the design behind the altar being the most complex of the entire cathedral. This intersecting wall results in half of the window being obscured (see Figure 7.41).

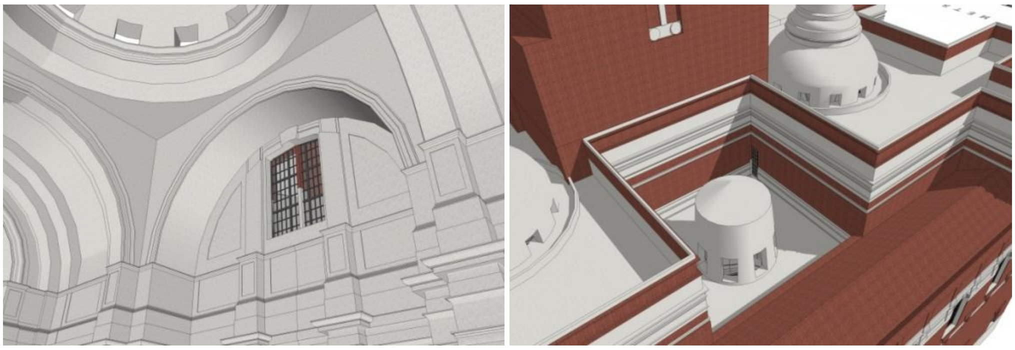


Figure 7.41: The wall forming the back of the Sanctuary intersects with the centre line of the chapels, resulting in half of the window being obscured by the wall. The external render (right) shows the un-obscured half of the window in the centre of the image.

It must be stated that this discrepancy would have been found if the Cathedral had been built. However, it provides an insight into how Lutyens and his workforce designed the spaces; starting from the overall design and working to a greater level of detail as the design progressed. The discrepancy demonstrates that working from two-dimensional drawings alone can be misleading, resulting in an increased margin for error. It is also unlikely that the error would have been found by Thorp's model of 1934, as modelling of the area in question was not completed due to a lack of funds (Limehouse Heritage 2011).

7.7 Chapter summary

Using the systematic analytical technique developed as part of the thesis enables the case study research to be carried out in a structured and methodical manner (see Figure 7.42). Beginning with a series of primary and secondary sources on Lutyens and his design for the cathedral, the research demonstrates how knowledge of the design can be enhanced via the use of digital techniques. Once lines of enquiry were generated, the first step was to create a three-dimensional digital model of the unbuilt design. This was because, although other digital techniques were employed, the digital model became the key tool for analysis as it was used for all of the lines of enquiry without exception. Once created, the digital representation of the cathedral could be used in its broadest sense to enable a greater spatial understanding of what the design would have looked like, both internally and externally. Therefore it can be seen as an additional representation to the physical model exhibited at the Museum of Liverpool offering an enhanced understanding, especially of the cathedral interior. This is primarily due to scale, as the digital representation enables one to walk around the design at a human scale using a computer screen, rather than the physical model in which spatial understanding of the interior is only partially understood via the use of an endoscopic film.

Beyond utilising the digital model itself to visualise the design with, for instance, SketchUp or Quest, many of the lines of enquiry required additional digital representations to enable analysis. These include the use of Kerkythea to accurately ray trace the digital model, and the utilisation of publicly available material such as the Google 3D warehouse. In addition to this, the research aims to go beyond simply using the digitally created visual representation of the design, and include other methods such as comparative studies with other buildings and analysis techniques such as the use of Boolean operations. Also, the digital nature of the research allows multiple iterations of the design to be created relatively quickly which can then form part of an additional comparative study, as seen in the design development of the cathedral between 1929 and 1934. Finally, the creation of a digital representation has the added benefit of potentially revealing serendipitous results. This can be seen in the mistake discovered in the window of the Lady Chapel and Blessed Sacrament Chapel. Although it is highly likely that the design team would have discovered this error if the scheme had developed to construction drawings, and is therefore not a negative criticism of the building, it reveals how the design team worked; starting from a larger and more general section drawing working towards a more detailed section drawing of the design and how in that process mistakes can be made.

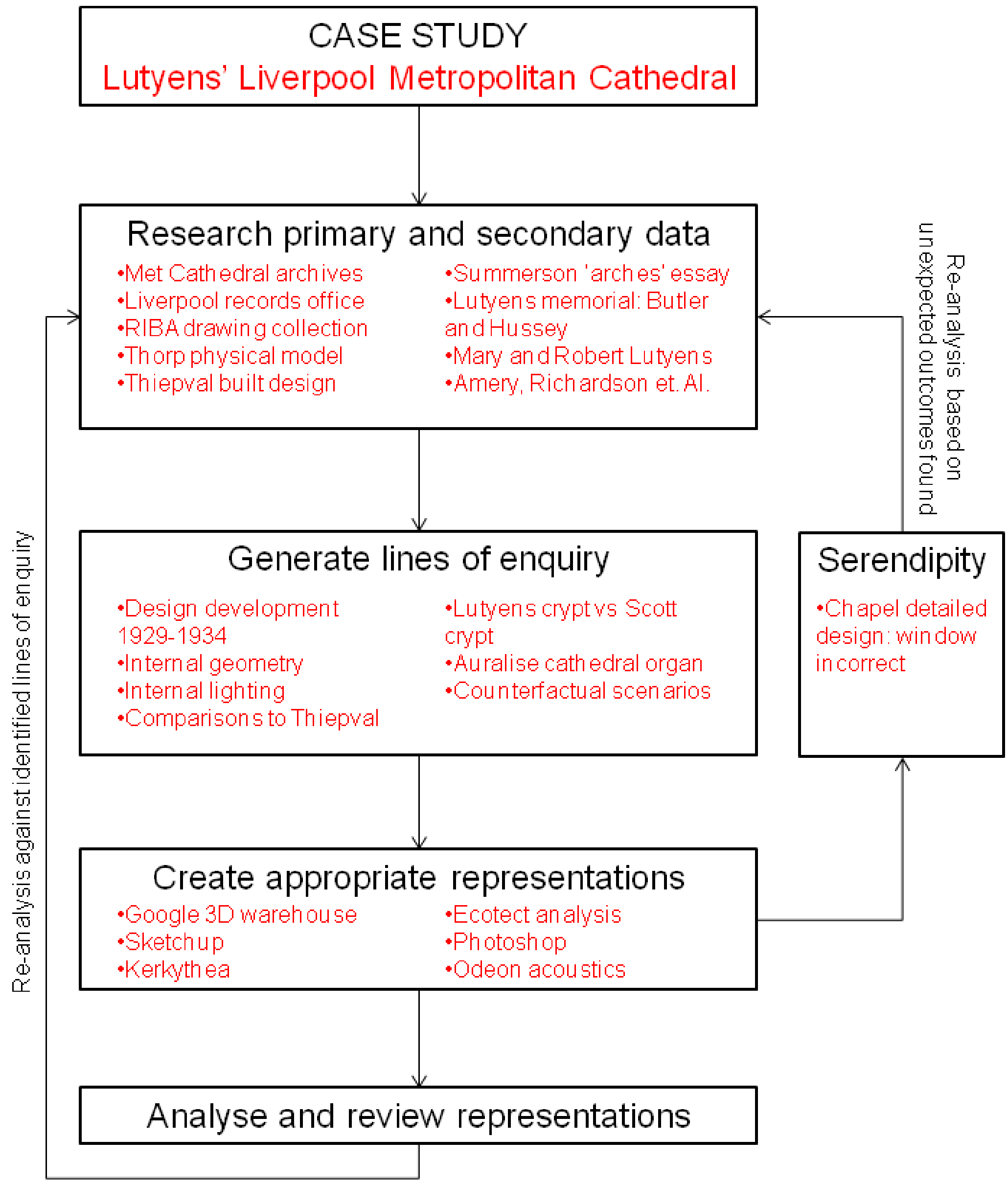


Figure 7.42: Sketch diagram demonstrating how the methodology was applied to the Lutyens case study.

8 Lessons learned and review

This chapter will provide a summary and discussion of the main findings from the three case studies as well as direct outcomes in terms of providing understanding of a piece of architecture, or architect; a further key aim of the research. A consequential detailed review of the methodology will then be explored based on the lessons learned from this case study research. The validity of the findings attained using the analytical technique will then be investigated. Following this, the validity of the representations produced will be reviewed in terms of them being based on partial information. Finally, the pedagogic opportunities that using the methodology could provide will be reflected upon.

8.1 Key case study findings

The use of a number of different architectural projects and contexts forming the three case studies enabled a range of problem types to be addressed. This section gives a summary of findings with particular emphasis on the most important ones relating to each case study. This is undertaken in order to make recommendations on which elements of the methodology are successful and where there is still scope for further improvements and refinements.

8.1.1 Stirling's Newton Aycliffe Community Centre thesis

As an initial preliminary investigation, the Stirling case study was particularly encouraging in demonstrating that the process of constructing a digital simulation of an unbuilt work of architecture can provide new information about an architect and buildings they designed. It was during this process of digital construction that the first serendipitous result was discovered; based on the archive drawings available, they indicated that the community centre design would have featured columns protruding past the façade they were supporting above, which was almost certainly an error or oversight by the architect (see section 5.2.2). This then initiated the question of whether a consistent analytical technique could be formulated to produce further analysis using additional case studies.

Upon revisiting the Stirling case study once the methodology of using a consistent analytical technique had been fully devised, the process of following lines of enquiry to enhance understanding of aspects of the community centre design was particularly successful. For example, the extent of how the golden section was utilised in the design could quickly be investigated using digital techniques (see section 5.6.1). Additionally, the case study demonstrated that the process of researching primary and secondary information in order to generate and answer lines of enquiry can also lead to enhanced understanding of how an architect designs. This can be seen in the exploration of colour and materiality in the community centre design; in which the research process suggests that Stirling may have used the colours shown in his diagrammatic plans to inform the materiality of their built equivalent (see section 5.6.2). For example, yellow is used on the zoning plans to indicate communal and circulation areas; of which the same colour can often be seen in the materiality of his built works.

8.1.2 Perret's Musée Moderne and Musée Bourdelle

In terms of developing and expanding the research carried out for the Stirling case study, the investigation into two of Perret's unbuilt museum projects was particularly useful. This was firstly because the Musée Moderne narrative enabled the exploration of an unbuilt project based primarily on textual rather than graphic information. Therefore it offered an opportunity to explore how a different type of source data could influence the findings. Consequently, it resulted in a far greater spatial understanding of Perret's narrative, as the viewer is offered a visual reference of the text he used to describe his ideal museum. However, the Musée Moderne study proved to be less successful in terms of generating lines of enquiry beyond basic spatial analysis. This may have been due to the smaller amount of secondary information available compared to the other two case studies.

The second of Perret's unbuilt museum projects studied was the Musée Bourdelle; which was primarily successful in obtaining results generated serendipitously. An example of this can be seen in the enhanced understanding of Perret's use of customised concrete blocks, which was realised accidentally during the process of constructing the Musée Bourdelle digital representation (see section 6.3.5). The construction process was also valuable at highlighting issues arising from conflicting source data; the main problem here being how to represent a design digitally when the source data suggests several different scenarios of what the design would have looked like. The solution to this problem with the Musée Bourdelle digital model was to represent each different scenario based on the source data available, in order to demonstrate to the viewer that there was more than one likely design (see section 6.3.6). This addressed the issue of avoiding ambiguity as discussed in section 3.5.

8.1.3 Lutyens' Liverpool Metropolitan Cathedral

The research into Lutyens' unbuilt design of the Liverpool Metropolitan Cathedral was significant in developing the use of lines of enquiry to obtain results. This is demonstrated in section 7.5, in which several lines of enquiry were successfully investigated. This included enhanced understanding of what the crypt would have looked like had it been completed to Lutyens' design, especially in terms of visual appearance and lighting. Lines of enquiry followed also offered enhanced critique of the geometric relationship between the cathedral design and the Thiepval Memorial to the Missing of the Somme; a monument that Lutyens conceived at the same time as the cathedral. The large amount of secondary information relating to the design was particularly useful at developing lines of enquiry for the research.

In addition to the above lines of enquiry, the Lutyens case study was valuable at exploring the use of counterfactual scenarios, in which the cathedral design was digitally juxtaposed alongside the modern cityscape of Liverpool (see section 7.5.7). This scenario enabled an exploration of how the design may have impacted the city had it been completed beyond the crypt. The Lutyens case study did not produce many serendipitous results; the reason for this being there was a near complete set of source data, which resulted in less contentious issues during the process of constructing the digital representation of the design. However, the one serendipitous result found was useful at demonstrating how traditional two-dimensional architectural drawings can be deceptive (see section 7.6).

8.2 Influence of the case study research on the methodology

The key findings of the case study research enables a discussion and review of the different stages of the methodology proposed in section 1.3.1, of which the flow diagram has been re-presented here (see Figure 8.1). This section will address the stages of the methodology in terms of which elements are successful and which could still be revised.

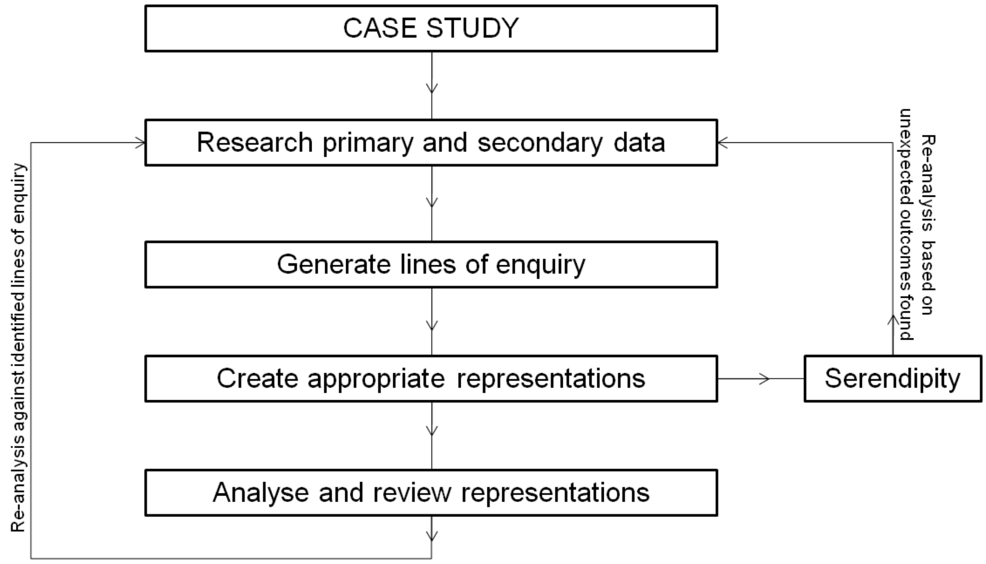


Figure 8.1: Flow diagram demonstrating the research methodology proposed based on initial investigation into the subject. Re-presented from Figure 1.1.

8.2.1 Researching primary and secondary data

Researching all of the information available for a specific design and the architects that designed them was divided into the two areas of primary and secondary data. Gathering primary information almost always began with archival research to access artefacts such as architectural drawings, sketches, models, correspondence and photographs. The amount of primary documentation available influenced the process of constructing the digital representations; those with less data available required more attention in terms of avoiding ambiguity and uncertainty. On the other hand, those with more primary data available were less ambiguous as a near complete representation could be created before inferences were required.

Researching secondary source data, such as journal articles and books, also influenced the results. This is because as a general rule, the more significant the design scheme, the more likely it would be that information was available for it. This consequently resulted in the potential to create more lines of enquiry than those with less secondary information available; an example being the lack of lines of enquiry generated from the Perret case study compared to the Lutyens case study. This was due to there being less secondary information on Perret, particularly written in English, whereas a wealth of information was available on Lutyens and his unbuilt cathedral design for Liverpool.

8.2.2 Creating the digital representations

As mentioned in the previous section, the amount of source data available influenced the ability to create a representation as objectively as possible. When the amount of unknowns in a design increased based on missing source data, the amount of subjectivity and ambiguity also increased. Therefore it is critical to make clear how inferences have been made in order to construct a complete digital representation of a design. This process of filling in unknown elements is carried out at two stages of the methodology; it is firstly addressed once all known source data has been collected, then missing elements can be identified. Secondly, further missing elements are frequently found during the digital model construction process itself; in which serendipitous results are often found as a result of this.

8.2.3 Results from lines of enquiry versus results found serendipitously

Lines of enquiry were a distinctly different way of providing enhanced critique for a design in comparison to results found serendipitously. This is because serendipitous results were found accidentally as a result of the digital representation construction process, whereas results based on lines of enquiry were found using the digital representation as a starting point for analysis.

The main difference in terms of approach is that investigating a design and relying solely on serendipity for results can be unreliable. This is because the amount of results gained this way compared to the amount of time and effort put into researching source data and constructing the digital representations is unpredictable. For example, in the Lutyens case study several months were spent researching and constructing the digital representation of the cathedral, in which only one significant serendipitous result was found. Therefore generating lines of enquiry is an essential part of the research strategy and methodology to ensure that results will be found from the process, regardless of serendipity. Without this, the only line of enquiry that can be followed in detail is the spatial analysis of a design, which can be investigated simply by constructing a three-dimensional digital representation. Besides, the research shows how generating lines of enquiry can lead to new information being found.

8.2.4 Analysing and reviewing the digital representations

The analysis and review of the digital representations created was heavily linked to the lines of enquiry generated. This can be seen in the case study research where analysis and review were both included in the lines of enquiry discussion itself. In scenarios where the case study was more reliant on results found accidentally as part of the digital representation construction process, the analysis and review of the design was discussed in the sections relating to serendipity.

8.3 Revising the methodology based on the case study research

The discussion in section 8.1 and 8.2 outlines the main issues based on the case study research. Consequently, recommendations can be made of how to improve the methodology shown in Figure 8.1. Looking at the case studies as a whole in relation to the methodology, the first proposed change was to switch ‘create appropriate representations’ with ‘generate lines of enquiry’. This is because, as the discussion in the previous sections shows, creating the representations generally occurred before lines of enquiry were investigated and discussed. In addition to this, as serendipitous results are explicitly linked with the process of creating a digital representation, these were also found before lines of enquiry were investigated.

However, swapping the order is not appropriate as it suggests that lines of enquiry become an afterthought, rather than central to the methodological process. The discussion shows that lines of enquiry are vital to the methodology, as serendipity leaves results to chance. Therefore posing specific questions about an unbuilt, damaged or destroyed work of architecture is essential, as such lines of enquiry are much more reliable at gathering results than those generated through serendipity.

Acknowledging these two key factors found from testing the methodology, the process has been refined by adding an extra section ‘investigate lines of enquiry’. The revised methodology is shown in Figure 8.2. This takes into account the issue of serendipitous results usually being produced before those formed from specific lines of enquiry, whilst also acknowledging that lines of enquiry need to be generated before digital representations are created. Essentially, the phase of the methodology looking at lines of enquiry has been split into two sections of ‘generating’ and ‘investigating’. This enables lines of enquiry to be generated based on research carried out into primary and secondary source data, and then once the appropriate digital representation has been created, lines of enquiry can be investigated based on this. This revision updates the methodology further, enabling an improved analytical technique to investigate significant unbuilt, damaged or destroyed works of architecture using current digital representation tools.

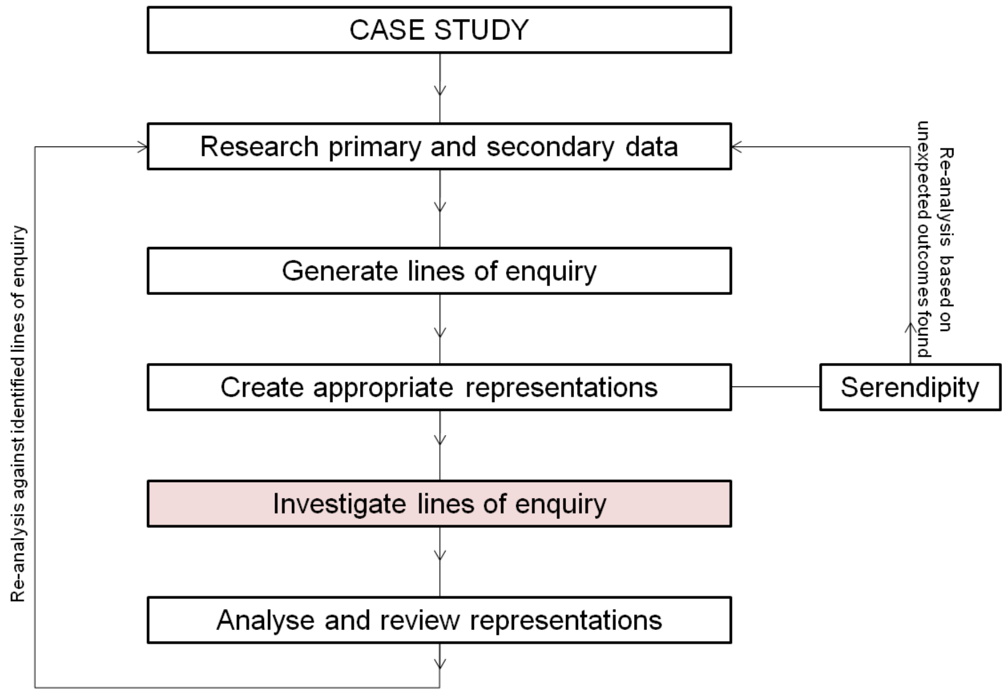


Figure 8.2: Flow diagram demonstrating the revised research methodology addressing the case study discussion. An additional section 'investigate lines of enquiry' has been included and is highlighted in red.

8.4 Validity of findings

A question was raised during the research process that suggested some of the results found using digital techniques could have been acquired without them. The main aim of the research is to provide enhanced and augmented critique of unbuilt, damaged and destroyed architecture using digital techniques; the keywords here being 'enhanced' and 'augmented'. In this sense, the research aims to add to research and critique already carried out by others. An analogy of using representation techniques to enhance understanding of a particular subject can be seen in Muybridge's investigation of horses galloping, which was discussed in detail in section 4.1.7. Strictly speaking, it would have been possible to demonstrate that horses raise all four hooves off the ground when galloping without the use of photography; however, the use of such techniques provided irrefutable evidence that this was the case. Kalay (2004, p.75) re-iterates this statement by suggesting that computers 'can reveal details and nuances that formerly only a very talented artist could draw.'

With this in mind, the role of the research presented here becomes apparent. When a comment or statement is made about an unbuilt, damaged or destroyed work of architecture, the techniques and methodological process presented here provide enhanced evidence to support the extent of whether or not such statements are still reliable. It is important to note that digital techniques would not have been available for the architects or designers to use at the time. For example, in the Lutyens case study, architectural historians suggest there is a close relationship between the cathedral design and the Thiepval Memorial to the Missing of the Somme; the extent of that relationship was clearly demonstrated in the research discussed in section 7.5.4 using digital analytical techniques. Again, this shows that the role of the research is to *augment* and *enhance* understanding of damaged, destroyed or and unbuilt works of architecture.

8.5 Validity of representations

As previously discussed, the validity of the digital representations created is a significant issue addressed in the research; both in terms of using digital techniques that are valid and creating representations that are truthful in terms of how they have been produced. Mitchell (1998) stated that investigations posing counterfactual scenarios of unbuilt architecture can be ‘slippery’; this is due to the nature of such studies, as the source data available to construct digital representations of damaged, destroyed or unbuilt works of architecture is almost always incomplete. Therefore care must be taken so that ambiguity and uncertainty are avoided (Kensek 2005). The research has shown that with more source data available and more common parts of a design, the less contentious issues there will be.

Ensuring validity has been addressed in several ways in the representations discussed here; firstly, more than one version of a design scheme is presented in order to acknowledge that there may be several potentially definitive versions. This is especially applicable to the exploration of damaged, destroyed or unbuilt works of architecture, as the source data often indicates more than one likely scenario of what a design would have looked like. An example of this can be seen in the investigation of Perret’s museum projects in chapter six; where the primary archive drawings indicated two different options for a column and wall design, therefore both versions were represented (see section 6.3.6).

Ambiguity is also avoided by creating a series of digital representations of design in chronological order. This is critical not only to ensure the validity of the digital representations created, but also to demonstrate that source data depicting a design may be misleading. This can be seen in the Lutyens case study where the most widely used image of the cathedral in publications is a rendering of the original 1929 design (see Figure 7.1), whereas the dome of the finished design changed considerably (see Figure 7.9). Therefore, digital representations are created at several key stages of the design's development in order to ensure the viewer understands there are many iterations of the unbuilt cathedral (see Figure 7.16).

In certain cases, such as exhibiting a digital model of a design to the public, it may be appropriate to show that the representations are based on incomplete source data. This can be achieved in several ways, which is discussed in section 3.5. For example, colour coding can be shown on supporting images that demonstrates the levels of inferences required to construct the digital representation. This technique was utilised in the Lutyens case study, where greater confidence in the source data was represented using shades of green, and less confidence was represented using shades of red (see Figure 7.15).

8.6 Contextual studies

Besides the methodological process developed for the research, another major finding is recognising the importance associated with the process that has to be undertaken in order to construct a convincing digital representation of a lost, damaged or destroyed work of architecture. The case studies demonstrate how the source data of such schemes is almost always fragmentary; therefore contextual study is required to fill in missing elements. As previously discussed, this ranges from investigation into the architect's other designs and their design philosophy, the contemporary context they worked in, their educational background as well as potential precedents studied.

This is an important facet of the study as it enables the researcher to look afresh at all of the source data available in order to produce a satisfactory representation, and therefore has the potential to find new information about an architect and buildings they designed. An analogy of this can be seen in police crime forensics, in which cases are re-investigated using the latest technologies. The benefits of this contextual approach can be seen in the Stirling case study, where suggestions could be made on the architect's use of materiality and colour in his later schemes (see section 5.6.2), and in the Perret study where his use of customised concrete panels was questioned (see section 6.3.5).

8.7 Opportunity in education

The contextual studies discussed in the previous section provide an opportunity as a potential educational tool looking at the process required to construct a digital representation. This builds on the work of others, notably Novitski (1998), Harfmann and Akins (2000) and Brown (2001). The opportunity here would be to give students of architecture a set of incomplete source data of an unbuilt, damaged or destroyed architectural artefact and then present them the task of constructing a digital representation of it.

The benefits would be twofold; the first being the issue of filling in missing source data in order to produce a satisfactory digital representation. It is during this investigative process that the student has to research the architectural practice of the work of architecture in question, their other projects, the contemporary context they worked in as well as relevant construction techniques. As a consequence, not only has the student produced a digital representation of a significant work of architecture, but they have also gained enhanced knowledge and understanding about an architect and their design ideas and influences. The potentials of this process in an educational context is discussed by Brown (2001) in his study of the partially built Lords Court scheme by Connell, Ward and Lucus, which was reviewed in section 3.4; here the student is encouraged to produce a fake journal article describing the digitally produced design and the context surrounding it. The second benefit of the technique in an educational context builds on the research of Harfmann and Akins (2000), which investigates how three-dimensional digital representations can be used to enhance construction lecture material in architecture (see section 3.2). Similarly, creating a three-dimensional digital representation of a significant unbuilt, damaged or destroyed work of architecture requires the maker to consider the design in all three dimensions, rather than two, which can be seen in the study of traditional plans, sections and elevations. For example, a column no longer becomes a hatched square in plan; it becomes a three-dimensional object that intersects with beams, cladding and floors. This process of creating a digital representation provides the student with a much more rigorous and detailed study of a work of architecture than simply looking at traditional two-dimensional media.

Linking back to the first benefit, this process can provide unexpected serendipitous findings, as seen in the case studies presented here, which then require a study of the architect in order to resolve contentious issues effectively.

8.8 Chapter summary

The chapter begins by offering key findings from each case study investigated; highlighting the areas which were particularly successful and those which could still be refined. This information was then used as a starting point forming a discussion of the methodological process, with focus on the strengths and weaknesses it provides. Recommendations were then made to show how the systematic analysis technique could be further refined if more case studies were investigated in the future.

The validity of the findings was then discussed in order to acknowledge potential critique of the process. Following this, the validity of the representations was investigated to demonstrate how issues such as ambiguity and uncertainty were avoided. The use of digital techniques over traditional techniques as a method of critique is also considered to recognise that other techniques may have been used in some cases; however, the use of digital tools in the research presented here aims to enhance and augment the research already undertaken by others. Finally, the opportunities of using such digital analysis techniques are recognised in an educational context for the benefits they could bring in teaching students about the history of architecture.

9 Conclusion

The research presented here investigates how a consistent analytical technique incorporating current digital representation tools can be used to enhance and augment our understanding of unbuilt, damaged and destroyed works of architecture. Defining and refining the methodological process to achieve this is central to the research. This chapter firstly gives a summary of the research in response to the aims and objectives set out in the introductory chapter. Following this, the limitations and scope of the process is discussed to recognise where there is potential for further research. The contribution to knowledge made is then demonstrated, with particular emphasis on the analytical technique formulated and the benefits this brings to architectural historical and digital research. Finally, recommendations for future work are suggested based on the above discussions.

9.1 Response to aims and objectives

The main aim and objectives of the research which were set out in section 1.2 will be discussed in terms of how they have been addressed in the thesis. The main research question, or aim, was divided into several objectives which formed the basis of the chapter headings for the research process (see section 1.2.1 and Figure 1.1).

9.1.1 Response to objective one

The first objective was to investigate the relationship between significant built and unbuilt works of architecture in the context of what can be learned about a particular architect and buildings they designed by looking at such architectural artefacts. This was explored in the second chapter, which separated the two areas of built and unbuilt architecture into several headings in order to demonstrate their complexity (see Figure 2.1). The objective dealt with the fact that built designs can be questioned in terms of whether or not they represent reality in comparison to unbuilt designs that do not physically exist.

Examples such as Le Corbusier's Villa Savoye in France were chosen to demonstrate this; a building which has a complex history involving several different uses and has undergone major restoration work. However, the complicated history regarding the deterioration of the design before restoration occurred is little discussed; rather its current restored version is accepted by many as being the same as the original building. Other significant works of architecture are also used to explain this, such as the Frauenkirche in Germany, which was almost completely destroyed and consequently rebuilt. However, it is still seen in much the same light as its destroyed counterpart, although not to the same extent as the way in which Le Corbusier's Villa Savoye is viewed.

The research objective is further explored by discussing destroyed architectural artefacts, particularly when all traces of a building are completely lost. In these cases, there is no primary source data available relating to a work of architecture; therefore knowledge and understanding are based on secondary information passed down from generation to generation. An example used to demonstrate this is the statue of Colossus at Rhodes; which is documented as being built, but was subsequently lost without a trace. This leaves the question of whether or not the statue ever actually physically existed, highlighting the fragile reality of many significant works of architecture.

The complexity of the relationship between built and unbuilt architecture is also revealed when discussing proposed and unfinished buildings. In these cases, which could be considered somewhere in-between the built and unbuilt categories, the designs in question may be 'left on the drawing board' for many years. Another fate would be that the construction period of the building in question could be longer than the lives of the architects that originally designed them. Eventually, these designs are either physically competed or construction is abandoned. The Sagrada Familia church in Spain is an example of when the construction process takes longer than the life of the architect that designed the building; which was discussed in the second chapter to highlight issues such as dealing with incomplete source data to finish a design, as well as critical reactions to continuators completing an architect's design.

Once the broad area of built architecture had been discussed, an examination of unbuilt architecture could commence. This was split into two sections; designs that were intended to be built, but for particular reasons they were not, and designs that were not ever intended to be built. These are crucial to the research presented here, as the case studies forming the later chapters of the thesis were all unbuilt works of architecture to an extent. Such unbuilt architecture is purposely discussed in relation to built architecture as it demonstrates that many significant architectural designs were not built at all, or ever intended to be. This can be seen in designs such as

Peter Cook's Solar City; a scheme purely intended to advance ideas relating to the use of technology in buildings. Such examples are critical for the research in this thesis, as they show that significant works of architecture do not have to physically exist, or have ever physically existed.

The relationship between reality and virtual reality is then discussed in order to demonstrate that physically rebuilding damaged or destroyed architecture, as well as constructing previously unbuilt schemes, is often artificial and selective (Jarzombek 2004, Bevan 2006). Additionally, the role of modern media and its use to explore and study works of architecture using virtual environments is discussed. These points further blur notions of reality in the built environment; which consequently gives enhanced justification to research unbuilt, damaged or destroyed designs especially in the context of utilising digital techniques.

9.1.2 Response to objective two

Once the role of reality in the built environment had been explored to meet the first objective, the second objective could be researched. The task here, which formed the third chapter, was to review previous work investigating the use of digital techniques to enhance understanding of an architect and works of architecture. A flow diagram was formulated to categorise a work of architecture's status in relation to the type of digital representation required for analysis, followed by the type of enquiry and critique used (see Figure 3.1). This categorisation enabled the status of the design, whether existing, proposed, damaged/destroyed or unbuilt, to be clearly addressed under different headings.

The use of digital techniques to enhance understanding of existing buildings was investigated first, in order to show how such methods could potentially be applied to unbuilt, damaged or destroyed works of architecture in the research for this thesis. Similarly, the use of digital techniques as a tool to enhance understanding of proposed buildings was also investigated. Digital design and visualisation tools for proposed buildings are widespread in the architectural profession; therefore the techniques used were investigated in detail to meet the third research objective.

The most important task to meet the second objective was to examine how comparable precedents and parallels in other research had been carried out relating to unbuilt, damaged and destroyed works of architecture. The aim of the second objective was to explore how other researchers have utilised digital techniques; which revealed that in the early development of such practices, focus was placed on enhanced spatial understanding of the designs researched (Mitchell 1992a, Forte and Siliotti 1997, Novitski 1998). This can be seen in archaeological studies, where digital visualisation tools became rapidly widespread to illustrate what a damaged or destroyed building or buildings would have looked like. However, in recent years the use of techniques has advanced and become increasingly critical and analytical, examples of which can be seen in the research of Bharat (2005) and Mark (2011).

Simulations of unbuilt works of architecture, or counterfactual scenarios, were also explored in terms of research already carried out by others. This was dealt with separately to damaged and destroyed architecture due to the potentially controversial nature of such studies. This is because historians such as Carr (1990) suggest that counterfactual historical studies are 'mere parlour games'. However, the research shows that the investigation of unbuilt architectural designs has a unique place in this argument; which is highlighted in the previous objective and illustrates that representations of architecture can be just as significant as works of architecture themselves. Therefore, the use of source data describing unbuilt architectural designs can offer a plausible scenario in terms of investigating a counterfactual argument.

The research of others using digital techniques to enhance understanding of unbuilt architecture was then explored. Similar to damaged and destroyed architecture, this began with straight forward visualisation of such designs then continued by investigating more complex analysis methods. An example of this can be seen in the studies of Palladio's unbuilt villas using rule based grammars (Sass 2001).

The final part of the objective was to deal with ambiguity and uncertainty in the digital representations created. It became apparent that this needed to be addressed based on the research carried out to meet the objective of understanding studies that had already been achieved in the field. The main issue here was to acknowledge that inferences have to be made based on incomplete source data available for unbuilt, damaged and destroyed works of architecture; therefore it is important to document that this is the case. This section reviewed different methods of addressing this, such as using different representation techniques as discussed by Knight et al. (2001) and Kensek et al. (2002).

9.1.3 Response to objective three

The third objective of the thesis was firstly to examine traditional representation techniques and the resulting critique this enabled in the arts and architecture. This consequently led into an examination of digital techniques in architecture; as the addition of such tools have had a significant impact on the profession. A comprehensive range of contemporary digital techniques in architecture were then discussed in the context of how they can be used to enhance critique of unbuilt, damaged or destroyed architecture. These research areas in objective three formed the fourth chapter of the thesis.

The reasoning for this objective was firstly to understand how technological and representational advances have led to enhanced critique and understanding of architecture and the arts throughout history. In doing so, this highlights how contemporary digital techniques can be used in a similar manner. Particular attention here is paid to devices that enhance drawing techniques, such as Dürer's draftsmen's net; which aimed to replicate an image as close to reality as possible. Another key development was Muybridge's use of the photographic image to prove a horse raises all four hooves off the floor when galloping, as well as Choisy's use of axonometric at the end of the nineteenth century to enhance discussion and critique of historic architecture.

The advances of digital techniques are then investigated, firstly by addressing the rapid development of computer hardware and software since the early 1980s and the changes this has brought to the architectural profession. This is important as it highlights how much the introduction of the computer has changed the profession in terms of visualisation, drafting and design tools and techniques.

The final stage of the objective was to offer a range of current digital representation techniques and discuss them in terms of how they could be utilised for the case study research presented here. In this sense, a toolbox of different techniques were offered, giving particular emphasis on how they could be used in the context of reconstructing damaged or destroyed buildings, or simulating unbuilt designs digitally.

9.1.4 Response to objective four

Having studied a range of digital tools as part of the criteria to meet the third objective, the fourth objective was to develop a consistent analytical technique incorporating current digital representation tools that can be used to systematically study significant works of architecture. The three case studies formed the fifth, sixth and seventh chapters of the thesis and offered different perspectives of how to test the methodological process proposed in Figure 1.1. For example, the Stirling case study was an exploratory investigation that enabled principles and techniques to be established, whereas the Perret case study built on this by establishing significant serendipitous results. Additionally, the Lutyens case study was successful in demonstrating how results could be found primarily using lines of enquiry, with supporting results found through serendipity. The analysis and review of these case studies formed the final objective.

As well enabling the methodological process to be tested and explored, the case studies also showed how enhanced understanding of unbuilt works of architecture can be achieved using digital techniques. This gives two-fold benefits to the research; firstly the methodological process of utilising digital techniques is improved and secondly enhanced understanding of significant works of architecture is achieved. It is here that specific new knowledge can be found about an architect and buildings that they designed.

9.1.5 Response to objective five

The final objective was to analyse and review the case study research carried out, following which key conclusions were given in terms of refining the methodology for further research. This was primarily achieved in chapter eight, where the methodological process was dissected first in terms of how it related to each case study. Following this, each stage of the methodology was discussed and critiqued, which led to recommendations of how to develop it further. This can be seen in Figure 8.2, where the ‘lines of enquiry’ section of the diagram was split into two categories of ‘generate lines of enquiry’ and ‘investigate lines of enquiry’.

The validity of the results found and representations created was then discussed in order to acknowledge where improvements could be made, and to address critique of the methodological process. Further responses to the fifth objective will be made here in the concluding chapter.

9.2 Limitations

There are some limitations which need to be acknowledged in order to understand the scope of the investigations presented here, which in turn can be used to demonstrate how the research could be refined and expanded. Firstly, the majority of the case studies utilised are unbuilt works of architecture, with the exception of Lutyens' Liverpool Metropolitan Cathedral design which could also be classed as partially built. The research aims to address damaged and destroyed architecture as well as unbuilt architecture; and although the process is much the same regardless of the design's status, additional case studies that represent damaged and destroyed buildings could be used to test the process further. The predicted main difference here would be that primary source data could also include archaeological remains, possible photographs of the artefact in its built condition, as well as potential eye-witness accounts of what it was like. Although it is unlikely that these additional types of source data would affect the research methodology, it may reveal different results compared to that of unbuilt works of architecture. For example it could provide enhanced accuracy at providing material swatches using scanning techniques and the ability to match and compare images of the original building with the digital representations.

The research is also limited by the case studies in terms of focussing on significant designs by renowned architects. Less significant schemes such as housing developments, or designs by less well known architects, are examples of areas not covered in the research presented here. Again, such work could be included in future plans as it may affect the methodology used. For example, if a scheme is deemed insignificant, the amount of source data available, such as architectural drawings, may be limited. Additionally, there may be less commentary on the designs by architectural historians and academics, meaning that the ability to generate lines of enquiry could be increasingly difficult.

The case studies chosen for this research are all examples of twentieth century architecture; therefore works of architecture deemed significant from this period may differ from those deemed significant from an older period. This also highlights the fact that the older a design or building, the less likely it is that there will be a complete set of source data available. For instance it is much more probable that data will be available for a twentieth century work of architecture than, for example, one from the fifteenth century. This is because source data, particularly paper based, is increasingly likely to be lost or destroyed over time.

The research was also limited in terms of the validity of the software and hardware available to follow particular lines of enquiry for the case studies. This can be seen in the Lutyens case study, which may have provided enhanced results if auralisation software had been available to investigate the acoustics of the cathedral design in detail. The issue here was the financial cost of purchasing the software compared to the benefits it could bring; which was deemed inappropriate for the scope of this study, as well as the level of specialist knowledge required to produce valid results.

9.3 Contribution to knowledge

The research makes a contribution to knowledge firstly in developing a consistent analytical technique that utilises digital techniques to systematically study unbuilt, damaged or destroyed works of architecture. This analytical technique also represents an original contribution to knowledge in the results found relating to specific works of architecture that are utilised to test the process here. This can be seen in the discussion of serendipitous results and lines of enquiry followed in each of the three case studies, where the methodological process enables enhanced critique and understanding of the unbuilt works of architecture in question.

As well as developing an analytical technique, reasoning of how the research represents a contribution to knowledge can be seen in the utilisation of a range of digital tools providing breadth in terms of the tools used, rather than a detailed study of one particular tool. This breadth of tools then enables depth in the study in terms of gaining enhanced understanding and critique of an architect and buildings they designed.

Additionally, the research is original in terms of giving partial focus on the process of constructing the digital representations as discussed in section 8.6. It is during this stage of the investigation that re-analysis of the case studies is provided through unexpected serendipitous outcomes. Giving attention to the process also highlights how it achieves enhanced understanding of an architect and their designs by the researcher, and how this could be used as a pedagogic technique.

The thesis can be considered an original contribution to two separate areas of architectural research; firstly computer aided design and research, and secondly history of architecture. As previously discussed, the research utilises a range of techniques found in computer aided design and brings them together to develop a consistent analytical method. The research makes a contribution to historic studies of architecture in terms of the knowledge gained into specific architects and buildings they designed from enquires followed using these digital techniques.

Some would argue that a number of the results may have been found without the use of digital techniques. The response to this is discussed in section 8.4. To re-iterate, the aim of the study is to augment and enhance critique of unbuilt, damaged or destroyed works of architecture. Therefore, it is possible that some of the results may have been found without digital techniques; however, their use gives enhanced evidence and understanding of what may have occurred. An analogy of this is aspects of police crime forensics, where the evidence available for a re-opened case is re-analysed using the most recent and up-to-date techniques.

9.4 Recommendations and future work

The first recommendation for future work is addressed in the previous chapter in which the methodology has been refined based on the case study research carried out. Therefore, the first task would be to test the revised methodology using further case studies. This would then make certain that the proposed changes are necessary, as well as whether additional refinements are required. Another recommendation that has already been discussed is the limitations of using only unbuilt significant works of architecture. Again, the exploration of damaged or destroyed works of architecture as well as the inclusion of less significant schemes or pre-twentieth century schemes could help to expand the scope of the research further.

The study of Perret's Musée Moderne, a narrative in which source data primarily consisted of text, could be expanded using parametric language and grammars. The opportunity here would be to investigate the design further based purely on the text; for example Perret sets out specific requirements of wall thicknesses, location of niches and other accommodation. Here his requirements could be interpreted using software such as Grasshopper for Rhinoceros, and the parameters of each statement made could then be investigated in terms of their impact on the final digital representations created. This would then enable different versions of the Musée Moderne design to be assessed.

The use of parametric language in digital modelling could also be explored using a possible case study that has already been identified. This is the Chinese Cemetery and Memorial in Noyelles-sur-Mer, France; which is also designed by Lutyens. Therefore, the future case study can be seen as an extension of the research already carried out into his architecture. At the Chinese cemetery, Lutyens combines his own design style with that of traditional Chinese architecture. Therefore the opportunity would be to investigate the extent of the influence of his design philosophy compared to that of Chinese architecture. Parametric design could also be utilised for this in terms of establishing the language of the design, as seen in other work such as Li (2000) and Sass (2001). The design is also appropriate to the work presented here, as it is already built. Therefore, it offers an extension of the methodology in terms of testing an existing design.

The use of the methodology as an educational tool, as discussed in section 8.7, is part of the research that is currently underutilised. A future aim is to test and develop the process as a pedagogic tool in order to better inform students about historic unbuilt, damaged or destroyed works of architecture.

The final recommendation is to further utilise the digital representations created for the research presented here. This will be achieved by returning to the first major use of digital modelling in relation to unbuilt, damaged and destroyed works of architecture; to enhance spatial understanding of such schemes. For this to occur, the representations need to be displayed to a wider audience, such as in museums, exhibitions and online. This would result in augmented understanding and critique of works of architecture that once physically existed, or did not ever physically exist at all.

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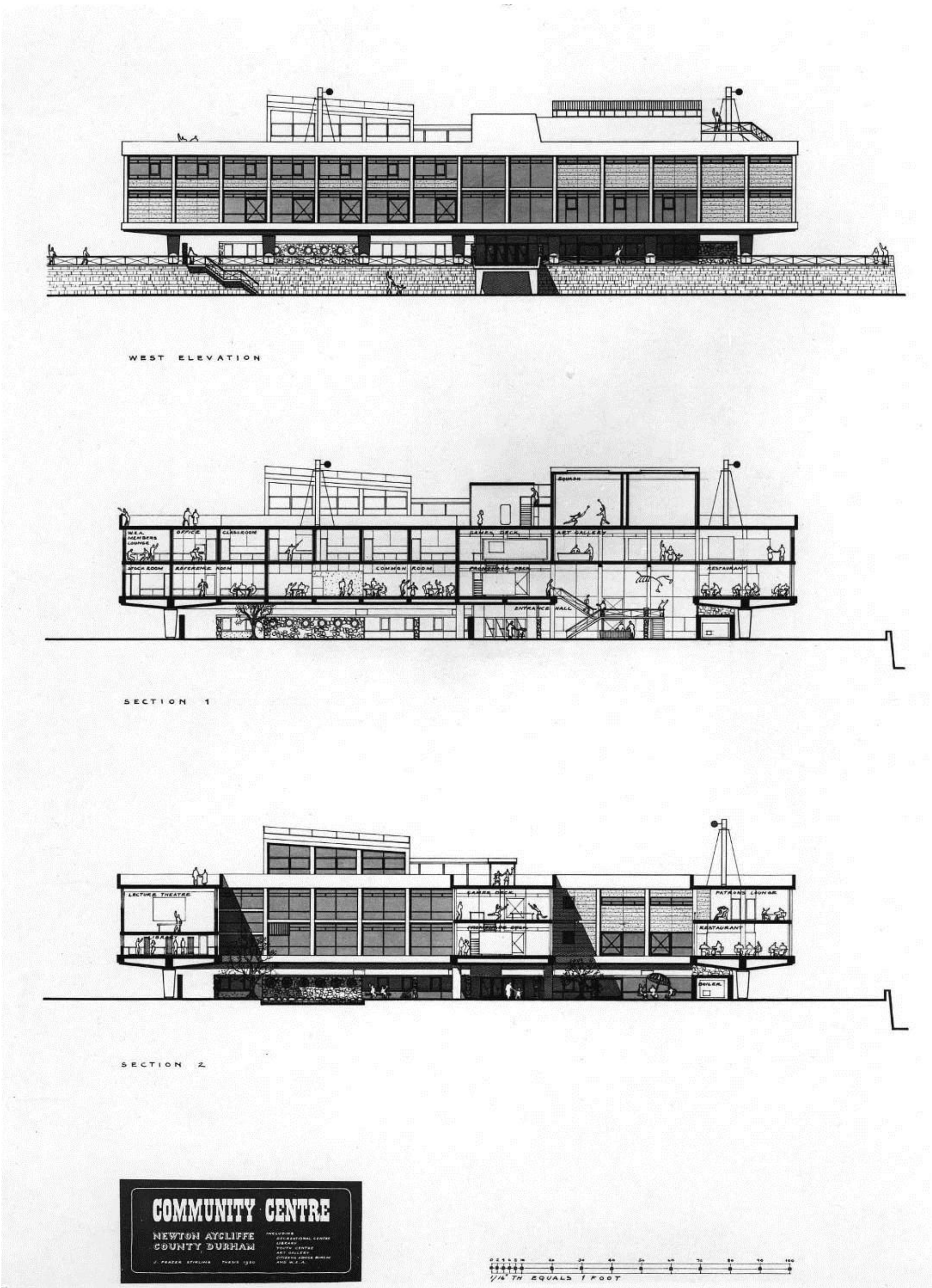
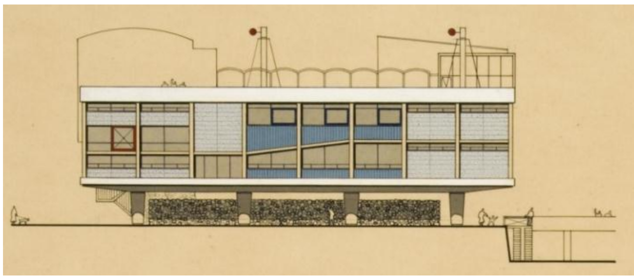
Appendix A – Additional Stirling images

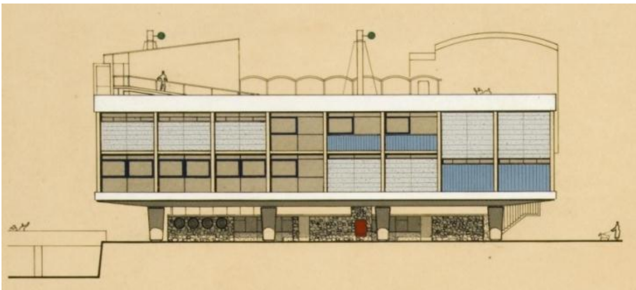


Appendix A - 1: Original west elevation and section drawings. Image credit: University of Liverpool Archives, reproduced by Dunne and Richmond (2008, p.56).

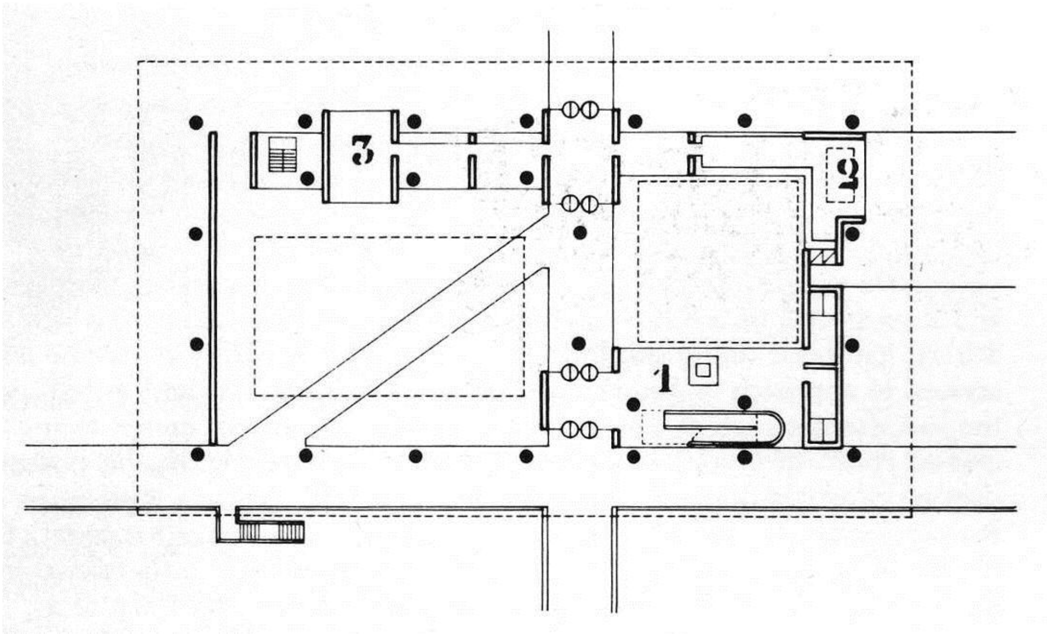
Appendix A - 2: East elevation drawing. Image credit: Canadian Centre for Architecture (2010)



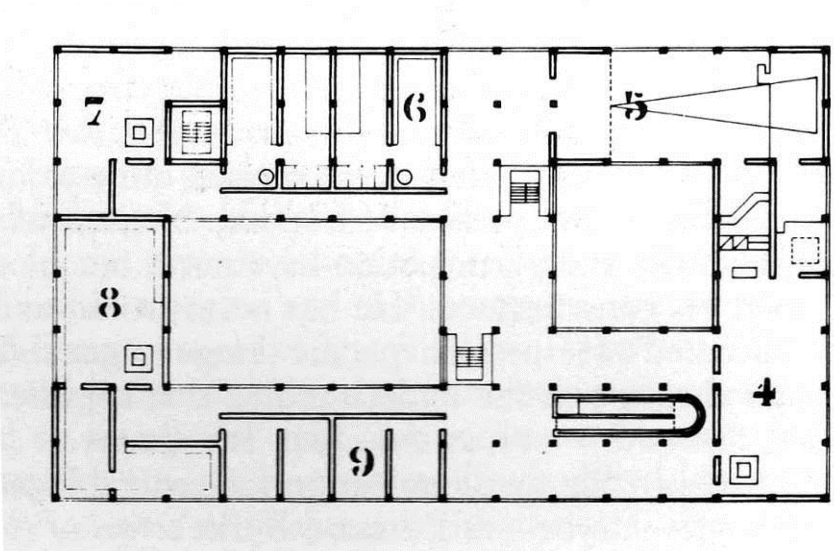
Appendix A - 3: North elevation drawing. Image credit: Canadian Centre for Architecture (2010)



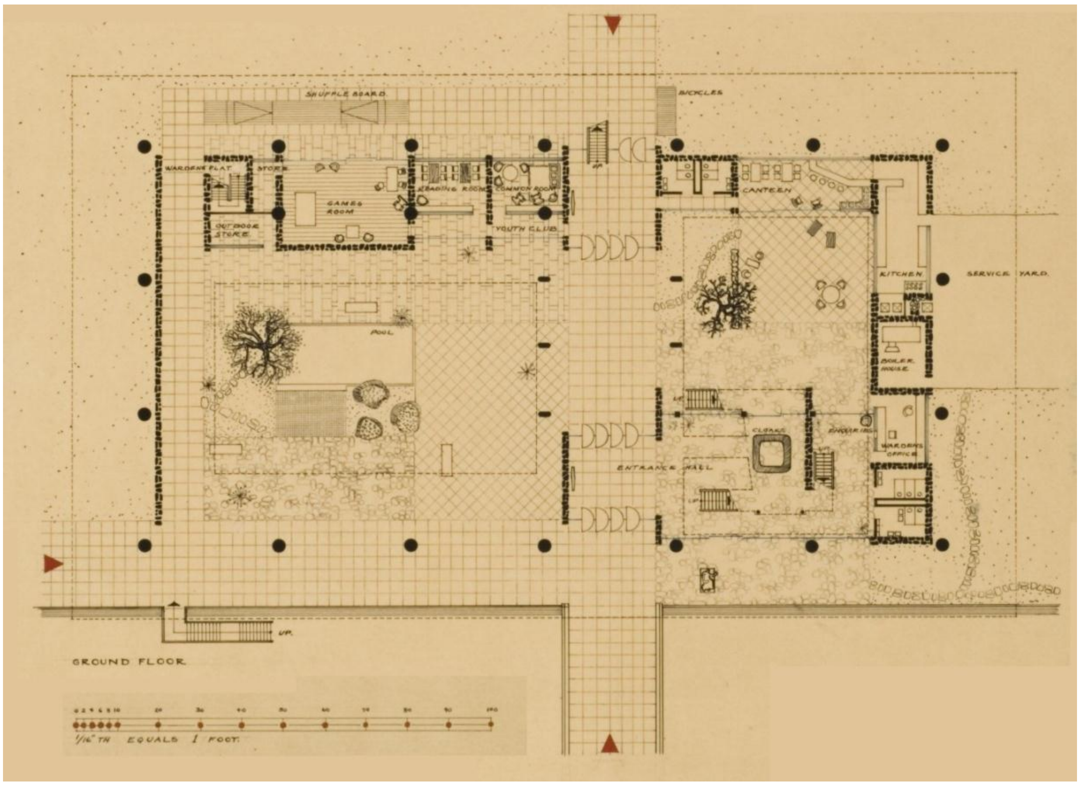
Appendix A - 4: South elevation drawing. Image credit: Canadian Centre for Architecture (2010)



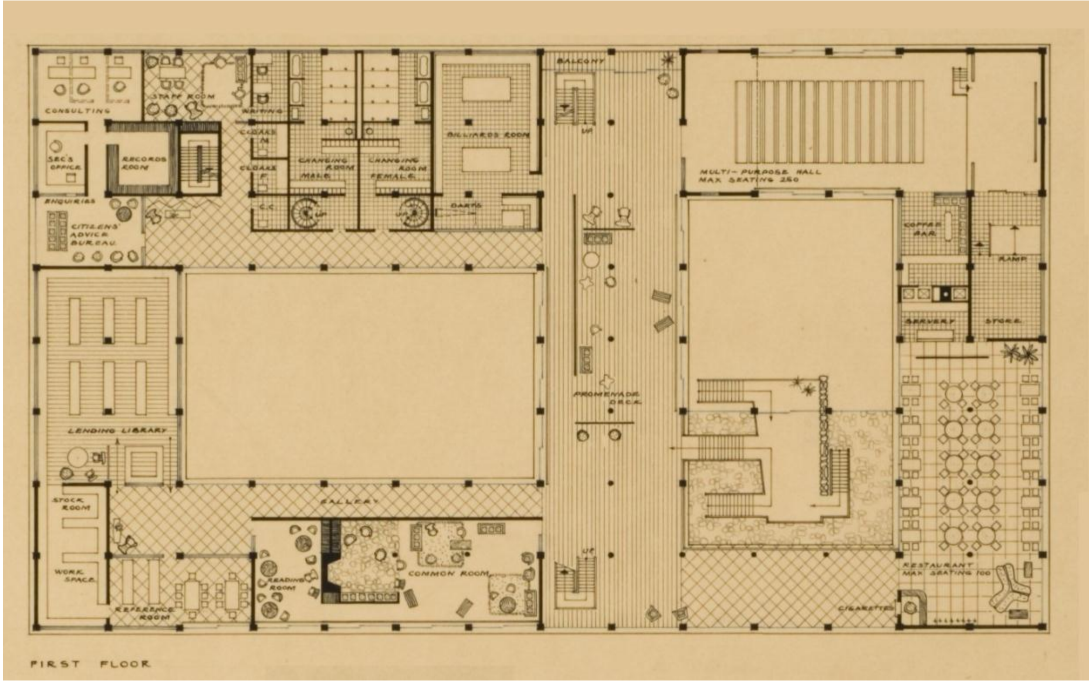
Appendix A - 5: Early ground floor plan. Note the two columns placed centrally in the courtyard. Image credit: Arnell and Bickford (1984, p.28).



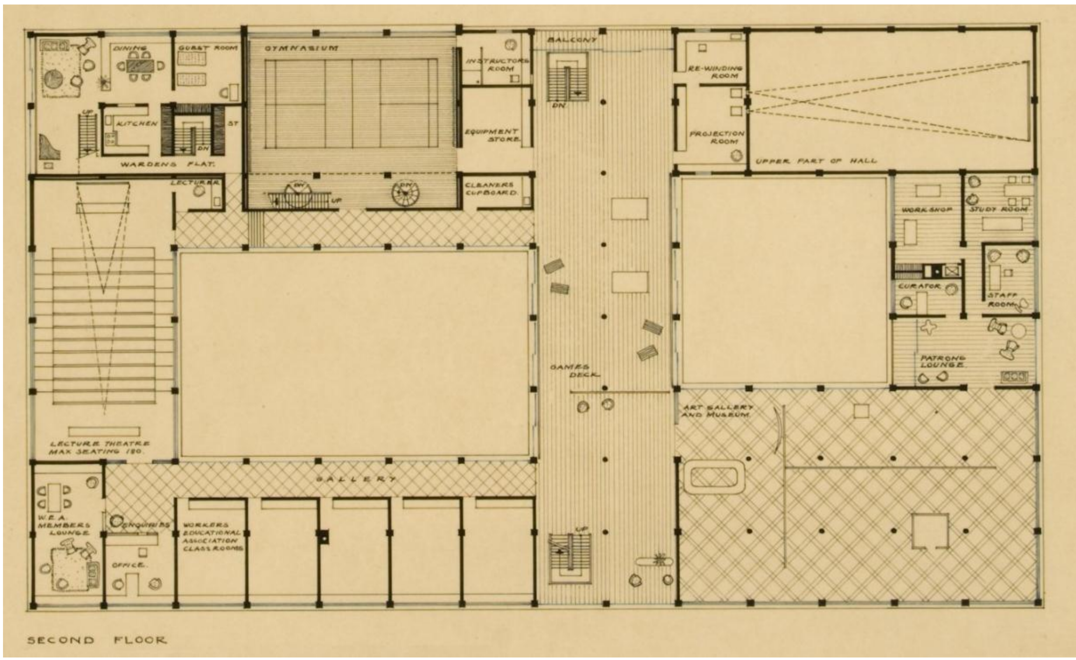
Appendix A - 6: Early first floor plan. Image credit: Arnell and Bickford (1984, p.28).



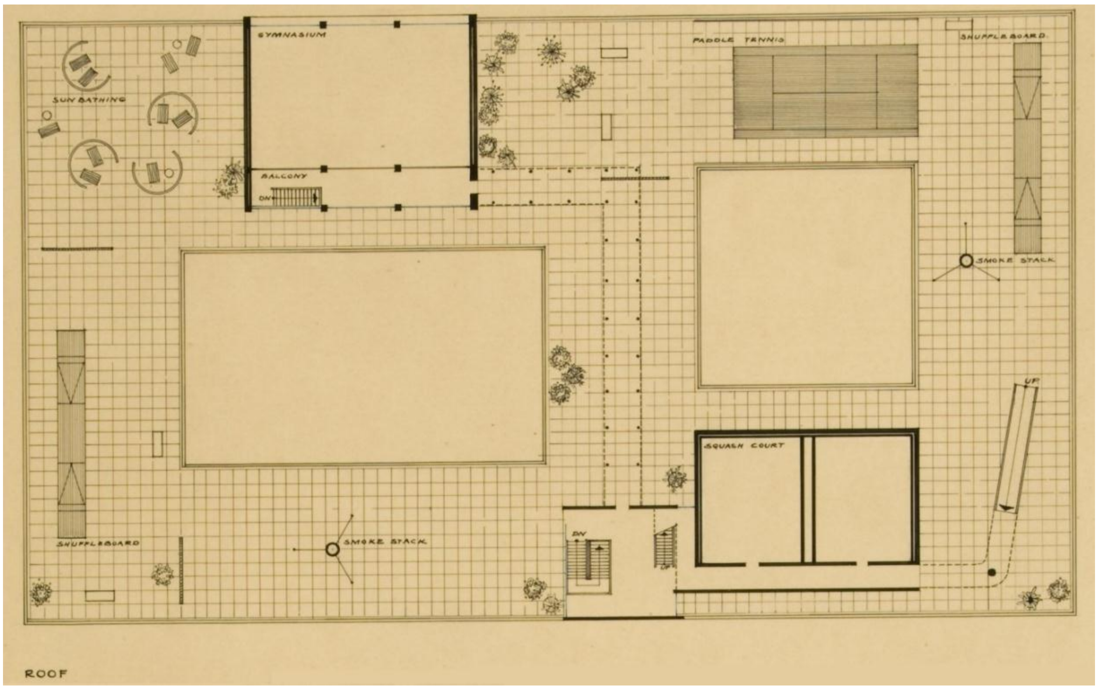
Appendix A - 7: Ground floor plan. Image credit: Canadian Centre for Architecture (2010).



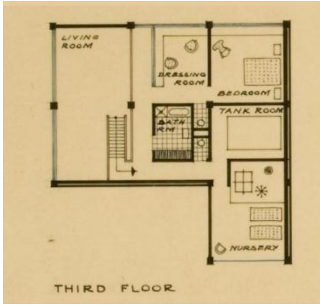
Appendix A - 8: First floor plan. Image credit: Canadian Centre for Architecture (2010).



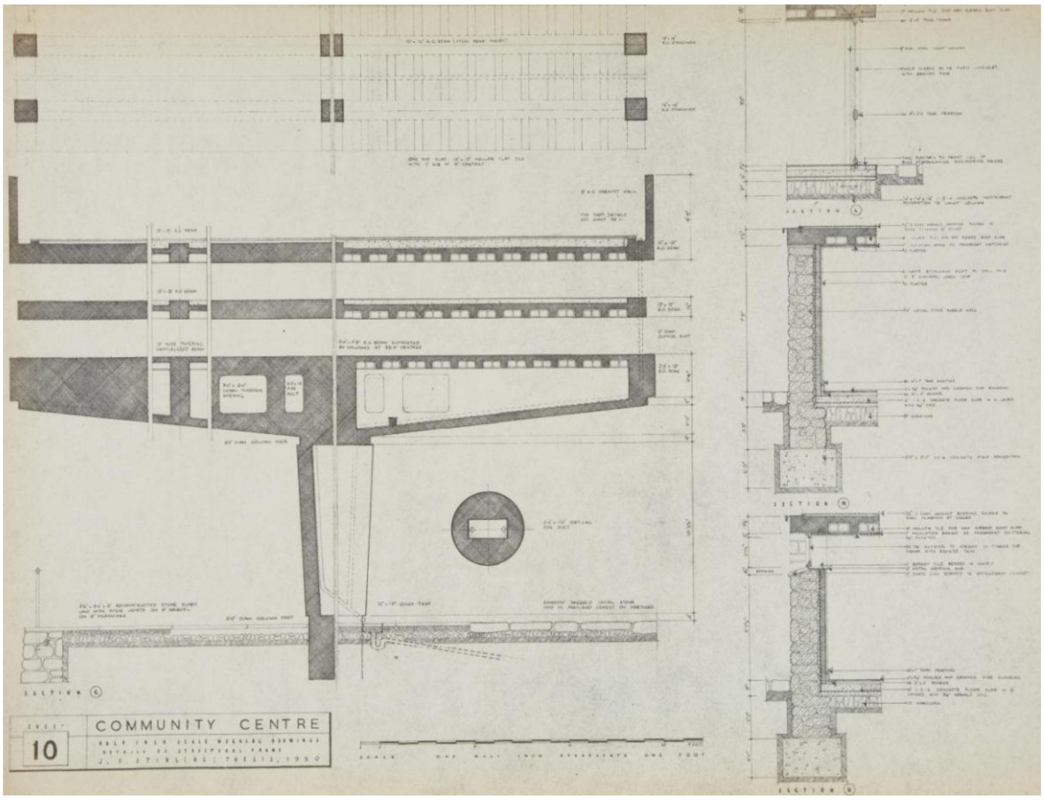
Appendix A - 9: Second floor plan. Image credit: Canadian Centre for Architecture (2010).



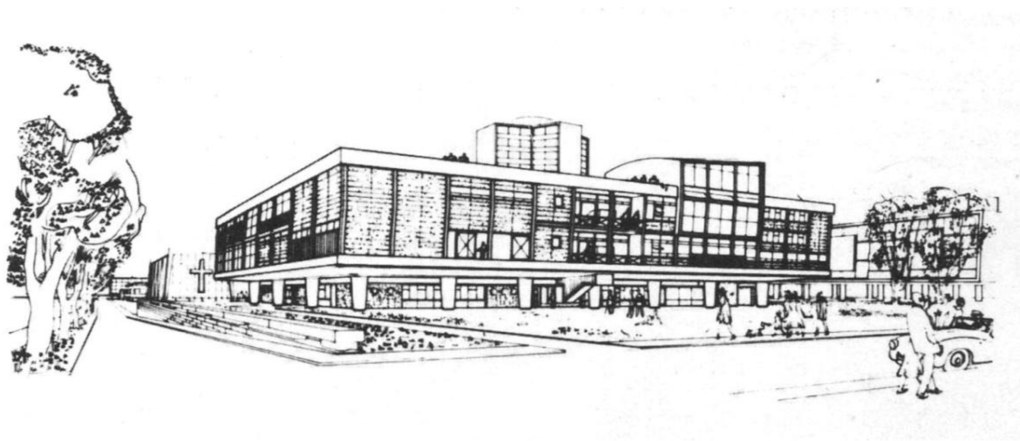
Appendix A - 10: Roof plan. Image credit: Canadian Centre for Architecture (2010).



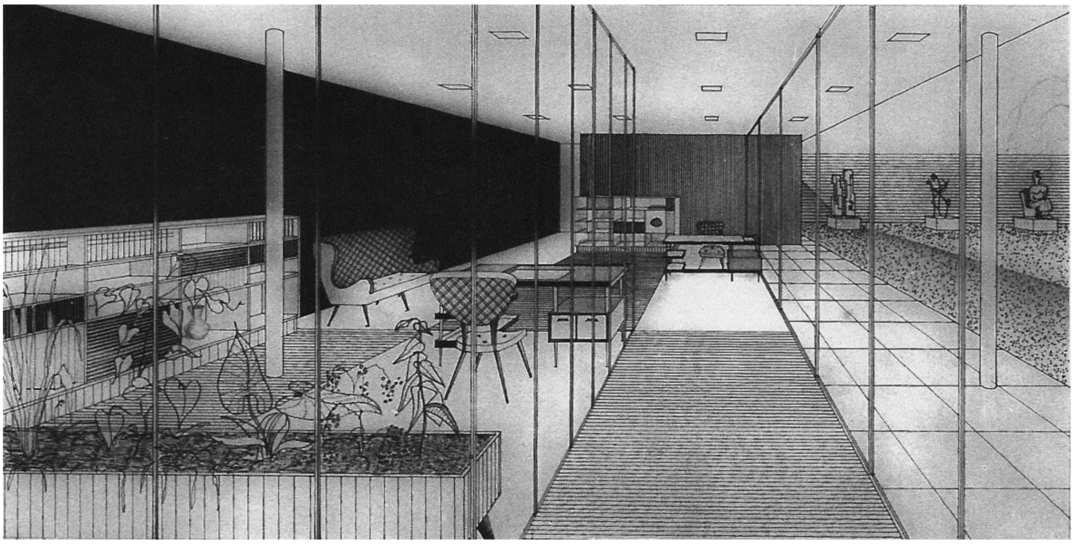
Appendix A - 11: Third floor plan. Image credit: Canadian Centre for Architecture (2010).



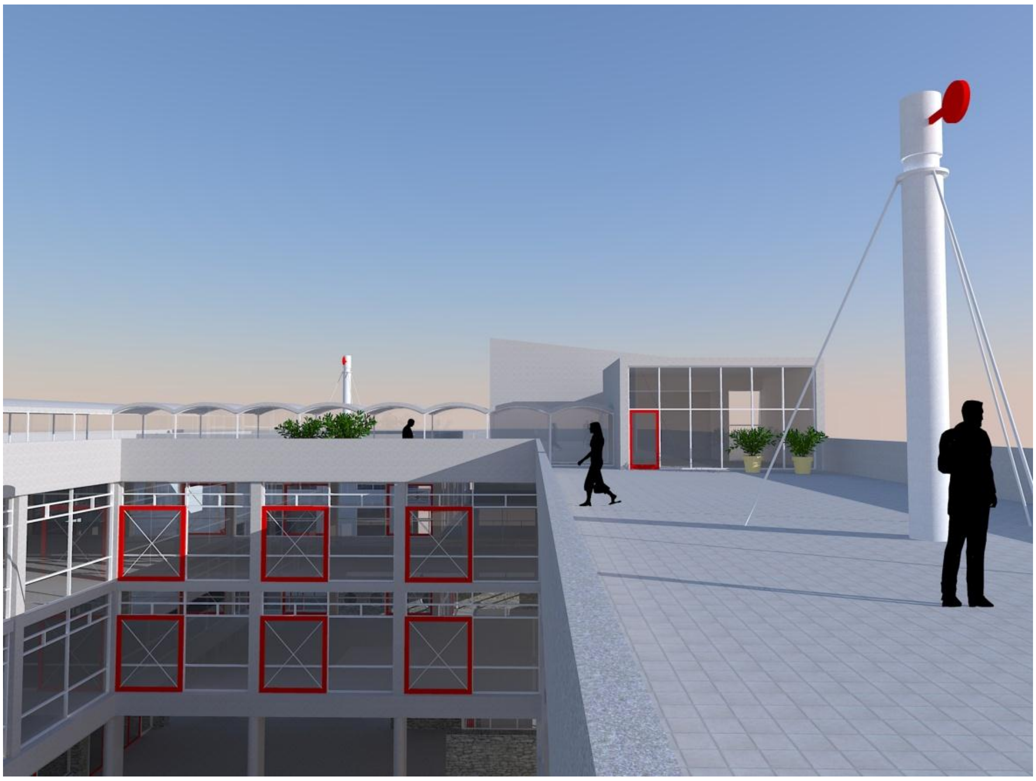
Appendix A - 12: Detail sheet. Image credit: Canadian Centre for Architecture (2010).



Appendix A - 13: Original exterior perspective drawn by Maxwell. Image credit: Arnell and Bickford (1984, p.29).

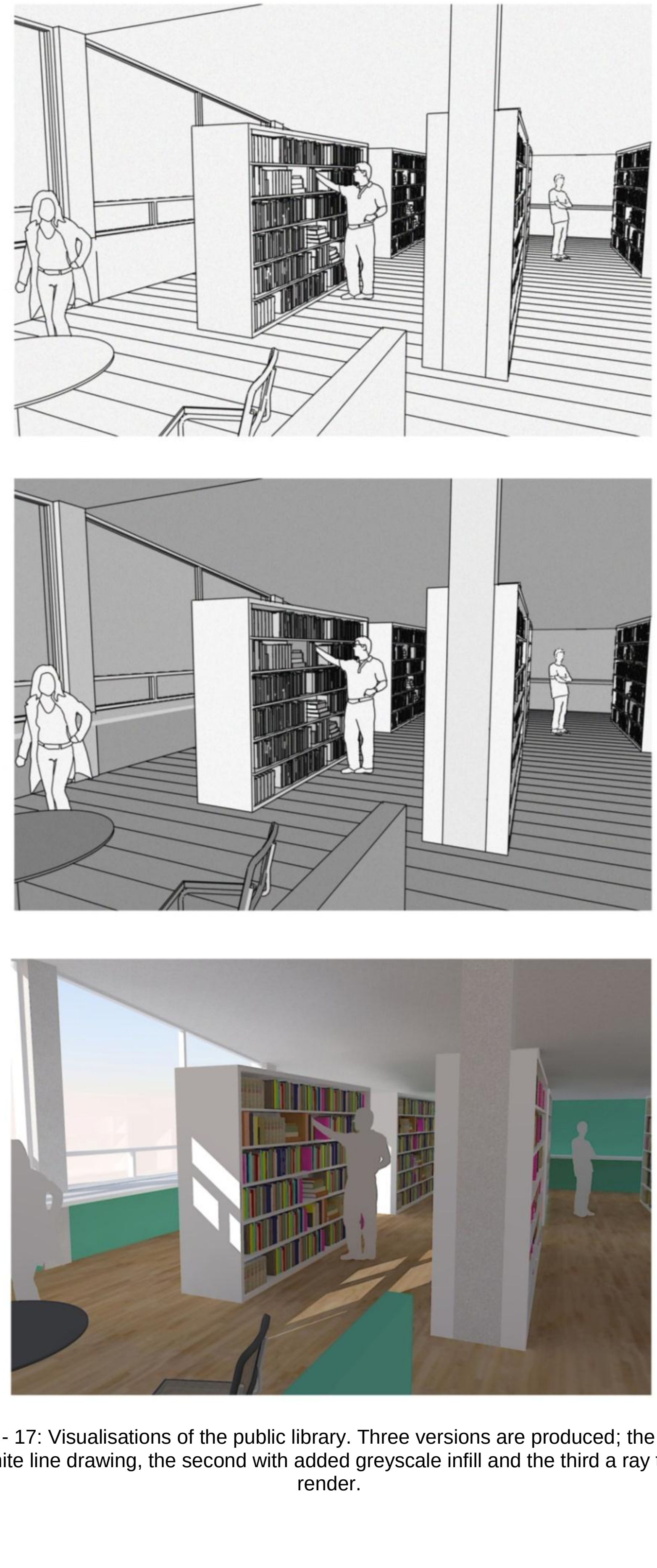


Appendix A - 14: Perspective line drawing with greyscale infill drawn for Carter's 1950 thesis project; a fellow student in Stirling's year at Liverpool. Image credit: University of Liverpool Archives.



Appendix A - 15: Ray traced rendering of Stirling's community centre thesis with a material palette taken from the original drawings and earlier student projects.

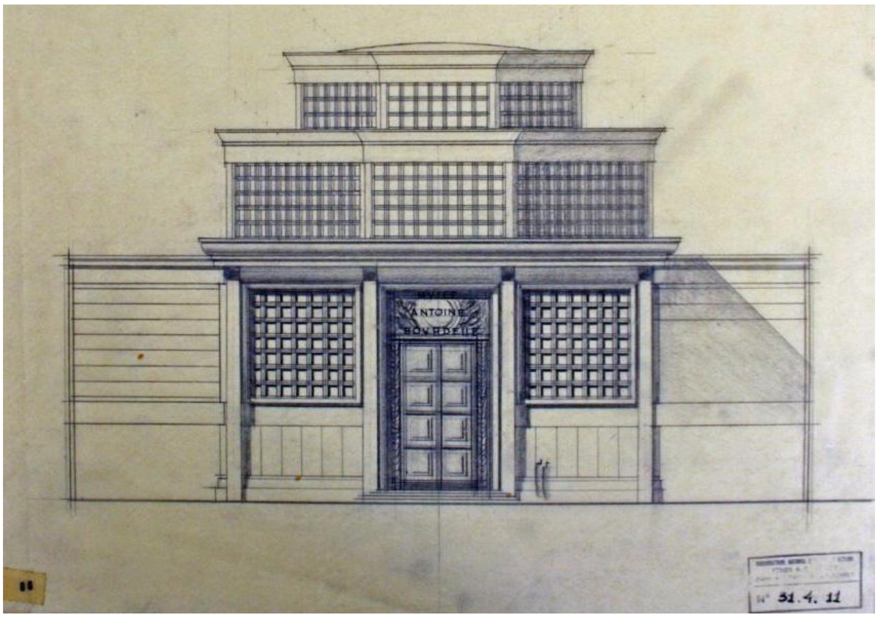
Appendix A - 16: Ray traced rendering of Stirling's community centre thesis with a material palette taken from early built designs such as Ham Common and the Cowes residence.



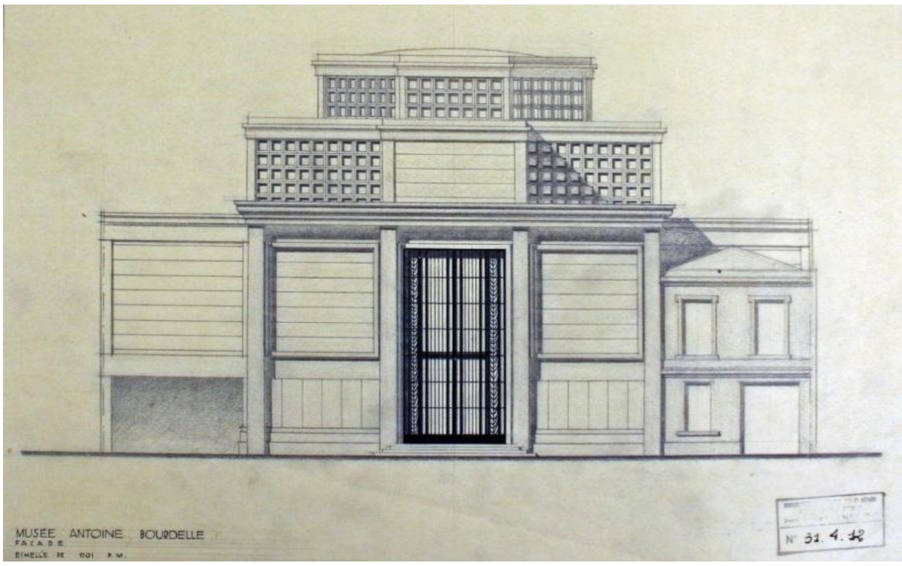
Appendix A - 17: Visualisations of the public library. Three versions are produced; the first being a black and white line drawing, the second with added greyscale infill and the third a ray traced colour render.

Appendix A - 18: Visualisations of the warden's flat. Three versions are produced; the first being a black and white line drawing, the second with added greyscale infill and the third a ray traced colour render.

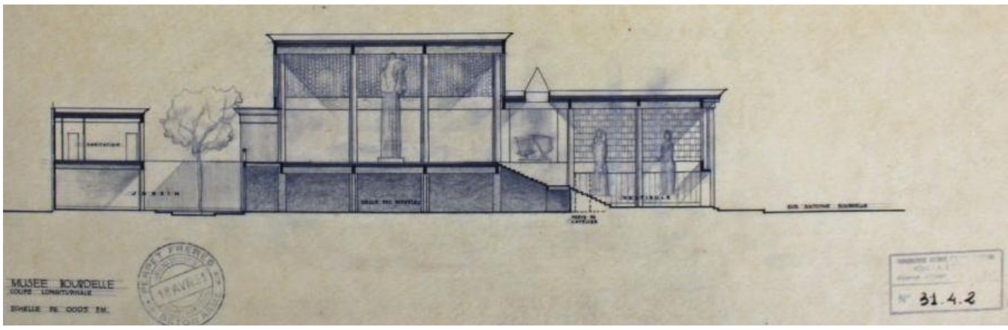
Appendix B – Additional Perret images



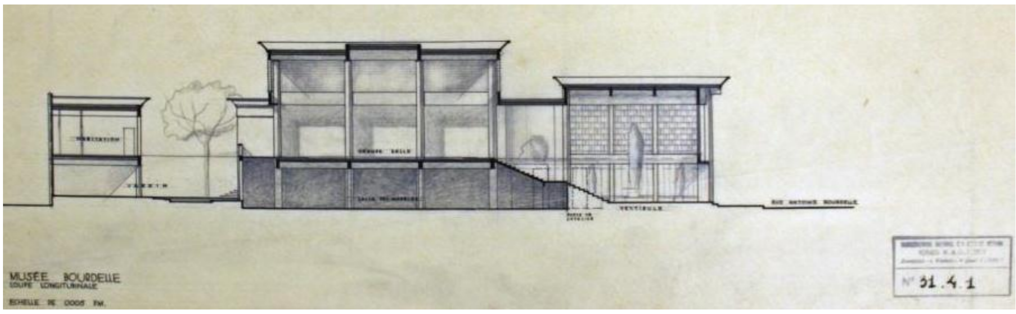
Appendix B - 1: Undated elevation drawing, presumed to be the earliest. Image credit: Perret (1931)



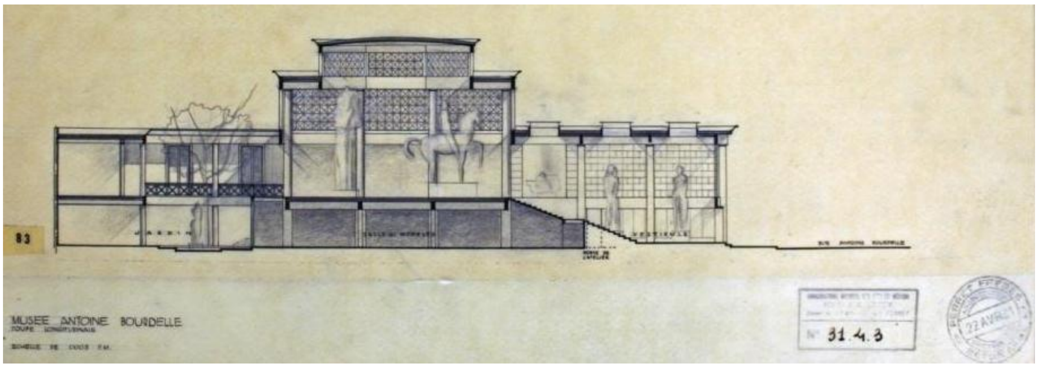
Appendix B - 2: Undated elevation drawing presumed to be the latest based on comparisons with the plans and section. Image credit: Perret (1931)



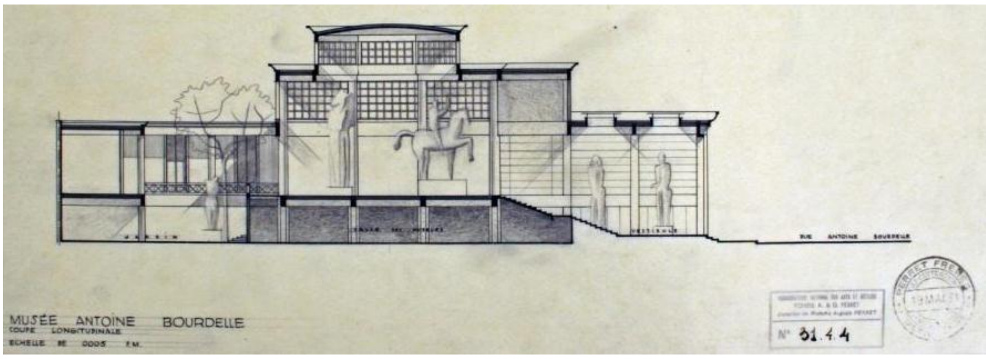
Appendix B - 3: 18th April 1931 section. Image credit: Perret (1931)



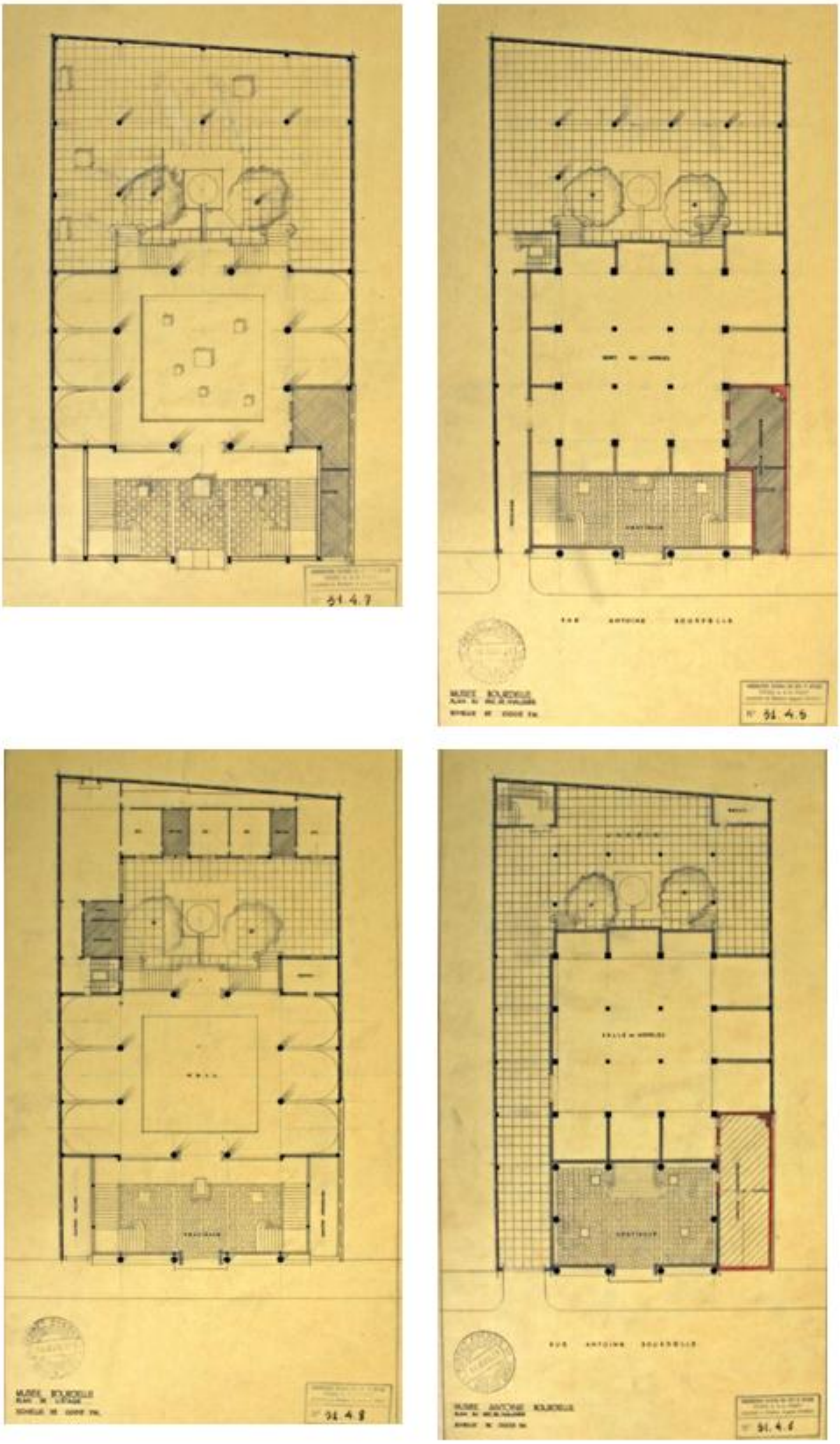
Appendix B - 4: Undated section presumed to be second in sequence based on its similarities with the earliest section and differences form the later dated versions. Image credit: Perret (1931)



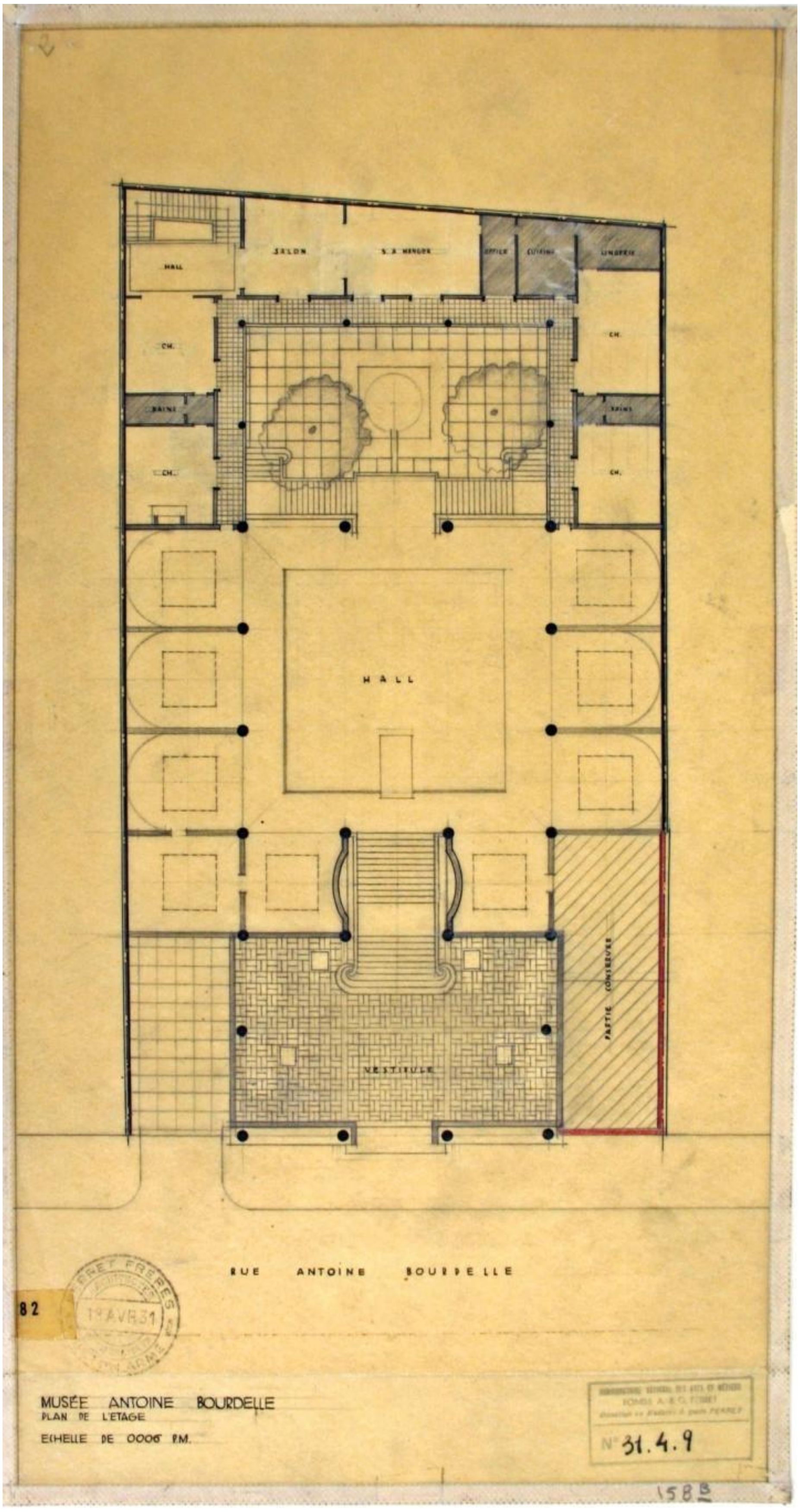
Appendix B - 5: 22nd April 1931 section. Image credit: Perret (1931)



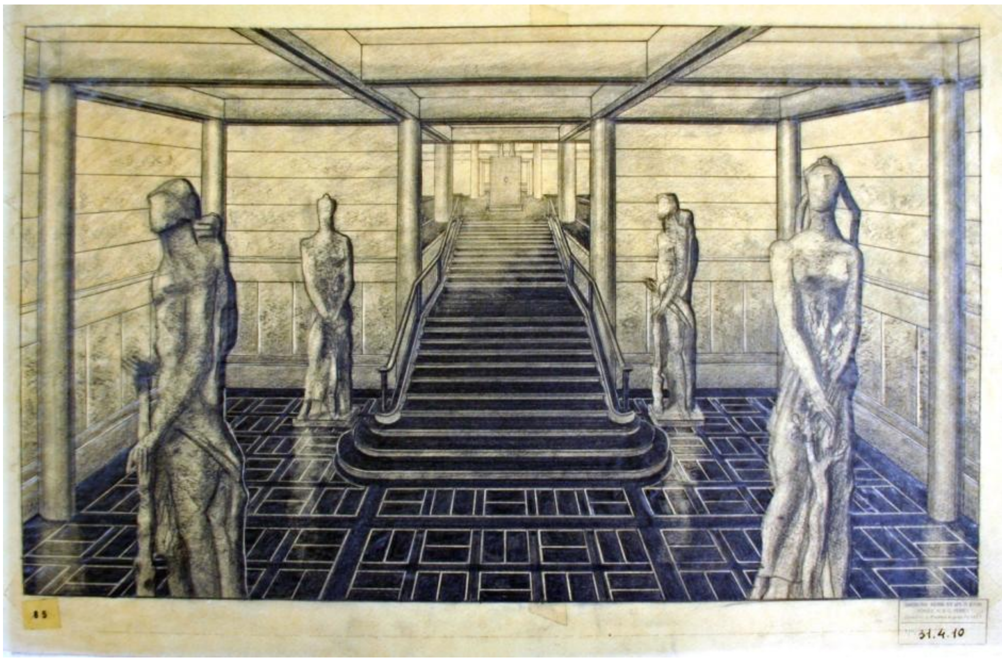
Appendix B - 6: 19th May 1931 section (latest version). Image credit: Perret (1931)



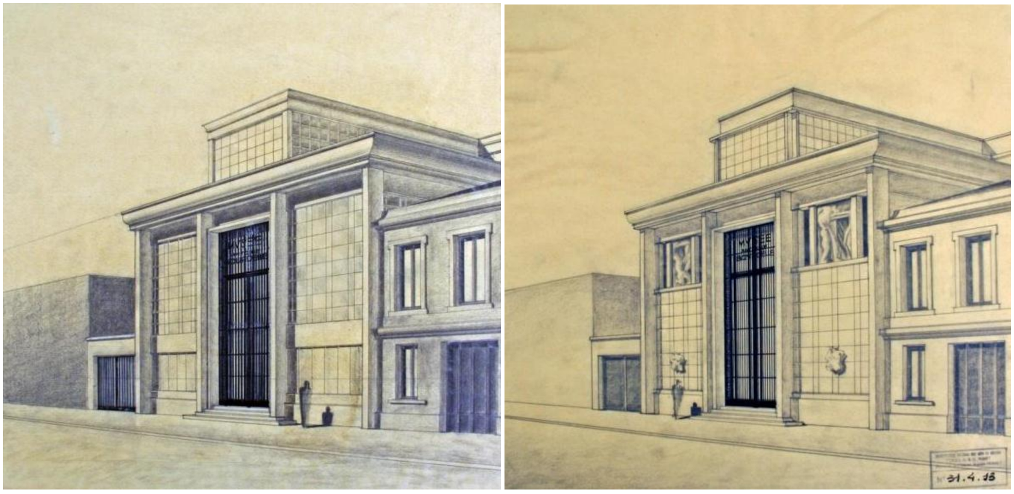
Appendix B - 7: Undated plan presumed to be the earliest (top left), 14th April 1931 lower ground floor plan (top right), 14th April 1931 upper ground floor plan (bottom left), 18th April 1931 lower ground floor plan (bottom right). Image credit: Perret (1931)



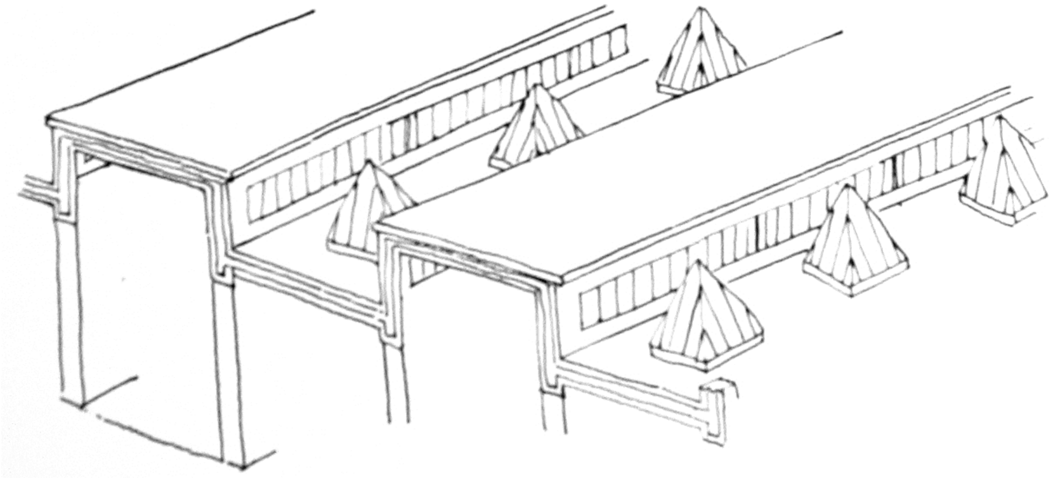
Appendix B - 8: 18th April 1931 upper ground floor plan (latest version). Image credit: Perret (1931)



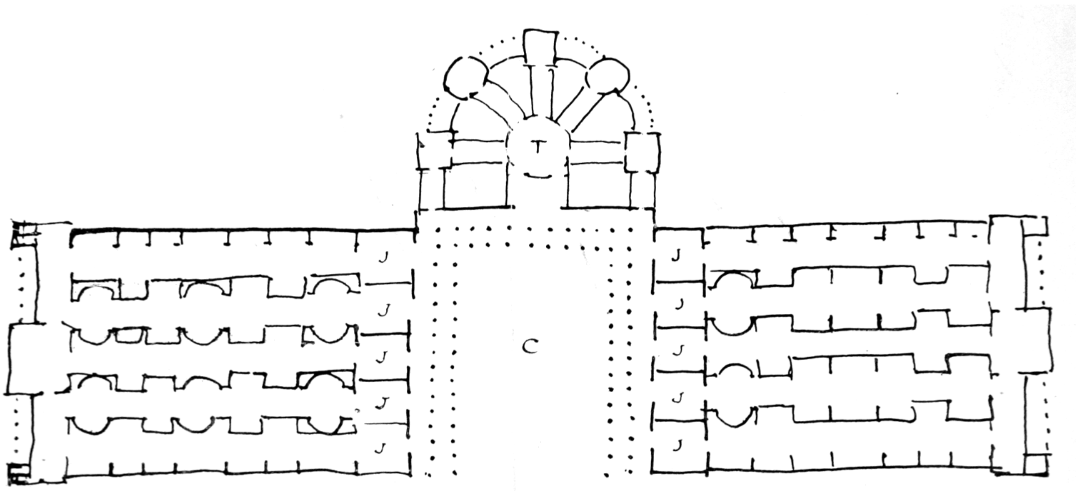
Appendix B - 9: Interior perspective. Image credit: Perret (1931)



Appendix B - 10: Undated early perspectives. Image credit: Perret (1931)

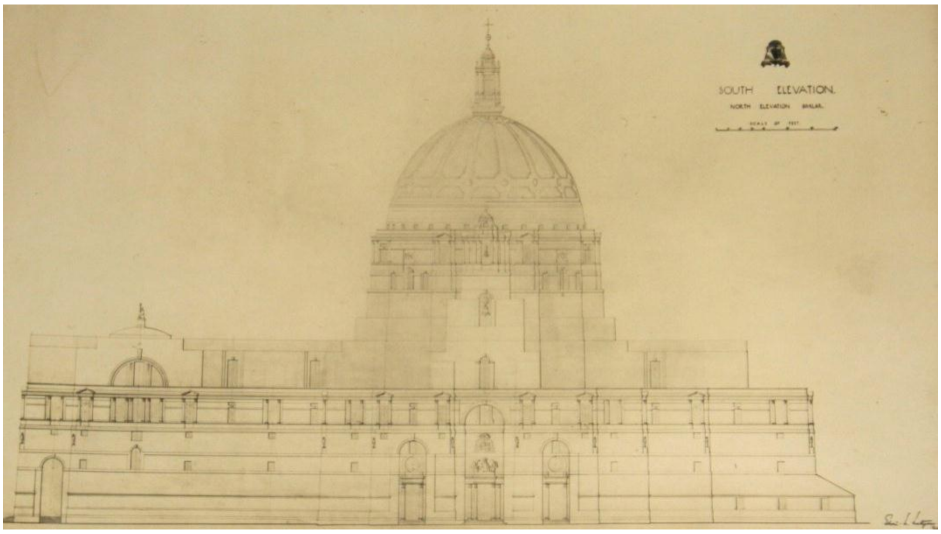


Appendix B - 11: Sectional sketch of the galleries in the Musée Moderne. Image credit: Perret (1929b, p.227).

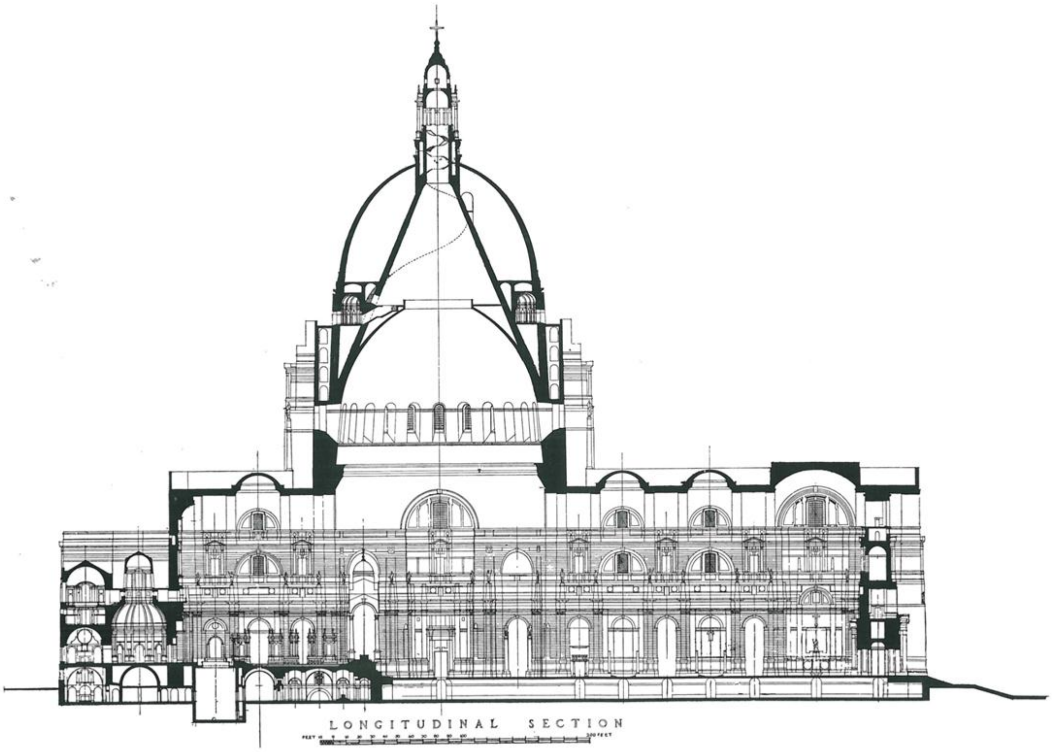


Appendix B - 12: Sketch plan of the Musée Moderne. Image credit: Perret (1929b, p.227).

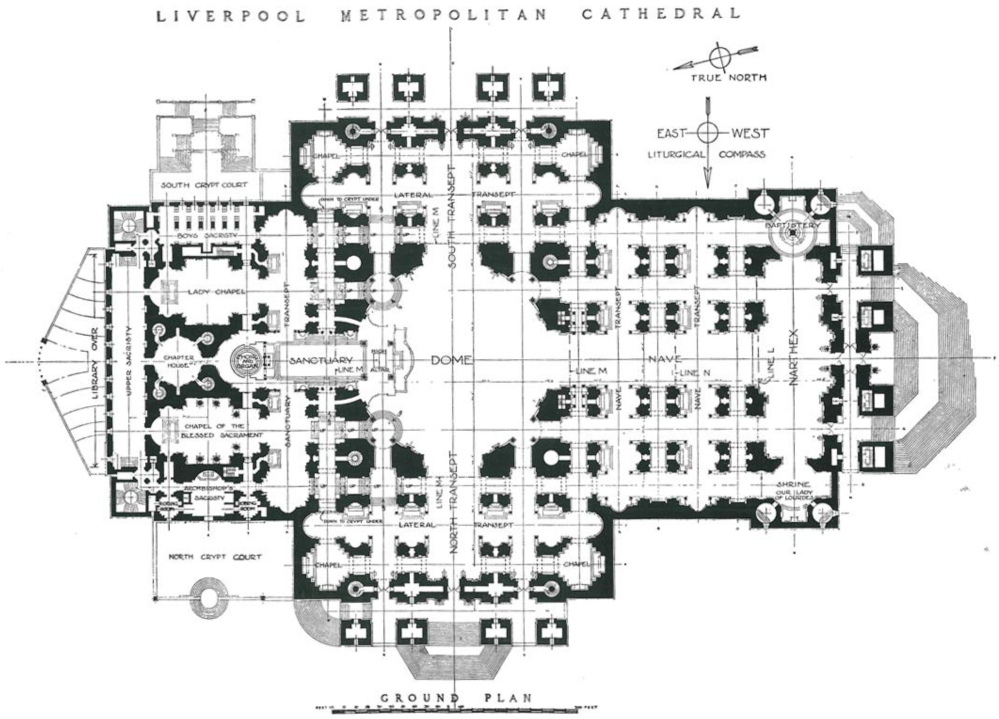
Appendix C – Additional Lutyens images



Appendix C - 1: Elevation of 1929 design. Image credit: Lutyens (1929a).



Appendix C - 2: Longitudinal section of the 1934 design. Image credit: Butler (1950b, plate XCII).



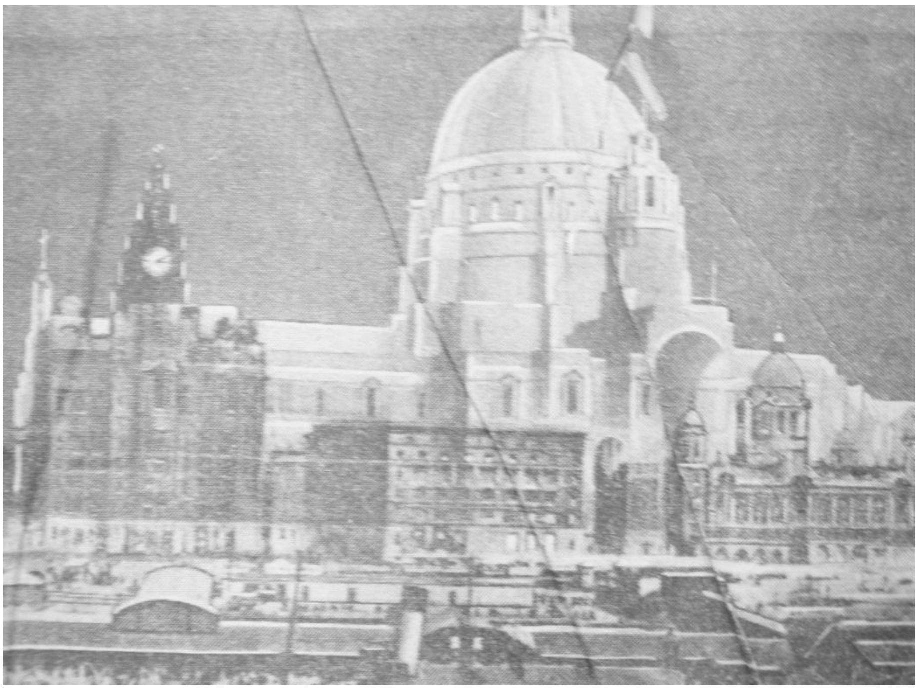
Appendix C - 3: Ground floor plan based on the 1932 set of drawings. Notice how the drawing is placed on a grid in order to split the design into manageable areas. Image credit: Butler (1950, plate LXXXIX).

Appendix C - 4: Current built environment (left) compared to what would have been if Lutyens' design had been built (right). The right hand image is based on Hussey (1950, p.530) stating that 'towards the north there comes into our sight, above the tiered cubes of the silhouette, such as spire as Wren might have set above a city church...'

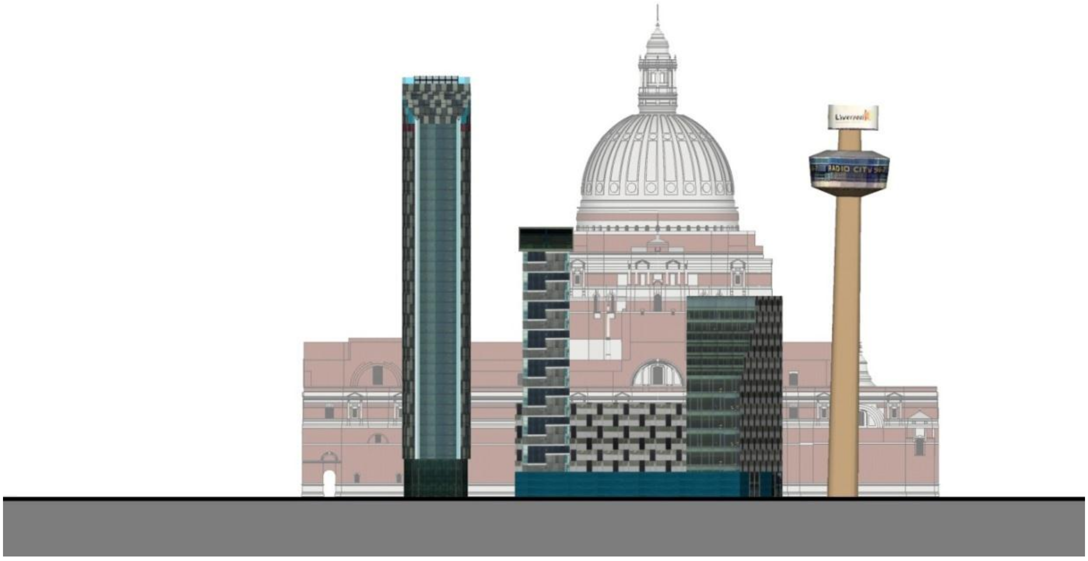
Appendix C - 5: Current built environment (left) compared to what would have been if Lutyens' design had been built (right). The right hand image is based on Hussey (1950, p.530) saying 'from our stance, too, we can see descending steps to the crypt...'

Appendix C - 6: Lutyens' master plan for the areas surrounding the cathedral. Two points of reference relating to contemporary Liverpool are the rail tracks leading into Lime Street Station (bottom left) and the Adelphi hotel (bottom centre). Image sourced online (Roberts 2008), dated September 1943. Original image source unknown.

Appendix C - 7: Google Earth image showing the Lutyens cathedral in relation to the Anglican Cathedral along Hope Street. Apart from the significant buildings modelled, a lack of additional buildings modelled in three dimensions results in an unclear understanding of the context surrounding the design.

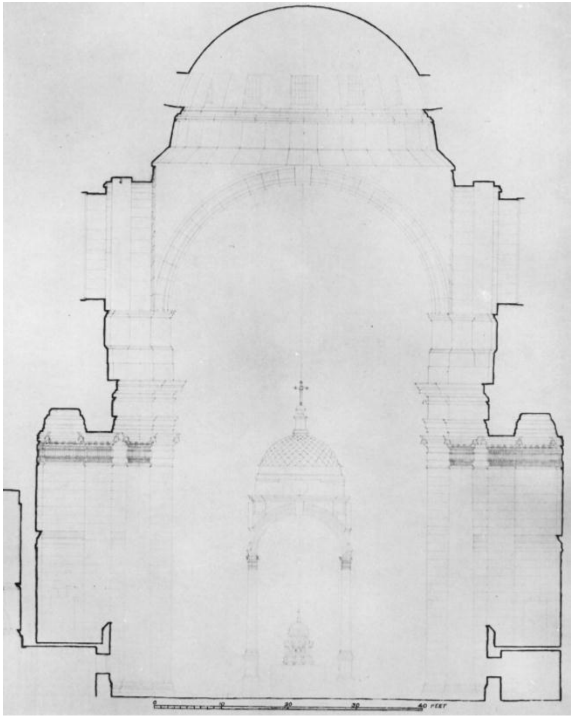


Appendix C - 8: Newspaper cutting from the 1930s juxtaposing the cathedral design against the Liverpool waterfront. Image credit: Liverpool Record Office.



Appendix C - 9: Lutyens' cathedral design juxtaposed against three modern Liverpool designs; Beetham West Tower (left), Unity building (centre) and Radio City Tower (right).

Appendix C - 10: Lutyens' cathedral design juxtaposed against St Peter’s Basilica (left) and St Paul’s Cathedral (right).



Appendix C - 11: Detailed section of the Blessed Sacrament Chapel clearly shows openings on either side high up in the design. Image credit: Butler (1950, image 152).

Appendix D – Additional Lutyens research

As discussed in section 1.5 of the introduction, there are cases in which lines of enquiry have been found, however, the validity of the representations produced are not valid. Such results for the Lutyens case study are consequently presented here for illustrative purposes only.

Lighting of the cathedral

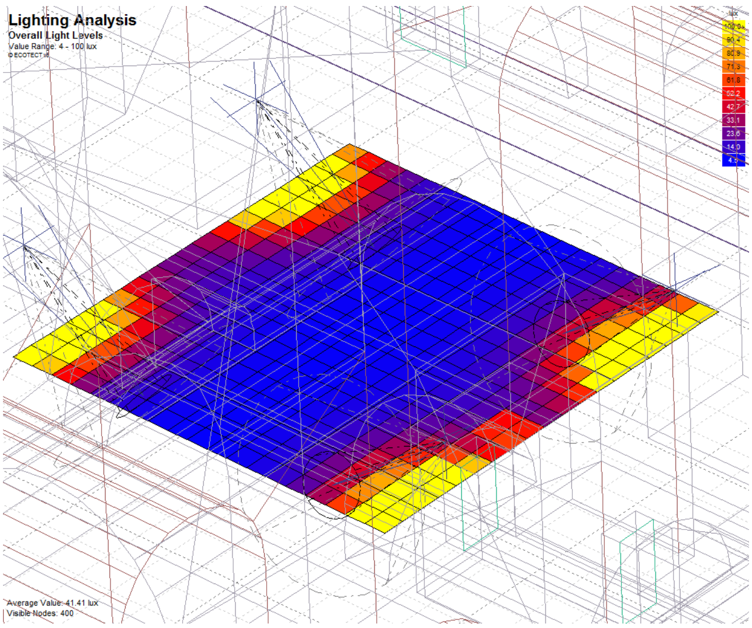
In addition to the ray traced visualisations produced in section 7.5.3, a more objective and scientific investigation is to ray trace the digital model using Autodesk Ecotect Analysis. Ecotect enables daylight factors and illuminance levels of the internal design to be simulated. It is recommended that interiors not supplemented by electric lighting should have a daylight factor of no less than 5% and if electric lighting is used during daytime the daylight factor should be no less than 2% (Chartered Institution of Building Service Engineers 2002). The daylight factor can be displayed on an analysis grid in Ecotect giving precise values which will be used to determine whether or not the lighting is adequate. A simplified version of the digital model created in SketchUp was imported into Ecotect and assigned with materials. The model was simplified as its level of detail was too great to enable it to function effectively in Ecotect; therefore it was stripped back to the basic geometry and window openings.

Initially an analysis grid was placed over the entire design; however this contained external areas such as the porches therefore the contrast between the values of external and internal daylight factors was so great that the variation of internal light levels across the grid could not be represented effectively. Consequently a smaller grid of 11.5 x 11.5 metres was placed at three key points in the interior of the design; the nave, aisles and underneath the dome. These were chosen based on the assumptions of lighting by Summerson (1981) discussed earlier. The daylight factor of the three areas was calculated by 'dividing the horizontal illuminance at a point of the interior by the horizontal illuminance of the exterior with an unobstructed sky and then multiplying the result by 100%' (Pritchard 1995). Each point on the grid was then analysed in this way; particles were sent in every direction from the various points and their reflection determined the level of illuminance, or lux. The illuminance of the external sky for the simulation was given as 5000 lux based on the average illuminance of a complete hemisphere of sky in the UK (Pritchard 1995). The results of the simulation with daylight only are as follows:

	Dome	Nave	Aisle
Illuminance (lux)	1.66	5.40	9.41
Average Daylight Factor (%)	0.03	0.11	0.19

The results support Summerson's statement that the lighting levels in the aisles would be greater than the nave; however, they contradict his statement that the area beneath the dome would be the main source of light as the results suggest that the dome would have lower lighting levels than the nave. This is due to the windows in the dome being nearly 60 metres above the analysis plane, resulting in the amount of daylight decreasing significantly according to the inverse square law. Also, the walls supporting the dome are over six metres deep to fulfil their structural needs which also affects the amount of light entering the space. In terms of recommended daylight factors, the simulations show that these fall way below the 5% needed to light a building without supplementary electric lighting. They are also considerably lower than the 2% daylight factor required if a building is day-lit with supplementary electric lighting. This supports Lutyens' statement that the interior would be 'mysterious' due to the fact it would be close to darkness without any additional lighting. The levels of illuminance are comparable to a full moon on a clear night (0.27 lux) which suggests a level of mystery and evocativeness. Pritchard (1995) gives a guide for illuminance levels of interiors stating the lowest possible value as 50 lux for 'interiors used rarely with visual tasks confined to movement and casual seeing without perception to detail.' This helps to re-iterate exactly how low the lighting levels of the cathedral would have been. It is also evidence in support of the requests of the cathedral authorities for floodlighting to be used as the data falls well below the 2% daylight factor required for a day-lit building with supplementary electric lighting (Chartered Institution of Building Service Engineers 2002). Although the results show that the levels of illuminance and daylight factors are very low in the cathedral interior, the spaces would still be perceived as being day lit due to the contrast between the bright openings high up in the structure and the very low light levels of the spaces at ground level. This can be seen in the render of the nave without additional lighting (see Figure 7.22).

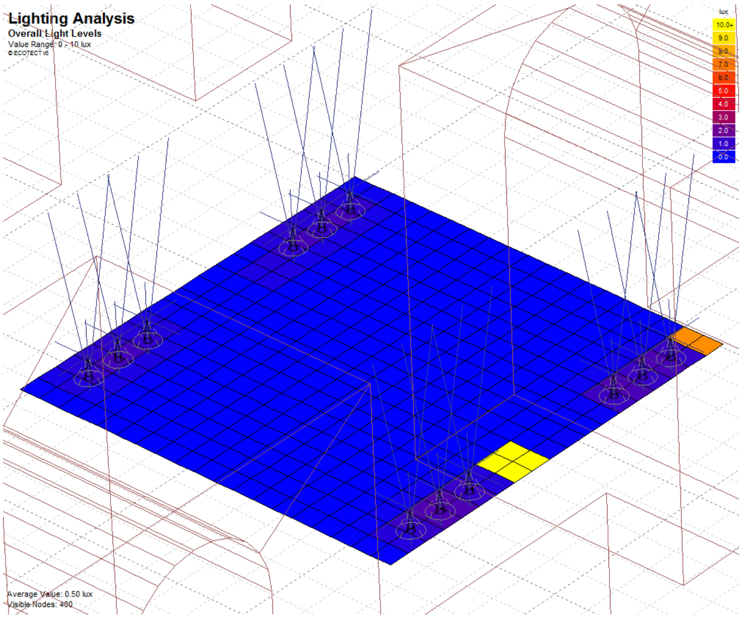
Ecotect can be further used to investigate the additional sources of lighting required to illuminate the cathedral interior. The nave was chosen as the primary area to study, as this is where the majority of people would congregate in a service. The Chartered Institute of Building Services Engineers (2002) state that the nave of a church should have illuminance levels between 100 and 200 lux at the height in which a hymn book could be read. Lights emitting 1200 lumens were initially chosen to replicate the up-lit floodlighting; however, it soon became apparent from the results of the simulation that up-lighting would not achieve the required levels of illuminance. Therefore down lighting was used which revealed an additional problem; the nave is approximately 14 metres wide with points to place the lighting only available on the piers either side due to the height of the nave being approximately 42 metres. Therefore the light had to be directed from the vertical surfaces at an angle towards the centre of the nave floor. This gave a candela value of 2500 based on the lumen value of the lighting being 1200. The resulting average illuminance level was 41.41 lux which is well below the required 100 lux. Several variations in levels of lumens, as well as positioning of the lights, were attempted without reaching 100 lux. It was then realised that this is again due to the width and height of the nave meaning that an even distribution of illuminance over the entire nave would be extremely difficult to achieve without using unacceptably high lumen levels. However, the down lighting does achieve levels above 100 lux closer to the nave piers (see Appendix D - 1). This is a more acceptable scenario as these areas are where people would be seated based on a conventional cathedral or church design with seating and a walkway down the centre. At a basic level, the use of Ecotect reveals what a difficult task it would have been to light the cathedral using electric light.



Appendix D - 1: Ecotect screenshot of the analysis grid in the nave showing the effect of electric lighting.

Lights replicating candles were placed in the digital simulation to compare with the results of electric lighting. These were placed on stands 1.5 metres above the floor. As candles have a candela value of 1 and lumen value of 12.5, the results were predictably very low with an average lux of 0.5 across the analysis grid. However, the results were closer to 2 lux around the candles (see Appendix D - 2). The analysis grid also shows that the effect of natural light on the interior spaces would be greater than the candles.

The results support the request of the cathedral authorities to use electric lighting, even though this would also be difficult to achieve an average illuminance of 100 lux across the entire width of the nave.



Appendix D - 2: Ecotect screenshot of the analysis grid in the nave showing the effect of candlelight. The brightest areas are a result of daylight.

Lutyens' original crypt design compared to Scott's version

In line with the lighting study comparing illuminance and daylight factors of the main cathedral space, Ecotect can also be used to quantitatively analyse the difference in lighting conditions that occurred between Lutyens' preferred crypt materiality and Scott's completed design as investigated in section 7.5.5. The crypt model was imported into Ecotect and assigned with materials as previously discussed in the lighting study of the main cathedral space. The two material options were simulated giving the following results:

	Scott's Crypt	Lutyens' Crypt
Illuminance (lux)	50.52	53.02
Average Daylight Factor (%)	1.01	1.06

The results confirm that Lutyens' use of plaster as a material finish rather than leaving the brickwork exposed, would have improved the illuminance and daylight factors in the crypt slightly. Although the values do not differ greatly, the ray traced images from Kerkythea can be used to demonstrate how the perceived illuminance of the space in Lutyens' design would be greater. The results also display how different the levels of illuminance would have been in the crypt hall (53.02 lux) compared to the main cathedral space such as in the nave (5.40 lux).

Auralisation of the cathedral organ

Auralisation works in exactly the same way as a ray traced visualisation; instead of calculating how light rays bounce off the surfaces within a digital representation, sound rays are traced. Sound sources are designated within a model and a point is defined which becomes the receiver of that sound, hence being able to auralise the sound within a space (D'Antonio 2001). Therefore, Dixon's suggestion that the sound would be 'weak and indecisive' in the nave could be tested using this technique. Two sound sources could be placed in the internal model of the cathedral; one in organ drum of the crypt and one in the choir stand in the sanctuary above. The sound sources of the organ and choir would have to be recorded in an isolation booth of a recording studio to minimise the reflection of sound. A receiver point is then added and the model ray traced. In this example, the receiver point would be the nave to test if Dixon was correct or not. Additional points around the cathedral could be established to further test how the organ would have performed. Although this is a viable line of enquiry in terms of technology, it is currently unviable financially due to the high cost of software required to auralise the cathedral interior.

Digital techniques can still be used to enhance our understanding of how the acoustics of the cathedral would have performed. Reverberation times are calculated using Sabine's equation, which takes into account the absorption coefficient of the materials, the volume of the space as well as the internal surface area. This was investigated using Autodesk Ecotect Analysis, which automatically takes into account the absorption coefficient of the materials assigned. Another advantage of the software is that it accurately calculates the surface area of the design based on the geometry of the digital model. The volume of the interior can also be calculated automatically using SketchUp. Therefore the combination of digital software ensures the results are a lot more accurate than trying to calculate the internal surface area and volume by hand. The resulting reverberation times calculated using Ecotect were as follows:

Freq (Hz)	63	125	250	500	1000	2000	4000	8000	16000
RT	53.17	68.71	67.26	67.26	47.81	36.08	25.51	19.53	18.25

The most accurate reverberation times are at mid frequency between 500 – 1000 Hz, as reverberation times over 1000 Hz decrease due to air absorption and below 500 Hz they can be controlled by the designer (Barron 1993). Therefore, the results indicate a reverberation time of approximately 57 seconds. This is clearly incorrect, with results expected to be less than ten seconds based on optimum reverberation times for music and speech. This is because, although Ecotect makes the use of the Sabine equation simpler, it is still a statistical calculation that does not take into account any of the geometric information about a design such as its shape and how sound would reflect off this. In the cathedral design this means that its complex shapes of barrel arches and a large dome are completely neglected, and is read as a cubic space of over 500,000m^3 instead, hence the overly long reverberation time. This reiterates the point that more complex software is required to fully investigate this line of enquiry.

Appendix E – Supporting papers

IJAC 2010 journal article

Brown, A. & Webb, N. 2010, *Examination of the Designs by Auguste Perret Using Digitally-Enabled Forensic Techniques*, International Journal of Architectural Computing vol. 8 – no. 4, pp.537.

This text box is where the unabridged thesis included the following third party copyrighted material:

Brown, A. & Webb, N. 2010, *Examination of the Designs by Auguste Perret Using Digitally-Enabled Forensic Techniques*, International Journal of Architectural Computing vol. 8 – no. 4, pp.537.

http://cumincad.scix.net/cgi-bin/works/Show?_id=ijac20108408&sort=DEFAULT&search=Webb&hits=4

CAADRIA 2011 conference paper

Webb, N. & Brown, A. 2011, *Digital forensics as a tool for augmenting historical architectural analysis: Case study: The student work of James Stirling,* Proceedings of the 16th International Conference on Computer Aided Architectural Design Research in Asia / The University of Newcastle, Australia 27-29 April 2011, pp 505.

This text box is where the unabridged thesis included the following third party copyrighted material:

Webb, N. & Brown, A. 2011, *Digital forensics as a tool for augmenting historical architectural analysis: Case study: The student work of James Stirling,* Proceedings of the 16th International Conference on Computer Aided Architectural Design Research in Asia / The University of Newcastle, Australia 27-29 April 2011, pp 505.

http://cumincad.scix.net/cgi-bin/works/Show?_id=caadria2011_048&sort=DEFAULT&search=Webb&hits=4

eCAADe 2011 conference paper:

Webb, N. & Brown, A. 2011, *Augmenting critique of lost or unbuilt works of architecture using digitally mediated techniques,* Respecting Fragile Places (29th eCAADe conference proceedings), University of Ljubljana, Slovenia 21-24 September 2011, pp 942.

This text box is where the unabridged thesis included the following third party copyrighted material:

Webb, N. & Brown, A. 2011, *Augmenting critique of lost or unbuilt works of architecture using digitally mediated techniques,* Respecting Fragile Places (29th eCAADe conference proceedings), University of Ljubljana, Slovenia 21-24 September 2011, pp 942.

http://cumincad.scix.net/cgi-bin/works/Show?_id=ecaade2011_129&sort=DEFAULT&search=Webb&hits=4

FBUA presentation (2011)

After being awarded a travel bursary to study Perret's architecture by the Franco British Union of Architects in France, I was invited to Le Havre to present my research to the committee.