Examination of the Designs by Auguste Perret Using Digitally-Enabled Forensic Techniques

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Abstract

This paper discusses how digitally-enabled techniques can be used to augment our understanding of a designer’s work, particularly in relation to unbuilt or lost projects. In the first half of the twentieth century Auguste Perret gained international recognition for his buildings and we employ two of his unbuilt museums as the basis for illustration of the technique. Current knowledge of his unbuilt projects is based on surviving literature and incomplete illustrations. We show that the use of digitally-enabled techniques facilitates a fuller examination of the original material. Interpretation of material requires parallel studies into the architect, their influences and the context they operated within in order to extrapolate and fill gaps in an informed way. The construction of various digital representations enables a forensic analysis of the projects; consequently we can produce a richer set of information that can, in turn, enhance our analysis and understanding of an architect and their work, in this case, Perret.
I. Introduction

Over the last thirty years architectural research has seen a growing interest in lost designs, whether built and destroyed or never built at all [1,2]. In some important recent cases the ultimate object has been to enable the construction of an incomplete project, such as Temple Sagrada Familia [3]. Projects such as this, and similar ones such as the reconstruction of Frauenkirche in Dresden [4] generate contention and debate about the merits of construction of an incomplete or destroyed architectural artefact. But contribution to that particular debate lies outside the scope of this paper. We focus, instead on techniques that can contribute to enhancing critical analysis and understanding of an architect and an architects work.

The sources of material left to study architectural projects can include archaeological remains, remnants of buildings that have been altered or added to, photographs and images of destroyed buildings as well as architectural drawings and models. From such sources data can be extracted allowing three dimensional digital models to be produced with a level of complexity that allows a range of analyses to be undertaken. Previously, such digital models have been exploited to visualise lost or unbuilt architecture [5]. But we can go beyond visualisation, and by methodical study, produce a range of digital representations that support and enable a better understanding and critical review of a design and the designer. As mentioned, the process of constructing a digital representation of a lost, unbuilt or destroyed architectural artefact is used to augment our understanding. That additional understanding may be derived from serendipity, or from a more deliberate set of investigative acts with pre-determined questions, or both. For instance, in the investigation of the work of Connell, Ward and Lucas undertaken by Brown [6], revealed, unexpectedly, that more of the Lords Court scheme in London had actually been constructed than previously thought. In contrast, in the analysis of the Museum designs by Perret, described here, we set out to interrogate Perret’s ‘ideal’ propositions against actual designs by Perret.

The mere act of turning 2D drawings and other information sources into data that can be used to construct the digital models often reveals that the data is incomplete. Therefore parallel research is required into the architect, their design methods, design outputs and the contemporary context they operated within in order to construct the missing elements of the digital model in an informed way.

The drawings, models, writing by, writing about and contemporary influences on an architect can all provide aspects of evidence to which a forensic type of analysis can be applied [7]. In a parallel with crime forensics we can take this information into a digital laboratory in which we undertake more detailed examination and apply tests.
2. Auguste Perret’s Ideal Museum

The French architect Auguste Perret (1874–1954) is well known for his rationalist structures and pioneering use of reinforced concrete [8]. He gained international recognition for buildings in Paris 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. Perret worked with his brother Gustave, and both were educated at the Ecole des Beaux-Arts in Paris whilst at the same time working for their father’s construction company as draughtsmen [9]. This combination of an education in French Classicist architecture and knowledge of construction was to define Auguste Perret’s career; a career that has seen him labelled by some as a Classical Rationalist [10]. Perret saw reinforced concrete as the perfect material for his pseudo-classical forms. The Ancient Greeks used petrification of stone to imitate wood; in Perret’s hands concrete was manipulated to deliver a similar effect. He became known for the use of rough wooden formwork used to create a timber texture to the cast concrete surfaces [9].

Two of Perret’s museum projects were selected for examination in the study reported here for two particular reasons; firstly they share a common typology and secondly in 1929 Perret had written in detail about his proposals for an ‘Ideal Museum’: the Musée Moderne [11]. In the early twentieth century, the arrival of the Modern Movement brought radical change to the profession. One feature of this period was prominent architects expressing their theoretical propositions on how buildings should be designed in the Modern style. Proposals were made for typological ideals and new aesthetics. It was in this climate that Perret produced a theoretical thesis on the Musée Moderne. His writing sets out specific requirements for the museum and is accompanied by a sketch plan and two perspectives. Not all information is available in drawn form, but Perret’s narrative is sufficiently rich to produce a unique model of a design with drawn information substantially augmented by text, enabling a visualisation of the ‘ideal’ scheme that has not been seen.

The second of the two analyses is Perret’s actual design for the Musée Bourdelle which was intended to exhibit the works of the late Antoine Bourdelle in 1931. This was Perret’s first opportunity to put the theories described in his Musée Moderne article into practice. The Musée Bourdelle was not built; however, we can identify in it elements of Perret’s Musée Moderne. A fundamental similarity is that, as in the ‘ideal’ it is planned on one floor as far as possible.

The construction of the Musée Bourdelle model was primarily based on surviving architectural drawings. The more comprehensive use of drawings rather than text meant the ability to test the Musée Bourdelle design in
terms of digital forensics was much more straightforward. The intention was that a comparison of the two unbuilt schemes could be carried out once the two models had been constructed. In the technique that we use the first step is most commonly to construct a digital model of an entire scheme. This then acts as a core reference and source against which variants and alternatives can be compared. An important approach to the forensic analysis is that the models were constructed in reverse chronological order as there was more archival and drawn information available for the Musée Bourdelle than the Musée Moderne. This meant that the information compiled to construct the Musée Bourdelle could subsequently be used for extrapolation purposes in addressing the contentious elements of the Musée Moderne model.

3. Musée Bourdelle

As an initial task, the original Musée Bourdelle drawings from the Paris archives had to be arranged in chronological order. Given the contemporary context they are likely to have been drawings produced for the planning stage but are still formal drawings rather than sketch designs. But the scheme had clearly undergone revisions at this stage, and consequently a particular problem here was that there were several variations of similar designs. Five different plans and four different sections were found in the archive. 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.

3.1. Tracing the Archive Drawings Using Digital Drafting Software

The archive material indicated a metric scale of 1/50, which made tracing a simple task as the drawings were on stable media. 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. As a key innovator in the development of the reinforced concrete frame Perret’s projects regularly had a consistent frame as the start point: ‘The composition of the framework is very important because it is to the building what the skeleton is to the animal’ [11]. The frame spacing was measured from the archive plan as a 5720mm square grid and this enabled the rest of the design to be built with this structural grid as the framework. Other key dimensions then had to be derived, 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 physical and at a scale of 1/50.
This, admittedly, would have led to some inaccuracies regarding the standard dimensions as measurements were taken at 1/50. For example, because of the thickness of pen lines drawn to represent thinner columns in plan, manual measurements revealed a variation between 300 mm and 400 mm in possible outside dimension. Therefore, detailed drawings in the archives of two of Perret’s built museums; the Musée des Travaux Publics and Mobilier National, were used to ascertain the dimensions used by Perret in similar schemes. The drawings provided construction details at a larger scale with annotation of dimensions and materials. This aspect of the forensic process - information from contemporary comparators - gave us confidence that the chosen dimensions were correct. We might describe this as circumstantial evidence derived by studying the m.o. (modus operandi) of the person being investigated.

Once these basic dimensions were established, the lower ground floor plan was traced, followed by the upper ground floor plan. This process revealed a first discrepancy, in the vestibule area of the design, where, on the lower ground plan the columns sit in front of the wall but on the upper ground plan they sit within the wall (Figure 1). Other drawings were consulted to reveal the likely intention. 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. 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 assumes the most recent plan has precedence. This inconsistency between drawings suggests an incomplete design development process [5].

![Figure 1. Bottom: On the lower ground plan the columns sit in front of the wall. Top: On the upper ground plan they sit within the wall. On the original internal perspective the columns sit in front of the wall](image)

Analysis of the drawings also revealed useful information confirming Perret’s employment of the classical orders. Construction of the curvature of the main staircase in the vestibule for the digital model made it 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. The
digital representation of the Fibonacci spiral was laid over the top of the original drawings for final confirmation of this.

Digital construction of the front elevation proved a particular challenge, as a perspective image of the facade was discovered with a date at the end of the drawing archive time line. Therefore the elevation drawing was used as a guide for basic dimensions, as it matched those of the section and plans. But details and surface treatment, such as the lettering on the door and friezes designed by Bourdelle were derived from the perspective image. Doing this revealed further inconsistencies between the drawings. The original perspective image shows the lower section constructed of seven infill panels vertically. In reality, only five panels could fit into the space in the digital reconstruction. This inconsistency could be because the later design was raised in height, or because the perspective was exaggerated to suggest the design was taller than it really was.

Again, comparison across the pieces of drawn evidence was undertaken. This comparison suggests that Perret had exaggerated the perspective, as the height between Bourdelle’s original house and the cornice of the front elevation in elevation and perspective and appeared to be the same. Once the interrogation, interpolation and inconsistency checks had been completed, in the manner described above, the two dimensional digital drawings were completed and exported to a 3d modelling program to begin construction.

3.2. Constructing the Three Dimensional Model

This process adopted for constructing the third dimension was similar to that of the two dimensional drawings; first the structural frame was modelled then detail was added. Constructing the model requires attention to each of elements. Relying on the archive drawings alone can mean that important features and nuances are missed [12]. For instance, when the beams were being constructed for the digital model the dimensions of 650 mm x 650 mm made them look oversized. Study of other buildings such as Perret’s train station at Amiens, reveals that Perret would split such large beams down the centre to give the appearance of two smaller beams. Closer inspection of a surviving interior perspective drawing of the Musée Bourdelle supported this proposition and provided sufficient evidence to reproduce the detail in the digital model.

The three dimensional model is explicit in demonstrating certain important aspects of the structure of the building. For example, it clearly shows how the beams and columns are thicker around the central area which supports an octagonal dome. In contrast, the two dimensional nature of the original drawings do not reflect this feature well; the beams in particular appear to be a standard size (Figure 2).

Inspection of the 3D representation then revealed an important inconsistency in the disposition of the beams and columns in the central area supporting the dome; the corner columns did not meet the beam they
were supporting above. The inconsistency was not apparent from the study of the original drawings.

The inconsistency arises because Perret commonly offset the beams enabling the columns to be expressed internally. This arrangement works 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 (Figure 3). Studying the archive drawings did not offer an answer; therefore it was decided to look at Perret's built works. Studies of Perret's parallel projects revealed that at the Church of St Joseph in Le Havre, a similar offset arrangement of column and beam had been employed. Perret resolved this by adding an extra element internally to the structure (Figure 4); what we might now call a drop slab, or spreader, at the top of the column. The problem at Le Havre was very similar to that at the museum, and consequently this gave enough justification to interpolate using the Church of St Joseph techniques as most likely solution that would have been adopted by Perret (Figure 3).

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 Perret’s
strict structural grid is primarily used for aesthetic purposes in a minority of cases with the structural qualities becoming secondary.

Another outcome of the process of digital representation raised questions in relation to the assertions made by some architectural historians. Perret’s construction technique generally involved expressing the structural column and beams, with that expressed frame infilled by non load bearing elements. Perret designed a system of precast infill blocks which were unique to each scheme he worked on, the dimensions chosen to fit perfectly into the infill areas required [9], such as those at the Mobilier National (Figure 5). In this sense he was working in the opposite way to

Figure 5. The Mobilier National demonstrates some of Perret’s design ideas such as expressing beams and columns, and using unique infill panels and windows spanning from floor to floor.
similar construction today, where it is seen as good practice to design using standard masonry dimensions to determine structural spacings. However, the process of digital reconstruction and interrogation revealed problems where the column dimensions change depending on the load they are supporting. For example, a dimension of 5070 mm for the infill area between two 650 mm wide columns forms the basis of the infill blocks, however, when constructing the model it highlighted different scenarios such as a 450 mm column next to a 650 mm column, leaving an infill area 100mm wider than the standard dimension of 5070 mm. To study this issue further an investigation into Perret’s other works was carried out. Again, the Church of Saint Joseph at Le Havre provided the likely solution. Here Perret resolved the matter by increasing the mortar joint width between the infill blocks in the slightly larger openings. Consequently this technique was replicated for the Musée Bourdelle digital model.

3.3. Adding Materiality to the Digital Model

Once the form of the model was complete, material and texture could be added to study certain visual aspects of the scheme. The issue of adding materiality to digital reconstructions has to be done with care, as it is important to make it clear what the degree of contention might be [13,14]. In other words, it is necessary to acknowledge to what degree the more photorealistic rendered images are based on interpolation from other designs.

In the cases presented here, such images were helpful in adding useful evidence, because of the widespread use of concrete in Perret’s built schemes (hence there were parallel sources), as well as the indication of the material on the original drawings. The materiality evident in Perret’s other buildings was used as reference material, and the Musée des Travaux Publics in Paris proved to be most useful. This was because it contains all of the elements that are apparent in the Musée Bourdelle design, such as the mixing of square and round column sections, similar infill panels and a high level of ornamental detail on finishes. Photographs were taken of the building in Paris. These were then digitally orthorectified to correct for any perspective distortion (Figure 6). These material swatches were then applied to the model. Other key elements such as friezes were obtained by capturing images of frieze designs by Bourdelle for the Théâtre des Champs-Élysées in Paris. These were added in the same way.

3.4. Observations from the Created Images

The previous sections demonstrate how the use of digital forensics enables a more rigorous analysis of a design and reveals evidence that can often be missed by simple inspection of artefacts such as drawings. In the case here the resulting model also enables a visualisation of an unbuilt scheme which can be used to aid understanding and share the results with a wider audience. The
digital representations created of the digital model offer an opportunity of direct comparison to the original perspective images drawn. Figure 7 shows the front facade rendering is very similar to the original except for the original being taller and thinner than the digital reconstruction. The most likely explanation is that Perret drew a deliberately exaggerated perspective to emphasise height.

The interior perspective image is a more contentious matter. Should it be presented based primarily on information from the original perspective or the original plans? Which should dominate? Our task was to add useful information to the debate and add understanding of the work; not to provide a definitive answer. Therefore, a digital 2d representation of both alternatives was produced in order to make clear there are two plausible solutions based on the entire information available (Figure 8 and 9). The representation gives a better spatial understanding of the design, for example the proportions and larger than expected volume of the interior become more apparent once a human figure is added next to Bourdelle’s sculptures.
4. Museé Moderne

Creating the Museé Moderne model was a much more straightforward task than the Musée Bourdelle model as the information already gathered for the Musée Bourdelle could inform the Musée Moderne model. Information such as basic measurements, material swatches and patterns provided a rich source of core digital material. However, it presented a particular challenge.
of visualising an unbuilt design based on text rather than graphic information as the dominant source. With this base information, the main task was to analyse the original article and translate the written information into a three dimensional model. There was a small amount of graphic information. The inclusion of a sketch plan and sketch perspective in the original article acted as visual aids for construction, especially for key elements such as a central dome (Figure 10).

Figure 10. Perret's sketch of the Musée Moderne

The first task was to arrive at the likely frame dimensions of the structural grid as this is not confirmed in his text on the Musée Moderne. However, Perret is explicit in saying that the museum should be constructed of reinforced concrete and 'be made of widely spaced columns that would support beams and slabs' [11]. Using the Musée Bourdelle grid of 5270 mm square as a guide, alongside another of his museum designs, the Mobilier National which had a grid of 5800 mm square, a grid dimension of 5500 mm square was decided upon. This was because similar sized components such as columns and beams were also to be utilised, hence it was very probable that the grid dimension would be close to this. The slightly larger Musée Bourdelle column and beam dimensions of 650 mm square were used as
the Musée Moderne design was generally larger with high ceilings and, consequently, slightly higher loads.

Perret set out very specific requirements for the external wall thicknesses to regulate heat. He states that they ‘will be made of five separate walls with four vacuums 4cm wide separating them’ [11]. The detailed drawings of the Mobilier National, used previously to help decide 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 was 80mm wide with an inner leaf 50mm wide. Based on Perret’s descriptions of three inner walls and two external ones, this resulted in a 470 mm wide wall (80+40+50+40+50+40+50+40+80). The heights of the museum galleries were determined using the golden section as Perret was strongly influenced by the classical orders and classical proportion. Inspection of height to width ratios in Perret’s sketch support the suggestion that golden section proportions would have been adopted (Figure 10).

In the text describing the ‘ideal museum’ Perret states that the framework of the building should provide rhythm, balance and symmetry [11]. The sketch plan he drew is symmetrical. The rhythm is defined by the layout of the columns and beams. This framework was set out with axial symmetry which meant that only half of the model had to be built. The half-model was mirrored to form the remaining half. It is possible that there would have been differences in each side of the museum if it were a real project; however, as we were creating an exemplar or ideal form for the digital model, this seemed appropriate. Perret provides a descriptive account of the various features of his ideal museum;

“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.” [11]

Perret also described the main gallery spaces as having a junction room nearest the central courtyard 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’ [11]. These descriptions offer an opportunity to create scenarios, allowing us to create a richer digital representation. For example Perret states that the courtyard area would be a place of enjoyment. Consequently the rendered image shown in Figure 11 has been created with notional indication of people occupying the space.

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 12. The layout meant that a visitor could walk around the courtyard space and
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Figure 11. Representation of the courtyard area in front of the museum as an occupied space; a view described by Perret but not drawn or modelled.

Figure 12. Visualisation of the junction room, with a large Picasso painting imagined work that is currently on display.

Visit the junction rooms to decide whether they wanted to visit the whole gallery or simply have an overview of the works. In the rendered image Picasso’s work is used as an example of art on display. In Perret’s ‘ideal’ thesis the junction room would exhibit selected major works with the main gallery showing a more comprehensive coverage of the artists work.

In Figures 11 and 12 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 such a case aspects such as proportion, element colour and texture, and lighting are most important.

The final area of the design of importance is the galleries themselves (Figure 13). 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 (referring to Figure 12) 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 [11]. 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.

Perret also states that if the museum were to be built in Paris, the Bois de Boulogne would be an ideal site [11] (Figure 14). 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 [11]. The image in Figure 14 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. In a 'counterfactual' extension of the study reported here, we can look at the 'what if?' of the consequences of the postulated decision, to place the ideal museum on the Bois de Boulogne site. The location was decided upon due to its
transport links with the centre of Paris. 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.

5. Comparisons

Comparing the two schemes, the ideal and the built, several key similarities are apparent, which means that the Musée Bourdelle reveals an apriorism in the Musée Moderne essay written two years previously. At its simplest level the ideal was to have the museum all across one level. Although the Musée Bourdelle is over two levels, it transpired that the lower floor is used for storage space. This was discovered when converting drawings to digital data. Exploration of the digital model revealed a clear distinction between public and private areas. It would appear that Perret did not have enough space on the site to include the various internal spaces required across one level; consequently he ensured that the main gallery spaces are on the upper level so they have direct light via roof lights and windows.

What is apparent in both designs is the sense of scale that Perret strived for. The digital models show what a vast building the Musée Moderne would have been. Following construction of the 3D digital model, Rapid prototyping has been used to produce 3d prints of them at the same scale to help understand the vast size of the postulated Musée Moderne (Figure 15). Together with the image placing the scheme in the context of the Bois de Boulogne (Figure 14) the impression of the scale now becomes clearer.

As mentioned, the original interior perspective of the Musée Bourdelle is misleading as the sculptures in the Perret drawings mislead, and when read as being at a human scale, lead the viewer to considerably

Figure 15. 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.
underestimating the size of the internal spaces. Adding a human figure to the
digital model gave a better impression of the true scale of the Musée
Bourdelle (Figure 8 and 9). The digital reconstruction also reflects the
simplicity of the design and uncomplicated journey envisaged by Perret's in
his museum ideal; 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. Lessons Learned

Overall the digital forensic analysis of the Musée Bourdelle was much more
fruitful in finding new information than the construction and interrogation
of the Musée Moderne. This was mainly due to the process of construction,
involving digital forensics, which required an understanding of Perret's design
principles and both precedents and antecedents. The case study clearly
shows how digital forensics can be used to enhance our understanding of a
particular architect or building. Its use has enabled us to challenged previous
studies of Perret's work; we have been able, for instance, 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 models are also particularly useful at enhancing spatial
understanding of the two museum designs. 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 (Figures 8 and 9).

A future aim of the research is to investigate digital forensics as an
educational tool for teaching students about the work of a particular
architect. In this sense, the process of researching and constructing the
models is invaluable. A further aim is to create an online resource
documenting the models and the process of construction. The intention is
to provide clarity of how the designs were constructed and enable the
research to be shared with a wider audience. Additional digital
representations now shown in this article can include interactive and virtual
walkthrough of the schemes. These can be used where movement and
transition form an important part of the understanding of the architecture,
architect or techniques being investigated.

In the case reported here the outcome has been to use digital
techniques to foster and enable a richer discourse into Perret's architecture
whether built, unbuilt or theoretical.

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