BIM AND THE BUILDING SITE

assimilating digital fabrication within craft traditions

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Abstract. This paper outlines a particular component of very well known project: Antoni Gaudí’s Sagrada Familia Basilica in Barcelona (1882– on-going but scheduled for completion in 2026). At the time of writing the realisation of the project has proceeded for 87 years since Gaudí’s death (1852-1926). As a building site it has been a living laboratory for the nexus between traditional construction, offsite manufacturing and digital fabrication since the computers were first introduced to the project: CAD in 1989 closely followed by CAAD two years later. More remarkably CAD/CAM commenced its significant influence in 1991 with the take-up of semi-robotised stone cutting and carving. The subject of this paper is an elevated auditorium space that is one of the relatively few ‘sketchy’ areas that Gaudí bequeathed the successors for the design of his magnum opus.

1. Introduction

The organisers of ASCAAD seek responses to their statement:
“... through digital design computation process, one would notice that the traditional master-builder design thinking approaches are still strongly implemented in processes such as: object making, digital fabrication, design-to-fabricate, parametric technology, BIM, machining, manufacturing analysis, building performance analysis. This evolution has combined the ability of fine crafted detailing with digital design and manufacturing and put a shift towards seamless collaboration between design and construction.”

This short position paper outlines a particular component of very well known project: Antoni Gaudí’s Sagrada Familia Basilica in Barcelona (1882 – on-going, but scheduled for completion in 2026). At the time of writing the realisation of the project has proceeded for 87 years since Gaudí’s death (1852-1926). As a building site it has been a living laboratory for the nexus between traditional construction, offsite manufacturing and digital fabrication since the computers were first introduced to the project: CAD in 1989 closely followed by CAAD two years later. More remarkably CAD/CAM commenced its significant influence in 1991 with the take-up of semi-robotised stone cutting and carving. The subject of this position paper is an elevated auditorium space that is one of the relatively few ‘sketchy’ areas that Gaudí bequeathed the successors for the design of his magnum opus.
When one discussed the project with architects and engineers outside the project office during the 1990s there were two subjects in any dialogue that inevitably cropped up: its place in history and its place in contemporary architecture. In response I would argue firstly that far from being an anachronism the project was drawing upon and promoting traditional building techniques such as Catalan vaulting\(^1\) and secondly, and in tandem with the use of traditional building techniques, advancing the project from Gaudi's original design required the use of cutting-edge technologies in order for the project to be viable as the 21\(^{st}\) Century approached. What may have been acceptable in Gaudi's day would not remain so to the building’s donors a century later – the building is only funded by donation drawing neither resources from the Catholic Church, the Government nor from sponsorship. Given the dearth of sophisticated design software for the AEC sector this project was among the first to use aeronautical, ship and vehicle parametric design software starting with Intergraph VDS\(^{TM}\) in 1990, Computervision’s (later PTC) CADDS5\(^{TM}\) in 1992, and Dassault Systèmes’ CATIA from 2000 followed by Gehry Technologies’ Digital Project since 2007\(^2\).

In 1992 I made an observation that “advances such as solid-modelling and parametric variation are, at last, helping to reorientate the computer towards intuitive and formal design” in one of the two major pieces I submitted to the UK’s Architects’ Journal, in an issue devoted to the Sagrada Familia Basilica. I had assumed parametric design software to be an obvious route to more effective design practice and building and I had imagined that its more general take-up was ‘just around the corner’ when in fact it was at least a decade and a half away. The subject of my contribution here, the ‘sala creuer’ for the Sagrada Familia Basilica, moves us that decade and a half forwards to 2007 when we experimented in developing novel approaches to its design and construction.

2. The ‘sala creuer’

The sala creuer is the elevated auditorium space that serves as a useful case study for the assimilation of the full gamut of digital technology within both the design process for the Sagrada Familia Basilica and its physical realisation using both traditional techniques and the latest developments in building technology, much of which has had to be innovated specifically for the project. Its location is shown in figures 1 and 2 below. In figure 1, the longitudinal section through the building that Gaudi had published during his later years, we can see that the sala creuer is in the hatched-out area above the centre of the basilica. We are not sure what his reasons are for deferring the design of this space to a later time which, unfortunately, he was prevented from ever reaching through his accidental death; we do know through contemporary commentaries emerging from his time that he intended the more spritely of the building’s visitors to ascend to the cross at the top. Such peregrinations require routing through this nebulous space, and it is for this reason we took up the clues in the section that suggest an ideal function as an auditorium space. This space has to serve as a collector for the visitors ascending from the base of the building towards the central tower (cimborium) via the four spire-like towers that flank the central tower. It serves as the principal architectural element that ties all five towers together connecting the group to a sixth and slightly lower tower over the apse to the building at its north western extreme.

The following series of images serve to distil the design, representational and construction innovations and methodologies that have afforded the (at the time of writing) nearly completed sala creuer. Principal among these have been the use of a shared digital 3D model for the first time placing the Sagrada Familia Basilica project in the forefront of adventurous BIM.
3. Designing, representing and building the sala creuer

Figure 1. Sagrada Familia Basilica: longitudinal section of the third and final version of the building by Gaudí published during his final years. The ‘Sala Creuer’ (literally ‘crossing room’) is the space above the crossing in the centre of the basilica below the main tower.

Figure 2. Plan of the Sagrada Familia Basilica showing the location (in plan) of the sala creuer, 70 metres above floor level with the four towers flanking the central tower to which the sala creuer is the base.

Figure 3. Parametric model of the sala creuer using the software CATIA™ (and subsequently Gehry Technologies’ Digital Project™). In the ‘tree’ each spatial component such as ‘tower’ or ‘window’ is a parametric element (‘part’) combined together as and ‘assembly’. Each part is parametrically linked to each other in the assembly such that a change in one part can have a direct effect on the geometry and relationships within another. The geometry parameters are principally interrelated via an Excel™ spread sheet.

Figure 4. An early version extracted in Rhino 3D™ from the parametrically variable spatial model of the sala creuer and the tower above.
**Figure 5.** This image characterises the professional working experience of design decision-making within the Sagrada Familia Basilica project team. Here in the model makers’ workshop model makers meet with architects, engineers, fabricators and builders to progress the design in a collaborative process that extends from the very initial stages of the project.

**Figure 6.** The Sagrada Familia Basilica was among the first architectural projects anywhere to make extensive use of 3D printing (rapid prototyping). In this image three versions of the sala creuer with the tower it supports and the four that flank it have been produced as 1:100 scale models. Prior to the introduction of the 3D printers on site, modelling at such a detailed scale was practically impossible. Modelling at this scale affords much more detailed interaction and design discussion between the various decision makers.

**Figure 7.** 1:100 sectional model of the sala creuer (later version). The sala creuer is an auditorium and principally acts as a space in which visitors to the cross at the top of the central tower (174 metres above floor level) can be marshalled into groups.

**Figure 8.** The auditorium is ‘floating’ within the sala creuer thereby allowing light to filter through into the auditorium space itself as well as beneath the bowl through to the hyperboloid vaults that form the ceiling above the crossing below.
before ascending.

Figure 9. Reflected ceiling plan of the sala creuer.

Figure 10. Auditorium plan within the sala creuer showing upper level access from the four flanking towers.

Figure 11. Cross section of the sala creuer showing the routes for natural light to illuminate the sala creuer auditorium itself and the crossing vaults below.

Figure 12. Rendered view of the sala creuer space under realistic lighting conditions. The space is due to be completed during 2014.
Figure 13. Realistically rendered view of one of the two ‘vomitoria’ providing lower level access to the auditorium from the four flanking towers.

Figure 14. Rendered view of ‘floating’ auditorium.

Figure 15. Rendered view of lower level entry into the sala creuer auditorium.

Figure 16. Lower level entry into the sala creuer auditorium: actual site nearing completion in 2013. The timber floor seen here is temporary and will reveal the crossing vaults below once removed.

Figure 17. Sala creuer space beneath the auditorium nearing completion in 2013.

Figure 18. ‘Vomitorium’ providing access to the lower level of the auditorium (sala creuer nearing completion in 2013).
Figure 19. Sala creuer space beneath the auditorium nearing completion in 2013.

Figure 20. Looking-up to the sala creuer space under construction from the southwest corner of the site (Passion Façade on left hand side).

Figure 21. Looking down to the sala creuer auditorium ‘floating’ bowl in an early stage of construction (2010).

Figure 22. Vomitorium entrance formed with reinforcement in place (sala creuer auditorium 2010).

Figure 23. In situ concrete work for the sala creuer auditorium well underway (2010)

Figure 24. Construction platform for the sala creuer auditorium ceiling temporarily supporting prefabricated elements before their incorporation into the windows that surround the sala creuer space (2011).
Figure 25. Construction of the sala creuer ceiling vaults well underway (2013). The hybrid nature of the construction is seen here where traditional techniques such as Catalan vaulting are exploited in tandem with the latest advances in prefabrication and robotised stone cutting and shaping.

Figure 26. The latest in thin-shell masonry construction. On a 5 hectare site 60 kms north of Barcelona both the shuttering (beneath the reinforcement) as well as the preassembled stone external facing are prefabricated. An example of the preassembled stone sections can just be seen at the bottom of the photograph. A special mix of concrete will flow between the exterior stone surface (acting as permanent shuttering) and the temporary shuttering. The interior surface of the concrete will be receive a bush-hammered final finish once the shuttering is removed, closely resembling the natural stone with which it is used in conjunction.

Figure 27. Prefabricated elements in place for the sala creuer ceiling vaults. To the right of the image the hyperboloid formers for the Catalan vaulting are seen in place.

Figure 28. Traditional Catalan vaulting with a concrete spray coating ready to receive its final concrete cover. Note that Gaudi's use of doubly ruled surface geometry is ideal for efficient structure just as in figure 27 where the ruled surface offer relatively easily constructed temporary formers for the Catalan vaulting, and they also direct efficient distribution of the tensile reinforcement elements.
Virtually none of the sala creuer includes horizontal or vertical (let alone) flat surfaces which has given our group many new challenges: we have found that careful photorealistic rendering is nevertheless very unsatisfactory in envisaging this ‘unfamiliar’ space, and despite modelling the sala creuer at various scales each scale offers a separate set of ambiguities. In terms of production this space has therefore helped herald in a new age of off-site fabrication for the project with our office establishing a 5 hectare prefabrication site approximately 60 kilometres northwest of the city near Bergà.

4. Concluding comments

I concluded the second of the two pieces for the 1992 Architects’ Journal referred to above with a quote from John Ruskin:

“In 1853, a year after Gaudí was born, John Ruskin made the following observation concerning the widening gap between the designer and the crafts:

We are always in these days endeavouring to separate the two; we want one man to be always thinking, and another to be always working, and we call one a gentleman, and the other an operative; whereas the workman ought often to be thinking, and the thinker often to be working... In each several profession, no master should be too proud to do its hardest work. The painter should grind his own colours; the architect work in the mason's yard with the men; the master-manufacturer be himself a more skilful operative than any man in his mills; and the distinction between one man and another be only inexperience and skill, and the authority and wealth which these must naturally and justly obtain”.

The whole of Gaudí’s architectural experience appears to have been orientated towards further harmonising the art and science of his work during a period of great social and
technological change. Can the opportunities of computers within the design and construction processes, inevitable even for the continuation of the Sagrada Família to remain viable, erode or exemplify holistic architectural endeavour?"\(^5\)

The question I concluded the AJ with over two decades ago was culturally motivated at a time when completion of the building was quite polemical. The interior was consecrated and opened on November 7 2010 and has continued to receive considerable acclaim not least winning Barcelona’s coveted ‘Building of the Year’ award the following year. I believe that undertaking the sala creuer project and taking on new challenges thereby has yielded a fresh set of questions albeit of quite a different note. These include ‘how do we appropriately and convincingly visualise unfamiliar spaces?’ and ‘how can we be more effective sharing 3D models of highly spatially sophisticated projects eliminating the duplications and gaps that risk arising through the complexities involved’ – that is, ‘life beyond BIM’. At least in terms of Ruskin we do have ready pointers towards continuing to enjoy each other’s skills be they design, technical or fabrication; along the way the Sagrada Família Basilica project has revealed a ready assimilation of digital fabrication within an on-going appreciation and take-up of traditional methods in all three domains. Digital does not necessarily spell the end to traditional.

Acknowledgements

I acknowledge the Sagrada Família Basilica Foundation who generously invites university based research teams such as ours to collaborate in the challenges Gaudí has bequeathed his successors. The Australian Research Council provided me with my Federation Fellowship that has afforded the overall research context. The project described here is obviously the work of many.

Endnotes

1 Catalan vaulting “(Catalan: volta catalana), also called Catalan turn, Catalan arch or timbrel vault, is a type of low arch made of plain bricks often used to make a structural floor surface. It is traditionally constructed by laying bricks lengthwise over a wood form or “centering”, making it a much gentler curve than has generally been produced by other methods of construction. It is a traditional form in Catalonia (where it is widely used), and has spread around the world through the work of Catalan architects such as Antoni Gaudí and Josep Puig i Cadafalch.” See Wikipedia, http://en.wikipedia.org/wiki/Catalan_vault [December 2013]
2 The project has made full use of many other software choices especially Rhino 3D™ with Grasshopper™ in recent years. The software listed are the high-end packages originally intended for engineering design.
4 John Ruskin, The Stones of Venice, (The Nature of Gothic) Book II.VI.XXI (1853)