TANGIBLE INTERFACES TO EXPLAIN GAUDÍ'S USE OF RULED-SURFACE GEOMETRIES

Interactive Systems Design for Haptic, Non-Verbal Learning

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Abstract. This paper summarises the development of a machine-readable model series for explaining Gaudí's use of ruled surface geometry in the Sagrada Familia in Barcelona, Spain. The first part discusses the modeling methods underlying the columns of the cathedral and the techniques required to translate them into built structures. The second part discusses the design and development of a tangible machine-readable model to explain column-modeling methods interactively in educational contexts such as art exhibitions. It is designed to explain the principles underlying the column design by means of physical interaction without using mathematical terms or language.

1. Introduction

Architect Gaudí's extensive use of double curved surfaces in the design of the Sagrada Familia is unique in the field of architecture and an extraordinary example of a pragmatic, yet astonishingly elegant design approach. Representing an outstanding cultural and intellectual achievement, these aesthetics and the underlying geometric concepts are consequently of great public interest yet at the same time anything but easy to understand. The challenge is to explain complex geometry to people of various levels of spatial understanding, and to do this effectively, efficiently and across cultural boundaries such as language barriers. This research project aims at developing and providing new types of interactive art exhibits allowing users to explore advanced geometric modelling through manipulating a tangible computer interface using neither mathematical terms, symbols nor spoken or written language.

In place of conventional drawings, Gaudí communicated his design of the Sagrada Família through physical models, most of which were destroyed during the civil war in the 1930s and subsequently restored during the following decades. Their re-construction in form of digital 3D models plays a key role in the process of putting Gaudí's design into practice. Digital 3D models produced for the purposes of actually building the project, and already used collaterally (in this context) to develop explanatory material for the museum, mainly in form of animations and multimedia CD-ROMs. In order to enhance what has up until now been time-based material through physical real-time user interaction, novel types of interfaces and software had to be developed by the internationally collaborating team.

The product - a tangible interface presented in this paper - is a special purpose tangible computer interface feeding parameters changed in physical representations of two-dimensional geometries into the computer where they are translated into an interaction-driven video-projected output animation. It provides an intuitive and easy-to-understand learning tool explaining highly complex spatial operations based on Boolean geometry.

2. Double Helix Columns by Antoni Gaudí

Figure 1 illustrates the procedure by which Gaudí's 'rectangular' double helix column design is generated. Two rectangles are counter-rotated around the common centre point and simultaneously translated along the z-axis. Figure 2 [1] shows the resulting circumscribed volumes manifesting as a physical object suspended in time before and after a Boolean intersection as

[1] visualized by Prof. M.C. Burry and published in [6].

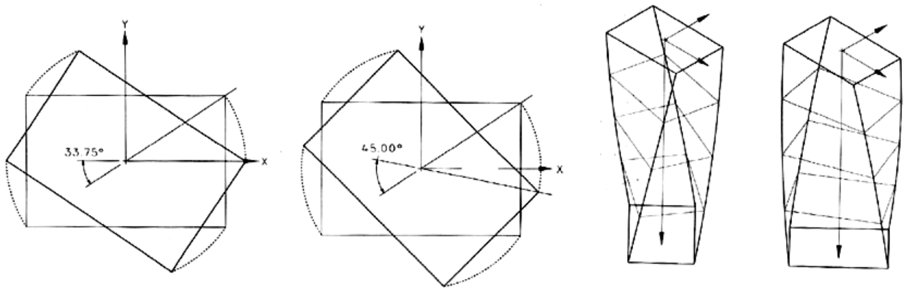

Figure 1: *'rectangular' column-modelling technique: Counter-rotation of two rectangles with a translation along the z-axis*

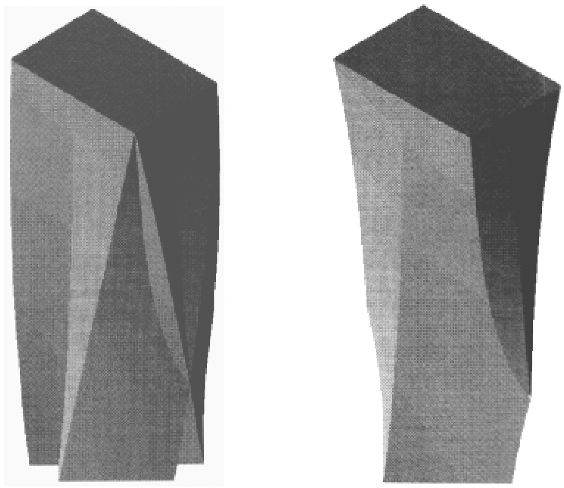

Figure 2: 'rectangular' column geometry before and after Boolean intersection[2]

found in one segment of the main columns of the Temple Sagrada Familia. In numerous variations Gaudí has made extensive use of the wealth of generative possibilities through the application of this principle. The complete columns in the Temple Sagrada Família are combinations of segments based on several of those variations. This generative process (figure 3) is reflected in the physical act of model making (at a scale of 1:10) on the building site of the Temple Sagrada Família.

Of all variations found in the temple design, there are a few relatively simple ones, which are based on rotations of only two profiles (other segments are based on multiple profiles). One of these segments is the rectangular column segment, shown on the right-hand side of figure 2. It is

[2] Taken from Gómez, J, Coll J, Melero J. C. and Burry, M.C: *La Sagrada Familia. De Gaudí a CAD*

found in the upper part of the main columns in the nave just below the point where the square sections – each based on two counter-rotated square profiles – branch out into the ceiling. Of those simple column segments, those with more significant rotation angles (12.5° and above) were selected for explanation by machine-readable models.

4. Machine Readable Model Design

> To display any object to its best advantage,
> be it a painting or a toothbrush,
> is always difficult: but displaying an idea is still more difficult,
> and the exhibition designer is often faced
> with both these problems at once.[3]
>
> [-- Richard Guyatt, 1950]

The three-dimensional volume of Gaudí's column (segment)s is circumscribed by two or more two-dimensional profiles.

As described above, the operation necessary to circumscribe Gaudí's columns is based on at least three (in case of two profiles) variables: The rotation of one profile, the corresponding counter-rotation of the second profile and the simultaneous translation of both profiles along the z-axis. Hence, initial ideas for the model design focused on the simultaneous input of all three variables (movements) similar to the prototyping setup (see figure 3) used to build 1:10 models on the building site in Barcelona. Real-time modeling, rendering of multiple variable input and variable perspective rendering have also been considered during early design stages but dismissed for the sake of simplicity for this first prototype in order to achieve a maximum of clarity during learning interaction. As all variables involved are functionally based on each other, the input of a single variable (rotation of one profile), a mechanical derivation of the second variable (counter-rotation of second profile) and a merely virtual representation of

Figure 3: Prototype modeling process on site in Barcelona

[3] Guyatt, R: *Models and Display Devices*. In Black, M 1950

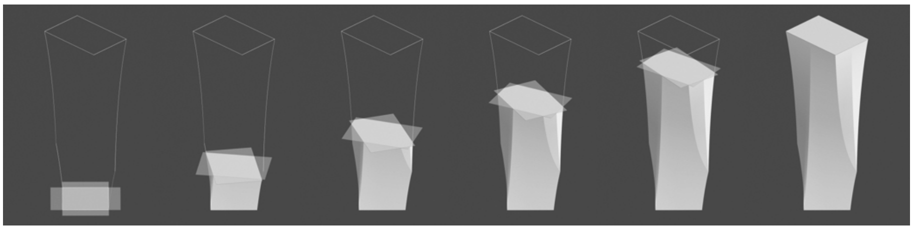

Figure 4: Visual output sequence

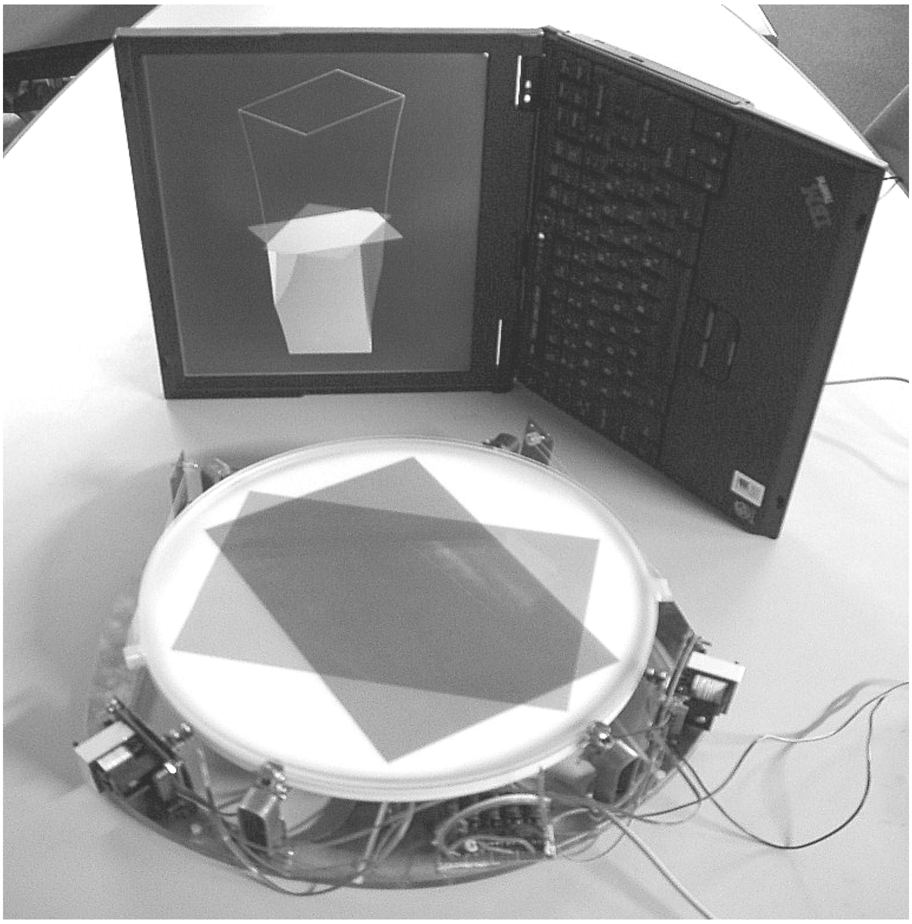

Figure 5: Tangible learning interface

the third variable (translation along z-axis) appear a more appropriate choice. It was thus possible to execute the interface model as a desktop turntable (see figure 5). Both two-dimensional profiles are represented by transparent color filters, which are also represented on the screen. In the overlapping area, both colours mix to a third colour which at any height represents the according plane column section.According to users rotating one profile, the model automatically counter-rotates the second profile. A rotation sensor feeds this movement into a computer that interactively displays generated column segments (see sequence in figure 4). An interactive backlight for the coloured profiles and sensors for continuous auto-calibration have been installed.

Figure 5 shows the tangible model design (video screen is turned sideways to match the vertical orientation of the subject). Casings can be designed separately according to requirements in different exhibition scenarios. In contrast to previously produced mouse-controlled interaction interfaces with animation renderings, this setup allows the input of real-time data for the original rotation movement directly, involving haptic and visual input and feedback and thus allowing active, multi-sensual and user-driven learning.

As in previous haptic interface developments[4], the computer between input interface and output display, converting an analog input movement into an analog output visualization through an interim digital stage, is not visible to the user in its accustomed form with mouse and keyboard. It exclusively translates haptic user input into output, thus acting as a single-purpose machine whereas computers and their standard user interfaces are typically designed for multiple purposes. The advent of purpose-oriented interface design in architecture and learning requires interface and model designers to act as toolmakers[5] and to build complex computer-enhanced models for known purposes in defined scenarios.

5. Model Building: Conclusion

The design and implementation process of this special purpose computer interface represents typical leads we can expect from post-industrial and post-digital designing and building. Involving only a very limited number of products (as normally found in art or architecture) but high production accuracy and CNC manufacturing of CAD plans, it involves new industrial tools and methods such as laser cutting and CNC milling on one hand. On the other, it involves hands-on handicraft for those subtasks, which due to the small number of output products, cannot be supported by industrial tools (e.g. chassis bending and circuit board soldering work).

[4] see for example: Fischer, T., Ceccato C. and Frazer, J.H.: *Haptic Programming with Machine-Readable Models*. In: Burry, C.M. et al. (ed.): 2001

[5] Ceccato, Cristiano [1999]: Microgenesis. The Architect as Toolmaker: Computer-Based Generative Design Tools and Methods.

The context of readily available access to rapid prototyping and production engineering facilities has provided particular efficiency and played a key role in the design and implementation phases. Having these advanced CAD-CAM facilities available to the collaborators including advanced computerisation and high production speeds, the team has been provided with an ideal background for this type of one-off purpose-centered (post)digital interface development, thus supporting novel types of learning locally and abroad. This perhaps will become more the norm and less the exception in extending the role of computers in spatial design education.

Acknowledgements

The authors acknowledge the contribution of the Sagrada Família technical office and Construction Committee in providing the purpose and motivation for this project. In particular, the Coordinating Architect and Director Sr Jordi Bonet is acknowledged for his insights especially with regard to the counter-rotating coloured profiles used in the haptic interface. The authors also acknowledge the considerable support from academic and research staff of the School of Design, especially the School of Design's Interactive Systems Design stream (led by Assistant Prof. Catherine Hu), the Design Research and Technology Centre and especially Cristiano Ceccato who continued contributing vital ideas to this project after changing his workplace. We also acknowledge the excellent support by Yasu Santo (Lingo programming) and SD's hands tool workshop staff, in particular Johnson Tam.

References

Black, M. (ed.): 1959, *Exhibition Design*. The Architectural Press, London, UK

Burry, M.C.: 1993, *The Expiatory Church of the Sagrada Familia*. Phadion, London, UK

Ceccato, C.: 1999: *Microgenesis. The Architect as Toolmaker*: Computer-Based Generative Design Tools and Methods. In: Soddu, C. (ed.): The Proceedings of the First International Generative Art Conference. Generative Design Lab at DiAP, Politecnico di Milano University

Fischer, T., Ceccato, C. and Frazer, J.H.: 2001, Haptic Programming with Machine-Readable Models. In: Burry, C.M. et al. (ed.): 2001, *The Proceedings of Mathematics and Design 2001 – The Third International Conference*. School of Architecture and Building, Deakin University, Geelong, Australia, pp. 158-165

Fischer, T., Herr, C.M. Herr and Ceccato C.: 2000, Towards Real Time Interaction Visualization in NED. In: Clayton, M.J.: 2000, ACADIA Conference Proceedings, Catholic University, Washington D.C

Frazer, H.J., Coates, P.S., Frazer, J.M.: 1983, 'Software and Hardware Approaches to Improving the Man-Machine Interface', *Computer Applications in Production and Engineering Conference*, Amsterdam, proceedings of First International IFIP Conference, North Holland 1983, pp. 1083-94.

Frazer, J.H.: 1995, *An Evolutionary Architecture*. Architectural Association, London, UK

Gómez, J., Coll J., Melero J.C. and Burry, C.M.: 1996: *La Sagrada Familia. De Gaudí a CAD*. Edicions UPC. Universitat Politècnica de Catalunya, Spain

Margarit J. and Buxade C.: 1969, *Calculo de Estructuras en Paraboloide Hiperbolico*. 1st edition. Publicationes del colegio official de architectos de cataluna y baleares, Spain

Velarde G. 1988, *Designing Exhibitions*. The Design Council, London, UK

The official Gaudí 2002 Barcelona / International Gaudí Year Web site: http://www.gaudi2002.bcn.es

Deakin University's Temple Sagrada Familia and Gaudí Web site: http://sagfam.deakin.edu.au