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# CAADence

in architecture

## Back to command

Edited by Mihály Szoboszlai

# 2016 CAADence in architecture

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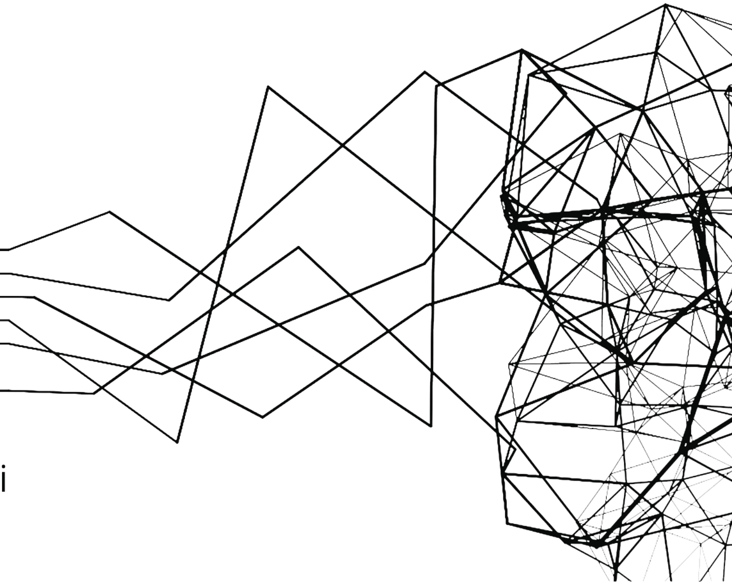

**Editor**

Mihály Szoboszlai
Faculty of Architecture
Budapest University of Technology and Economics

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Computer Aided Architectural Design

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# Theme

## CAADence in Architecture
## Back to command

The aim of these workshops and conference is to help transfer and spread newly appearing design technologies, educational methods and digital modelling supported by information technology in architecture. By organizing a workshop with a conference, we would like to close the distance between practice and theory.

Architects who keep up with the new design demanded by the building industry will remain at the forefront of the design process in our IT-based world. Being familiar with the tools available for simulations and early phase models will enable architects to lead the process. We can get "back to command".

Our slogan "Back to Command" contains another message. In the expanding world of IT applications, one must be able to change preliminary models readily by using different parameters and scripts. These approaches bring back the feeling of command-oriented systems, although with much greater effectiveness.

**Why CAADence in architecture?**

"The cadence is perhaps one of the most unusual elements of classical music, an indispensable addition to an orchestra-accompanied concerto that, though ubiquitous, can take a wide variety of forms. By definition, a cadence is a solo that precedes a closing formula, in which the soloist plays a series of personally selected or invented musical phrases, interspersed with previously played themes – in short, a free ground for virtuosic improvisation."

Nowadays sophisticated CAAD (Computer Aided Architectural Design) applications might operate in the hand of architects like instruments in the hand of musicians. We have used the word association cadence/caadence as a sort of word play to make this event even more memorable.

Mihály Szoboszlai
Chair of the Organizing Committee

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This conference was supported by our sponsors: GRAPHISOFT, AUTODESK, and STUDIO IN-EX. Additionally, the Faculty of Architecture at Budapest University of Technology and Economics provided support through its “Future Fund” (Jövő Alap), helping to bring internationally recognized speakers to this conference.
Members of our local organizing team have supported this event with their special contribution – namely, their hard work in preparing and managing this conference.

Mihály Szoboszlai
Chair of the Organizing Committee

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Reinhard König studied architecture and urban planning. He completed his PhD thesis in 2009 at the University of Karlsruhe. Dr. König has worked as a research assistant and appointed Interim Professor of the Chair for Computer Science in Architecture at Bauhaus-University Weimar. He heads research projects on the complexity of urban systems and societies, the understanding of cities by means of agent based models and cellular automata as well as the development of evolutionary design methods. From 2013 Reinhard König works at the Chair of Information Architecture, ETH Zurich. In 2014 Dr. König was guest professor at the Technical University Munich. His current research interests are applicability of multi-criteria optimisation techniques for design problems and the development of computational analysis methods for spatial configurations. Results from these research activities are transferred into planning software of the company DecodingSpaces. From 2015 Dr. König heads the Junior-Professorship for Computational Architecture at Bauhaus-University Weimar, and acts as Co-PI at the Future Cities Lab in Singapore, where he focus on Cognitive Design Computing.
Main research project: Planning Synthesis & Computational Planning Group see also the project description: Computational Planning Synthesis and his external research web site: Computational Planning Science

## BRANKO KOLAREVIC

Branko Kolarevic is a Professor of Architecture at the University of Calgary Faculty of Environmental Design, where he also holds the Chair in Integrated Design and co-directs the Laboratory for Integrative Design (LID). He has taught architecture at several universities in North America and Asia and has lectured worldwide on the use of digital technologies in design and production. He has authored, edited or co-edited several books, including “Building Dynamics: Exploring Architecture of Change” (with Vera Parlac), “Manufacturing Material Effects” (with Kevin Klinger), “Performative Architecture” (with Ali Malkawi) and “Architecture in the Digital Age.” He is a past president of the Association for Computer Aided Design in Architecture (ACADIA), past president of the Canadian Architectural Certification Board (CACB), and was recently elected future president of the Association of Collegiate Schools of Architecture (ACSA). He is a recipient of the ACADIA Award for Innovative Research in 2007 and ACADIA Society Award of Excellence in 2015. He holds doctoral and master’s degrees in design from Harvard University and a diploma engineer in architecture degree from the University of Belgrade.

# Performance-oriented Design Assisted by a Parametric Toolkit - Case study

*Bálint Botzheim[1], Kitti Gidófalvy[1], Patricia Emy Kikunaga[2], András Szollár[2], András Reith[1,2]*

*[1]Mérték Architectural Studio Ltd., [2]ABUD Engineering Ltd.*
*[2]e-mail: reith.andras@abud.hu*

**Abstract:** *Ongoing development of Budapest Zoo includes a Biodome building which is going to be the largest building of its kind in Europe. The Biodome was designed by Mérték Architectural Studio, supported by ABUD Engineering Ltd providing sustainability design. This paper describes a parametric method developed particularly for this project focusing on performance-oriented design. The parametric approach was used not only for describing and designing the complex geometry of the Biodome but helped structural engineering and sustainability design also. Several geometry variations were generated by the parametric system and these were run through preliminary structural simulations by built-in plugins. Therefore, the structural form resulting from the preliminary analyses was already close to optimal and the structurally ideal version could be identified at a very early design phase. The parametric system could also inform the sustainability design process directly. To find the version of the building with the smallest ecological footprint, Life Cycle Assessment was carried out on different building material scenarios. Solar radiation and shading analyses were performed to optimise building energy consumption by using integrated simulation tools. As a result of the parametric definition and combining different design and engineering parameters into one parametric system we got an integrated tool for performance oriented design.*

**Keywords:** *Keywords: Parametric design, Free-form, Grid Shell, Shading Design, Life Cycle Assessment, Sustainable Design, Environmental Analysis, Structural Optimization, Performance Oriented Design*

**DOI:** *10.3311/CAADence.1666*

## INTRODUCTION

The Budapest Zoo and Botanical Garden has been granted a new territory in 2014. with the site of the former Budapest Amusement Park. New developments started on this site called Pannonpark and Tale Park. The main feature of the Pannon Park will be a special building called Biodome, wich will function as a covered zoo. The interior will be inhabited with plants and animals in the artificial subtropical climate of the building. The building is divided into three parts: the Visitor Center, the Pannon Wilderness, and the Waterworld including the Pannon Sea Aquarium.

One of the attractive feature of the building will be the undulating, large span roof, planned to be made of steel and ETFE foil. It will incorporate four

Figure 1:
Aerial render of the Biodome in the context of the Zoo

domes and covers the whole 17500 $m^2$ floor area of the building. Freeform roofs are becoming not only a universal structural solution [1] for contemporary buildings, but often referred as a building skin [2] that integrates structure and facade into one architectural element. The Biodome's double curved roof will act as an intelligent skin, which will be able to react to the weather with shading to ensure the interior visual and thermal comfort.

Responding to the need of the 21st century's progressive design innovation, parametric design has an important role in the design process at Mérték Architectural Studio. New specialism referred as parametric design, includes the development, control and sharing geometry information within the design team, and explores multiple solutions related to an architectural design problem, with the use of parametric systems. [3] Rhino / Grasshopper is the most popular and widely used platform for parametric design. The platform is in the focus of programmers thus a plenty of plugins have been under development to help architectural designers. A parametric environment such as the Rhino / Grasshopper platform allows the design team to make their own parametric design tools. [4][5] This is made by algorithmic modelling and integrating simulation plugins into the parametric definition. The benefits of the parametric design approach are clearly demonstrated by the works of the Specialist Modelling Group at Foster and Partners. [6]

## PARAMETRIC DEFINITION OF THE COMPLEX GEOMETRY

There was a need to squeeze as much space into the site as possible to achieve the 17,500 $m^2$ floor area required. For this reason, the base contour of the Biodome follows the L-shaped site with the chain of curves tangent to each other. The base geometry of the Biodome roof structure is a freeform surface which is generated from a network of curves. The contour curve on the xy plane is made of arcs tangent to each other. (Left on Figure 2) There is another base-curve referred as z-silhouette curve which determines the silhouette of the final Biodome shape. Endpoints of the silhouette curve define the right and the left boundary of the shape. Additional 3 point curves are generated with starting points on the right boundary of the 2D contour, midpoints on the z-silhouette contour and endpoints on the left boundary of the 2D contour. This network of curves defines the base surface, which serves as an envelope for the grid points of the roof structure of the Biodome. (Right on Figure 2)

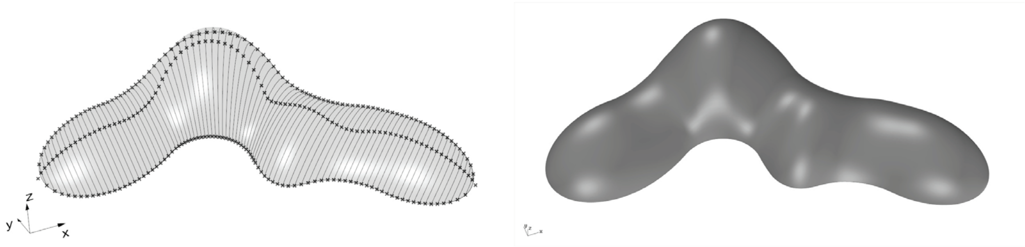

Figure 2:
Left: the base contour curve, the z-silhouette curve and the network of curves; Right: the envelope surface

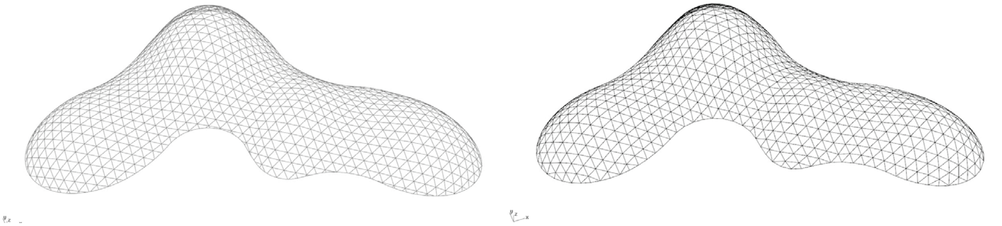

Figure 3:
The basic and the final triangulation generated using Kangaroo 3D

## ROOF GRID GENERATION

An integrated physics engine called Kangaroo 3D [7] was used to generate a triangular grid, constrained to the double curved envelope surface. (Figure 3) The goal of this process was to achieve an effective triangle grid, by its size and topology. The starting geometry of this process was an equally spaced triangle point grid. The physics engine distributed it on the envelope surface. For the physics engine, linear springs are assumed between the grid points, while each point is pulled to the surface with a force. [8] The physics engine finds the equilibrium state of this model with an iterative process. The resulting triangular grid was then simply cut along the boundary (Figure 4). The structural designers suggested to avoid short and steep line elements close to the boundary. On one hand, short line elements may get overstressed under temperature load, while too steep elements may not transfer any load. On the other hand, it is uneconomical to have too many joints.
Thus the grid had to be refined. (Figure 5.)
Thus in a separate Kangaroo task, the boundary edges of the geometry were pulled to match its topology for the grid, by constraining the closest points of the naked edges to the 2D boundary contour curve. Figure 6 shows the input and the result of this process with highlighted boundary points. Grey lines are deleted after the process, while the red lines are considered with 60% of the target edge size of the blue edges to avoid too short beam elements. This process was also useful to obtain the required mesh density: as the design process advanced, the triangle edge size needed to be increased to reduce overall cost. This was achieved by modifying the input boundary points. Due to the mesh generation process explained above, the triangular point grid obtained is distributed on the envelope surface to a given domain distance from each other.

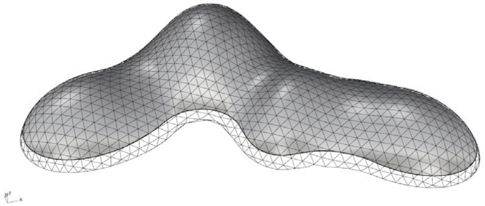

Figure 4:
The base grid after the Kangaroo simulation. The black curve indicates the plane of cutting

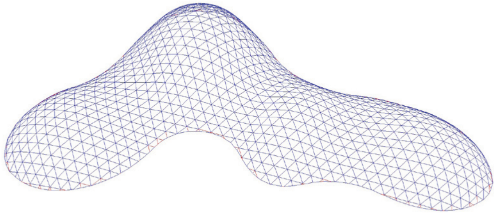

Figure 5:The number of short and steep beams around the boundary needed to be reduced

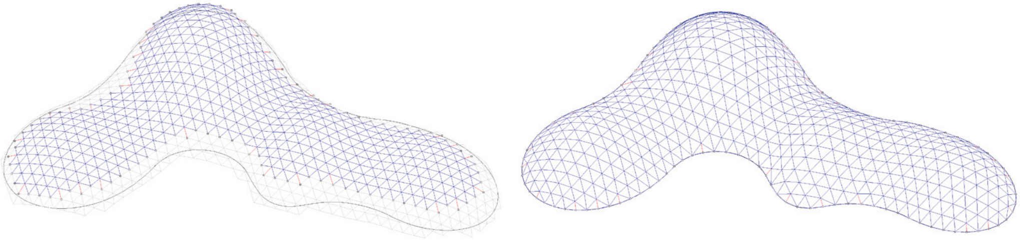

Figure 6:
The points of the triangular grid close to the boundary edges pulled to these edges using Kangaroo simulation

## COLLABORATION WITH STRUCTURAL ENGINEERS AND CONCEPTUAL SIMULATION

Due to the freeform shape of the Biodome structure, there is a close relationship between form and structural behaviour. Consequently, frequent collaboration was required with the structural engineers. A required centerline model was generated from the parametric model to speed up the communication between the design software and the engineering software.

From the very beginning of the project, also conceptual simulations were made, by an integrated Grasshopper plugin called Millipede. [9] This tool can visualize the deflection of the structure on gravitational loads, which helped to recognise the problematic zones of the structure. At the conceptual phase, several structural versions were compared including catenary based and circular based forms of the Biodome.

One of the most important decisions was to find a structurally ideal and aesthetic shape. [10] Catenary curves (blue on Figure 7) and arc based curves (biarc: green, arc: orange on Figure 8) with varying maximal heights were defined as a basis for the network of curves. The final choice for the section curve was the catenary curve based on aesthetic and structural aspects.

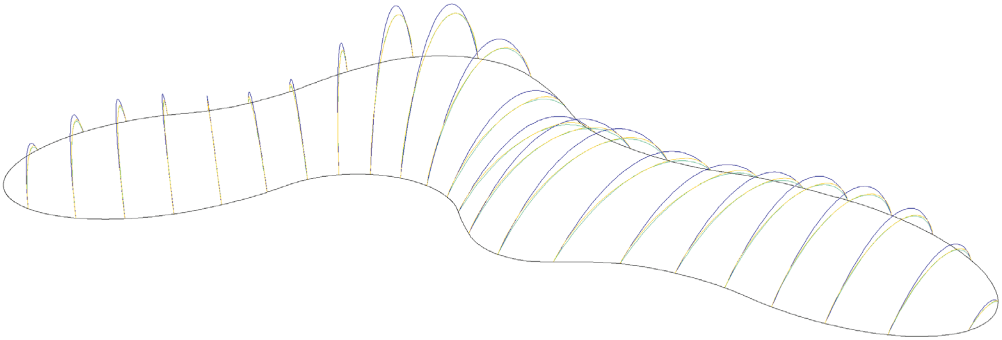

Figure 7:
Various section curves on the base contour

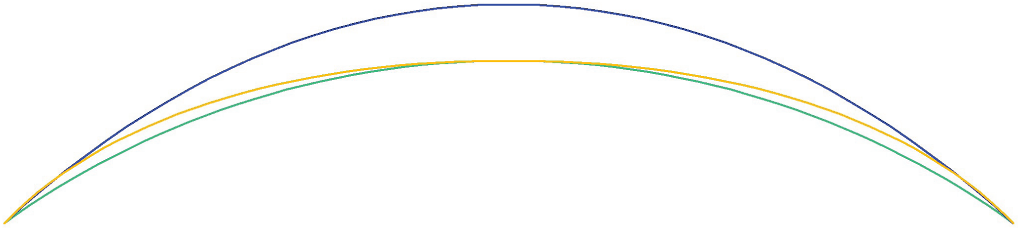

Figure 8:
Various section curves (catenary: blue, biarc: orange, arc: green)

## REACTIVE SOLAR DESIGN

The whole roof area of the Biodome will be covered by ETFE foil. [11] Preliminary analysis was made to compare Biodomes in Europe by their inner target climate, vegetation and the climate of their location. The Budapest Biodome will have the southernmost location in Europe. Also, comparing the amount of vegetation, we can see that the Budapest Biodome will embrace less vegetation than other Biodomes. Due to the low latitude, the solar radiation received by the building will be higher. At the same time, the cooling effect resulting from evapotranspiration will be smaller than on typical European Biodome sites. The main challenge for the engineering team was to find the optimal ratio between the use of active and passive design measures to ensure the required indoor lighting and thermal comfort conditionsFor all inhabitants of the Biodome, such as plants and animals and also for users of the Biodome, such as visitors and zookeepers. The aim was to cut down the use of active tools, such as high energy consuming HVAC

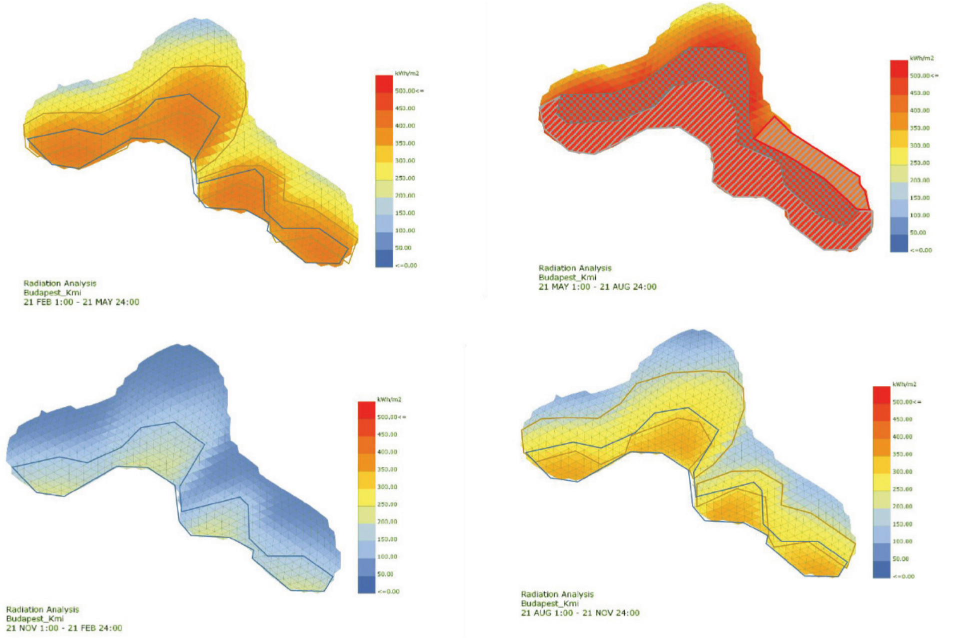

Figure 9:
Ladybug seasonal sums

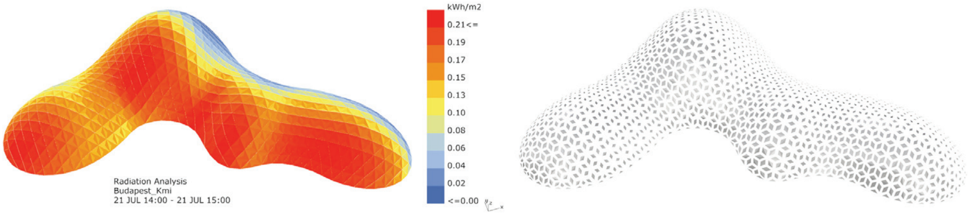

Figure 10:
Shading reactive to the radiation

systems by the use of passive solutions. Flexible shading system will be applied to the whole structure to ensure sufficient shading in the summer period and maximum light in the winter period. In a collaboration with the engineering team, solar radiation analyses were made with the use of an environmental plugin called Ladybug [12]. The plugin was integrated into the Grasshopper algorithm, thus the simulation could run on the original geometry, without the need of remodelling. Solar radiation analysis was carried out on the outer surface on specific dates and times to find out the minimum and maximum amount of radiation throughout the year. Additionally, seasonal sums were generated to identify the zones with the most and least amount of shading required. (Figure 9) Based on the results, the engineers could prescribe the operation of the shading system in a seasonal manner. Moreover, daily pattern of the shading operation could also be prescribed based on weather changes. Thus the shading system will be able to adapt to the seasonal needs but can also react to the rapid changes of the weather driven by real time data from sensors installed. (Figure 10) Figure 11 shows the complete Grasshopper 3D definition.

## LIFE CYCLE ASSESSMENT

Throughout the design process, sustainability aspects have been of high priorities. Life Cycle Assessment was performed in a separate non-parametric task to find the smallest ecological footprint version of the building. Material quantities for this study were generated directly from the parametric model. The first step for this type of assessment is the identification of key building materials which can be evaluated based on their ecological impacts. The second step and the most critical factor is the amount of these materials, which the building uses. Accordingly building materials were studied and sorted by their ecological footprints. This included steel, concrete and timber as structure material, glass and ETFE as building enclosure materials, and different types of surface treatments (galvanisation, painting etc.) for the structure. Different types of topologies of the grid structure were also studied this way to understand their ecological footprints. The three topologies were a square grid, a basic triangular grid and a relaxed triangular grid referred as geodesic grid (this was the final option generated using Kangaroo). Then scenarios were created, using different materials in combinations with the different structure grid topologies

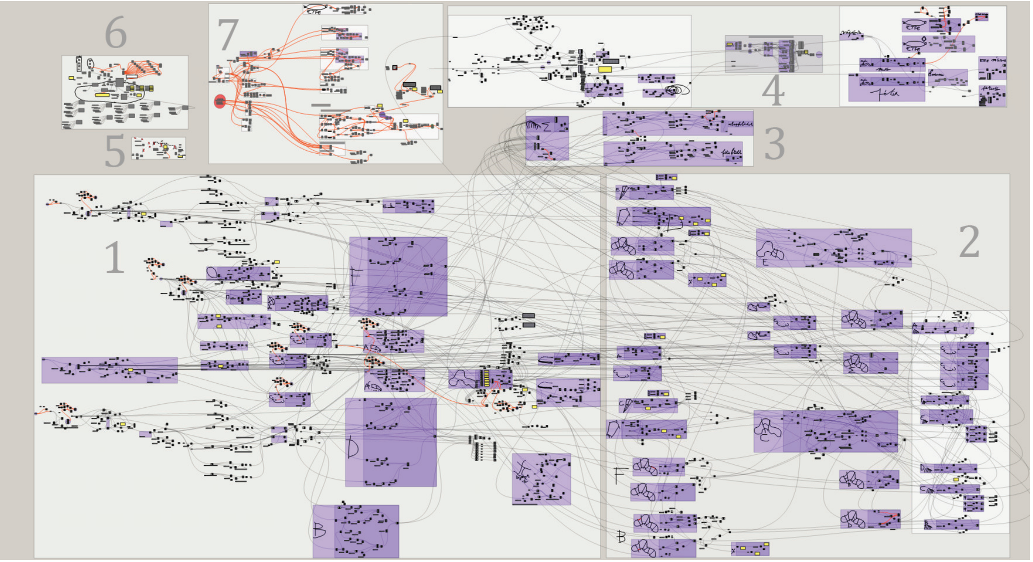

Figure 11:
The complete parametric definition of the Biodome: 1, contour curve generation; 2, z-silhouette curve generation; 3, curve network and envelope surface generation; 4, mesh grid generation and optimisation; 5, preliminary structural simulation; 6, environmental simulation; 7, shading generation

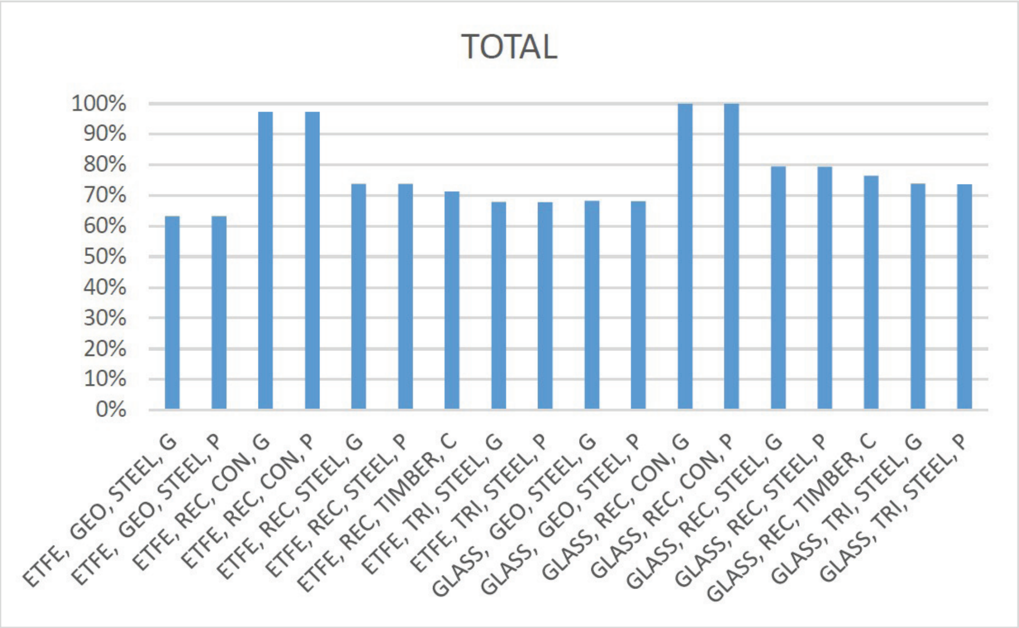

Figure 12:
LCA results comparing the total environmental impacts of all options

with their proper quantity of use. Then scenarios were compared to find theversion with the lowest environmental impact.(Figure 13) Since the environmental impacts were directly related to the amount of materials, the more the total quantity of materials was, the higher the embodied impact of the building became. The conclusion of the assessment was that the best option is the geodesic triangular grid with ETFE covering.

## CONCLUSION

Architecture in the 21st century is about formal innovation and environmental performance. Parametric tools stands all these demands from the early conceptual to the construction drawing phase of the project. Parametric tools can also handle the complexity of the geometry that can be generated only via an algorithmic process. The benefit of the algorithmic approach is that it can generate various versions of the design very quickly. Besides this, the environmental and structural performance can also be successively monitored during the design phases with integrated plugins and in-house tools. To constrain the number of versions to be evaluated, the variables were defined according to the key design performance indicators. The parametric model with this feature functioned as a design tool that enabled the development of key versions for discussion with the design team. As the project moved forward, design decisions were made along these conversations between the parties.

Traditional CAD systems were made to be digital drafting tables to make plans follow the design as a static entity. Today parametric programming environments like Rhino/Grasshopper 3D give the possibility to generate versions of design according to a design intent. Thus design is no more acting as an answer to a question but as field of possibilities related to a specified design problem. The way to the final plans resulted in series of decisions. In the parametric age, Architectural Practices are facing the challenge of developing their own design toolkit project by project. To address this, parametric environments need to be improved to integrate engineering phases seamlessly

## ACKNOWLEDGEMENTS

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# Author's index

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