## Introduction

In our days, singular projects are turning extremely complex in a variety of ways. Architects and engineers have to address a wide range of variables and issues during the design process in order to give the best answer to the needs of the project, the client and the site.
This complexity can be linked to four different sources:

**Geometrical complexity:** Recent architecture, especially singular architecture, shows a recurrent preference for non-Euclidean, organic forms. Designers no longer commit to the plan-elevation-section paradigm but instead they propose buildings without any rigidity in their geometry. Projects are becoming increasingly more difficult to describe from the traditional-projective manner, and parts and pieces should be detailed without making any assumptions. Moreover, projects start to reflect some sort of mass customization optimism, and present big amounts of similar-but-not-equal parts that have to/should be understood as process-dependent rather than as part of a series.

**Human complexity:** Current projects are developed by teams, groups of people specialized in particular areas, with different responsibilities and points of view. Architectural projects, especially larger ones, are no longer defined by *one* architect. Inter-disciplinary is a key today and design should be collaborative, communicative and de-centralized. The complexity here arises when different ideas have to be put together into a unique arrangement.

**Technological complexity:** As science and techniques evolve, some of them are transferred to the architectural realm. Architects and engineers are now more capable than ever of analyzing and predicting the behavior of their designs, and accordingly, the level of demand laid on the projects is maximal. The regulation requirements to be met by designs are strictly defined and the designers' competence is no longer assumed, but has to be demonstrated and documented for all the conditions established in the codes.

**Constraint complexity:** Projects are not seen any longer as sets of independent parts driven by independent concepts. As happens inside the designer's mind, each part, dimension or parameter of a project is deeply interconnected with several others. The width of a corridor, the number of seats in a row, the transmittance of a window... every variable can be evaluated from a global approach related to regulations, data analysis and geometrical inputs. Such a level of interrelation among parameters unveils an enormous complexity if every variable of a project is meant to be optimized.

In the same way, the development of tools, processes and design protocols can be seen as targeted to the management of these different types of complexity.

Initially, Computer Aided Design (CAD) packages allowed dealing with geometrical complexity by representing architectural objects in an abstract and two dimensional way. 3D modeling followed with the development of flexible and precise mathematical models and programs, ultimately making the production of planar representations –still the standard in architecture– an automatic process.

Then, Information and Communication Technologies (ICT) rapidly paid attention to collaborative design and thus, specific processes and tools were created to support teams working on the same project, trying to ease the coordination of information.

Besides, Computer-Aided Analysis (CAA) and Computer-Aided Manufacturing (CAM) tools were transferred from the mechanical realm to the architectural and building sector, engineers being capable of performing detailed analyses and simulations over design models. This implied the dismissal of simplified design methods and models traditionally applied to building definition, and each project was henceforth treated as a special case with enormous amounts of analysis output data. However, many of those simulation and analysis processes seem to take place in the late phases of design, and hence their impact on the general decisions and project configuration tends to be reduced.

Finally, several software technologies have arisen seeking to integrate the profound variety of constraints present in an architectural project. The Project/Product Lifecycle Management (PLM) approach was distilled into the Building Information Modeling technology (BIM) specifically developed for the building industry. Architectural objects are modeled, related and linked between them not only from a geometric point of view, but also including a large amount of data –from the material of an object to the web page of the supplier.

Unfortunately, all the effort done to provide more flexible, more stable and more capable tools is not enough to ensure the optimal result when these tools are used on a specific project. In our opinion, the specific complexity of a given project can only be faced by defining ad-hoc processes and protocols.

Custom tools should combine the four exposed technologies in such a way that the design is consciously dependent on them, and that the four types of complexity described above are controlled and balanced towards the best affordable result. At this point, our approach consists in explicitly expressing those processes, methods and protocols in the form of customized tools and programs, specifically tailored for the design problem under study.

In the following pages we present three experiences of customized design processes through the development of special tools and methods tightly connected to the project's constraints and issues. Our tools are based on different platforms, languages and algorithms, depending on the needs of the client, the project, and the team involved in its development.

## Study Cases

### MKS Cracovia Stadium - Kraków (Poland)

In December 2007, the city of Kraków selected a winner project of an international architectural competition for the refurbishing of MKS Cracovia Stadium [1]. The project's primary goal was to enlarge the venue from 6,500 seats to 15,000. Another goal was to convert the stadium into a UEFA four-star category, which means that the entire seating bowl should be roofed.

The main constraint of the project was the very strict urban regulations that only allowed the building to be 20-meter high on its southern façade and only 10-meter high on the northern one. The underlying reason was the landscape surrounding the stadium, as it is located on the border of a green area of the city, looking towards the Pope's Castle. The new premises, with all covered seats as the UEFA requires, could not break the view of the castle. Another big constrain was the plot itself because of its size and form factor. The space around the field was tight and a new 30,000 $m^2$ stadium had to be built in there. The winner team, a Spanish consortium formed up by Estudio Lamela and SENER, was able to fit the stadium while complaining with this tight constrains.

SENER acted as a sport design leader inside the consortium and was the one to define the bowl and the structure of the stadium. The challenge of the project was to fit the bowl of the stadium within the above mentioned constrains while ensuring the best quality of vision and comfort possible for the 15,000 spectators. Once the internal volume was fitted, the architectural team lead by Estudio Lamela was able to develop an architectural solution that respected the conditions and atmosphere of the surroundings. The proposed configuration would not compete but supplement the existing space - the vicinity of the Błonie National Museum.

The first decision taken during the competition phase was to take advantage of the new architectural tools based on BIM methodology, which allowed the design team to work in a coordinated 3D environment. The tool selected was REVIT, from Autodesk. This software is based on a parametric engine where specific objects called *families* maintain relationships and restraints among them. [2]

The Constrain Complexity to be solved was the ability to maintain an acceptable quality of vision, also known as C value, while the bowl was as close as possible to the pitch and lower enough to fit on the permitted height. This geometrical problem was established inside a family element that represented a grandstand of the stadium.

The parameters that meant a problem were the row depth, the riser step between rows, a C minimal value, and the location of the first row in relation to the pitch (X and Z distances). A change in any of these parameters generated a new grandstand profile with a different total height on the last row. [3]

The approach followed provided the design team with different geometrical solutions that complied with the project restrictions. This first approach to design a stadium was successful.

Some of the advantages were:

- Definition of core geometry was faster than by doing it on the traditional 2D way.
- 3D BIM environment permitted the changes to be automatically distributed over the entire project, and hence plans, sections, elevations and 3D views were always updated.

But the approach still lacked of some functionality, such as knowing in real time the total number of seats. There was still a semi-automated process for the deployment and layout of seats, corridors and vomitories. We could only know the total number of seats once the layout would be completed (Figure1).

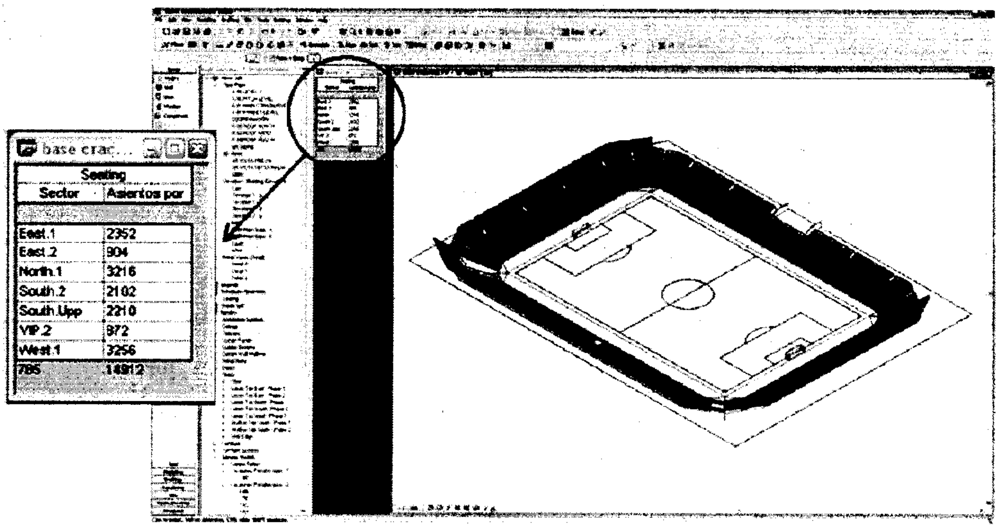


**Figure 1 :** Bowl definition with total number of seats

On a process of learnt lessons we tried to upgrade our capabilities on the next stadium we designed.

<u>ŁKS Stadium – Łódź (Poland)</u>

In October 2009, the municipality of Łódź called for bids on the design of a new football stadium [4] with 35,000 seats to be placed next to the existing Atlas Arena. This operation was framed within the Euro Cup 2012 investments. The stadium should re-utilize an existing field, which should remain in use during the regular season. Together with the sport venue, some complementary facilities and real estate units had to be designed.

For the development of the bid, SENER partnered with AGG, a local Polish architectural firm which should provide conceptual and urban design, visual definition and regulation advice. On its side, SENER would contribute with functional scheme and structural, safety and energetic design. A main part of SENER's duty was to define the seating bowl and ensure its parameters in terms of quality of vision and safety.

The seating bowl is the main structure of any sport venue. It defines the capacity of the stadium and conditions all supporting structures and facilities [3, 5]. Soon became clear that both teams should be able to explore different bowl arrangements and quality parameters in order to accommodate all the seats and the surrounding program. To afford this flexibility, a customized and complete bowl design tool was to be developed, since no convenient commercial software for bowl design was available at that time, and we already had previous experience of designing a stadium. The first step of the development was to set the requirements and specifications for the tool:

- **Integration:** Our tool should work on top of one of the CAD platforms used by the partnership. Instead of being a standalone application, it should integrate within our workflow without any information conversion.
- **Three-Dimensional:** Seating bowls have been traditionally designed trough specific sections which then were extruded to form the complete bowl. In our case, we wanted to ensure the quality of every view and also obtain the preliminary position of each seat; therefore our tool had to work in 3D.
- **Complete:** The tool should include not only the seats but also the corridors paying attention to fire escape routes and widths. Besides, the tool should be able to construct the stands and place every seat correctly for drawing extraction and further documentation.
- **Flexible:** We should be able to adjust the behavior of the tool at every step of the bowl calculation process. Manually fine-tuning the results was an important feature that would save considerable development time while allowing us to reach the best feasible solution.

Accepting these four conditions, we moved on to develop the tool in Grasshopper, a visual programming interface that runs on top of Rhinoceros, our standard modeling package. The algorithm structure can be described following the diagram (Figure 2).

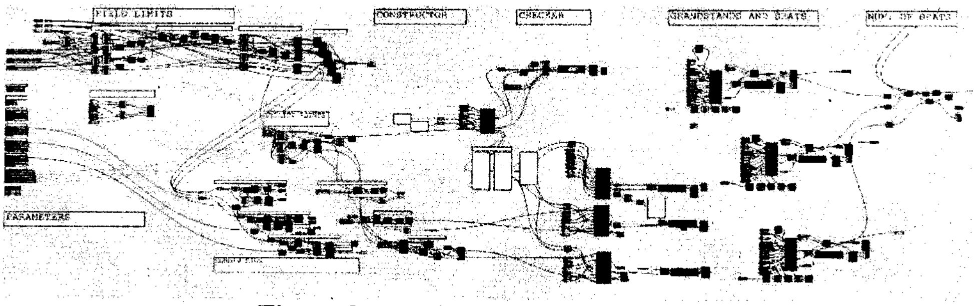

**Figure 2 :** Bowl Tool Symbolic Diagram

Basic parameters include field dimensions, offset from field, number of rows, minimum quality of vision values, seat dimensions and corridor width and positions. Besides, two lists with feasible dimensions for stands depths and heights are provided.

With these inputs, the tool calculates preliminary sections along the whole bowl ring. These sections are checked and can be manually tuned. After that, the whole structure's quality of vision is tested at every seat, and feedback is presented in the form of color gradient maps.

Next step consists in placing the vomitories and corridors, and then all the seats are arranged in an optimum way along each row. The total number of seats is calculated and displayed together with the quality-of-vision values.

Figure 3 shows different combinations of parameters, with the total number of seats for each stands level clearly reflected.

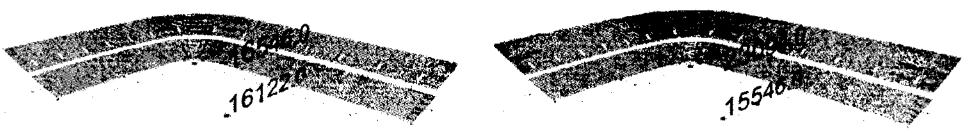

**Figure 3 :** Seating Bowl Configurations.

Together with the quality-of-vision values, the tool outputs the whole seating bowl as a set of Nurbs surfaces and the seats as a set of meshes. These objects were used in further development of the project and also for visualization purposes, as shown in Figure 4.

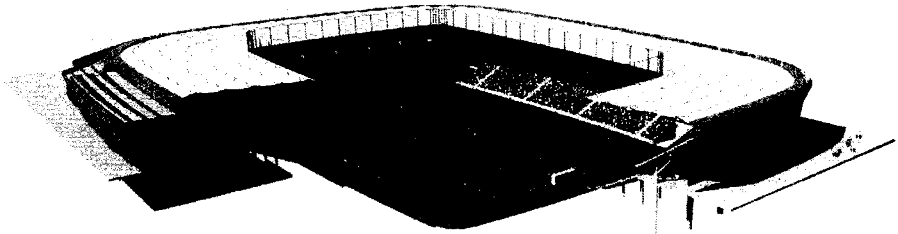

**Figure 4 :** Complete 3d Model of the Stadium.

La Laguna Transport Hub

In February 2009, the Metropolitan Transport Authority of Tenerife Island, Metropolitano, commissioned SENER the design and supervision of a new transport hub in San Cristóbal de La Laguna [6]. The new infrastructure should incorporate 22 bays for public buses, 210 parking lots and commercial and waiting areas.

For the bus station level, the client selected a configuration with a thick triangular roof covering the bays and commercial areas (Fig.5). The roof had to resemble a volcanic stone, so the concept included some holes in the roof structure. Despite the heavy appearance, the whole roof structure had to be lightweight, and had to ensure the basic stability and shelter against wind and rain. It also had to be easy to assemble and maintain, so a system of sheet metal trays with steel framed substructure was picked to solve the whole roof. (Fig.6)

**Figure 5 :** General View. La Laguna Hub.

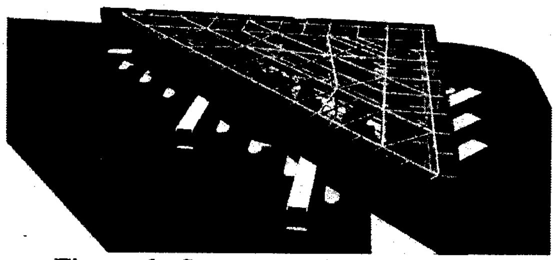

**Figure 6 :** Structure and façade system.

Part of the *volcanic stone* concept relied on a level of geometrical complexity and apparent randomness which should be accomplished with a basic system of regular pieces. Our work in this particular case was not focused on developing one single application to manage that complexity, but intended to define a complete process that could, on the one hand, assure a certain level of simplicity in the geometry of the roof and, on the other hand, control the shape and position of each tray while minimizing the waste of material.

Preliminary meetings with contractors and suppliers were held in order to adapt the design to industrial standards and processes, advancing some work for the later bidding phase. All the suppliers provided a similar description of the manufacturing of the trays, which could be briefly resumed in sheet unrolling out of a 1500 mm wide roll, cutting and cold-molding of each tray. The understanding of this process allowed us to better define the design and shop documentation process.

First, in order to maintain the complexity of the holes as low as possible while keeping an *organic* appearance, we set simple geometrical rules that simplified the construction and cutting of the holes. By defining every tray with a square angle and always instantiating the same type of hole an even number of times, we assured no extra material was wasted in the cutting process (Figure 7).

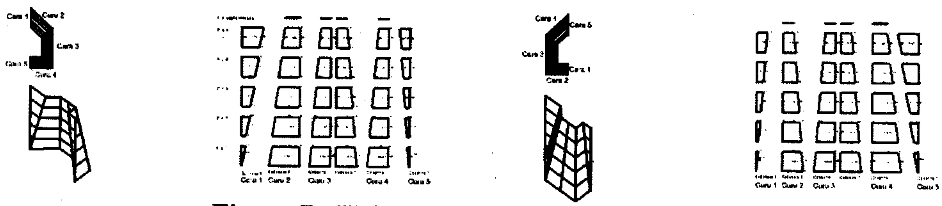

**Figure 7 :** Hole schemes and deployed trays.

Secondly, we developed small Visual Basic scripts to be run under Rhinoceros, the CAD package chosen for the modeling of the roof, in order to help us define the tray layout of the roof and its labeling. The scripts allowed us to automatically split and merge the tray pieces into smaller and bigger ones, to color them depending on their size and regularity and to label them and reflect their properties in excel spreadsheets. This way, we were able to keep track of every part and its level or singularity, with direct reflection on its economical consequences over the whole project. Fig. 8 shows a color coded diagram of the roof. Each tray is labeled accordingly to its type and position.

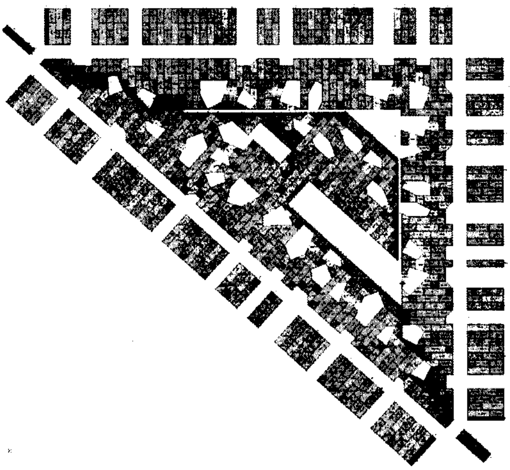

**Figure 8 :** Color coded deployed diagram of the roof trays.

Our split approach and the use of tiny scripts turned to be a very flexible method for the definition and shop documenting of the project. Several hundred of pieces where continuously tracked and all the changes where easily reflected by updating the model with the scripts.

## Conclusion

Three different experiences in the development and use of parametric tools have been presented in this paper. These cases, together with others out of the focus of this paper, allow us to enumerate the following conclusions on the development of customized tools for specific design problems:

- Design tool development requires a better understanding of the problems to be solved, so a deeper insight is achieved. Thus, a better response to the client and project's needs can be provided, and, in general, the total development time is not increased because the coding phase is compensated with the possibility of dynamically exploring different configurations and solutions with little extra effort.
- Tool development should be planned not only on the short term, but also for forthcoming needs or events, which should be assessed well in advance. However, tools will never be completely perfect, so small modifications or improvements should be considered with every new project and re-use.
- User friendliness is a key factor for the success of a custom development. Tools should be accessible to mid-end users in the most autonomous and possible way. This requirement shall imply the use of standard design

packages as development platforms and also a minimum level of documentation of the tool.

- Custom tools boost the design experience by enabling the user to explore new options and configurations. By saving time and effort in redundant tasks and establishing parametric linkages in the project structure, new solutions arise, improving the final results from every point of view.

Further research/work in the field should focus on integrating a higher number of parameters in the applied algorithms. Structural and energetic variables could be evaluated during the design phase if their equations are correctly established, thus increasing the performance of the process.

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