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Parametric Building Design Options Within Voronoï Diagram Based Urban Fabric

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Abstract. More convenient methods to analyse and to understand the built heritage in countries with similar spatial features as Morocco are required. The elaboration of a systematic digital based method for designing newly built spaces encompassing all design scales seems to be worthwhile. After carrying out few tests on the feasibility of articulations between different design scales, the building scale seems to be challenging. This building design issue represents an opportunity for additional and enriching explorations with a view to understand and make from the local heritage more responsive to future challenges with regard, for instance, to sustainability and resilience. As hypotheses, we suggested Voronoï diagram and Hankin's method as mathematical approaches among others to improve the design process in such urban settings with such heritage defies. We decided to carry on with the hypothesis of Voronoi diagram exclusively in this article. The design approach aims to analyse, to understand, to systematise and to digitalise the design process. The approach is based on deep research emphasising the link between building design and algorithms. The method uses CAD tools and computational programming. After investigation, it turned out that the application of such an approach on the design of a cultural facility could be useful to the local community. The site is located in the Bouregreg valley in Rabat, Morocco. It implies nice development opportunities between the city of Rabat and the city of Salé. The research process led us to the establishment of a facility that is well integrated vis-à-vis its surroundings. We were able to pay attention to raised difficulties encountered during the design of buildings. We suggested interesting spatial solutions so as to be converted into algorithms. This carefully influenced our choice for building volumes, indoor layouts and spatial distributions. It turns out that the Voronoï diagram hypothesis works well. The final design seems to be satisfactory from heritage, sustainability and resilience point of view.

Keywords. Parametric building design, Voronoi diagram, urban fabric, local heritage, algorithms, sustainability, resilience

1. Introduction

Voronoï diagram appears in nature, for example, on the neck of a reticulated giraffe, the shell of a turtle, dragonfly wings, human or animal skin cells, some types of fungi, plant leaves, trees and many other examples. Constructions aim to maintain close contact with the living past while having the desire to make something new. Traditional buildings in Morocco have a strong bond with Islamic architecture. This architecture extended from the middle east to the western coasts of North Africa. Morocco, the land of the setting sun, shows itself as a kingdom of traditions, but it is also a country that entered modernity. Islamic architectural art is characterized though assimilating useful

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cross disciplinary knowledge. During the last decade, many researches were carried out apropos the application of the Voronoï diagram in the design process of the built environment. New design strategies emerged such as parametric design in urbanism [1], parametric landscape design approaches for urban green infrastructures [2], urban form-finding parametric model based on the study of spontaneous urban tissues [3], application of Voronoï diagram as treehouse design tool [4], parametric urban design exploration [5], examining the use of Voronoï diagrams in architecture [6], ccomponents for parametric urban design in Grasshopper from street network to building geometry [7], design explorations of performance driven geometry in architectural design using parametric modeling and genetic algorithms [8].

2. A new design approach: Delaunay triangulation and Voronoï cells

In order to raise awareness among various actors and decision-makers vis-à-vis heritage in Morocco and elsewhere. The inspiration should come from local culture, tradition, crafts, architecture and more essentially from nature. Nature created a living and a dynamic system based on light and universal laws of balance and conservation. Designers are required to achieve well balanced design solutions. In this research, the designed urban fabric is inspired from the Voronoï diagram found in several organisms in nature. Voronoï and Hankin are two approaches that offer opportunities for rationalization of urban spaces and architectural details linking and bonding local heritage to different opportunities of modernization and making from newly built spaces more sustainable and resilient spaces. The notion of diagram, as a conceptual and technical tool, could catalyse the emergence of new architectural strategies. Voronoï diagram makes it possible to respond, in particular and in an algorithmic way to many types of problems. The working method is entirely digital. It relies on CAD tools and algorithms. It is based on the following points: Researching links between space, nature and algorithms, digital programming on Grasshopper and Rhinoceros covering the Voronoï diagram, the definition of an attractive architectural programme, the delimitation of an appropriate site. The algorithms developed are fairly clear to intervene from urban scale to finer scales. On the other hand, there are no existing algorithms to conduct architectural design within the Voronoï diagram. Hence, dozens of buildings have been designed within the cultural facility with the CAD tool so as to test the feasibility of these buildings in terms of their functionality, heritage and sustainability concerns. This part of the design process embodies a strong research contribution. Despite the design was developed in CAD, it has the potential to be integrated into an algorithm that deals with built spaces at different scales. This type of design is not yet available in the literature and especially within Moroccan urban settings. The research work led us to new volumes, building layouts, new openings, textures, colons and suitable materials. The method aims to designing algorithms in grasshopper, developing Voronoï diagram from neighbourhood scale till construction details and involving further building parameterization considering daylighting, natural ventilation, heating, cooling and so on. We propose a new design method that considers local heritage issues. The proposed Voronoï based urban fabric covers aspects such as land use decision making, massing and greening. The first step was based on using "Global Mapper". It consists in focusing in a specific site such the medina of Rabat and locating the mosques within it, the Voronoï diagram was therefore generated (see, figure 1).

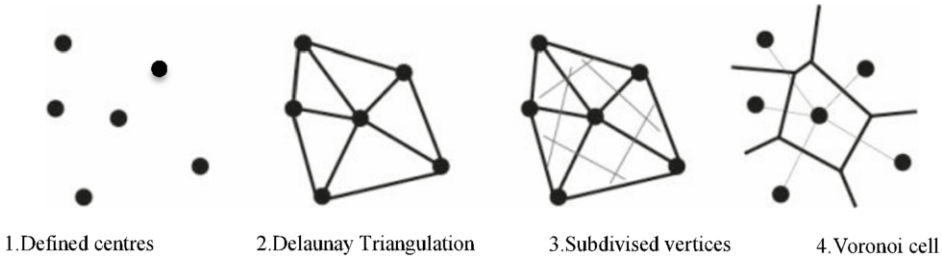

Figure 1. The process of designing Voronoï cells.

3. Design approach applications

Figure 2. The site on the top left showing connectivity and vistas, the site on top right showing the implementation of Voronoï cells and the process of generating Voronoï cells from Mosques' distributions in the medina of Rabat on the bottom.

The design was carried out over the second sequence of the Bouregreg Valley Special Development Plan, called Al Saha Al Kabira, which extends from the Hassan II Bridge to the ONCF Bridge over an area of 122Ha (see, figure 2). Voronoï diagram was implemented on many different scales during the design process of the cultural facility from neighbourhood scale, building scale and urban design till construction details such as facades. During the research we came up with many interrogations such as if local heritage could be explored via new design methods exploring the modelling of existing organisms in nature on macro and micro scales. This could lead to design introverted façades within patios, interior courtyards, and to develop new concepts related to historical urban fabric such as this found in medinas with its irregular shapes that are difficult to understand sometimes. Our questionings covered how we could design an urban fabric that is both contemporary and anchored in the local heritage providing for current and evolving needs, how could we design smart envelopes and new technologies in order to meet sustainability, resilience and enrich local heritage and how we could set up functional building layouts within a very restrictive Voronoï based urban fabric building scale.

4. Multi-scale Voronoï diagram based urban fabric

4.1. City scale: Land use decision-making

Medinas are composed of many important facilities such as Mosques, zawiyas (monasteries), madrasas (schools), souks (markets), foundouks (hotels), bazaars (marketplace or street where goods and services are exchanged), arts and crafts, fountains and so on and so forth. Here, we picked up mosques in the medina of Rabat and we applied some geometrical operations involving both Delaunay triangulation and Voronoï cells (see, figure 3). Such geometries represent connectivity between those facilities in the form of alleys and/or streets. At neighbourhood scale, Voronoï cells are locally subdivided in order to generate an other level of Voronoï cells. The dimensions of this level of cells represent courtyard buildings and the cells are established based on courtyards and patios located at the centre of each cell (see, figure 3).

4.2. Neighbourhood scale: Massing and greening

The cultural facility contains the following spatial programme: Five public gates, a fortification wall, green and negative spaces both inside and outside the wall (see, figures 4 and 5). The programme encompasses the following buildings: workshops, restaurants, media library, gallery, performing arts, museum, games and climbing, music conservatory, kiosks, a worship building and reception/orientation building.

4.3. Building scale: Parametric design options

- Games and music conservatory buildings

Games and climbing building: This building is reserved for games (see, figure 6). It is spread over two open floors. A floor dedicated to different games for adults and children. A second floor converted into a climbing club. The shape of the building

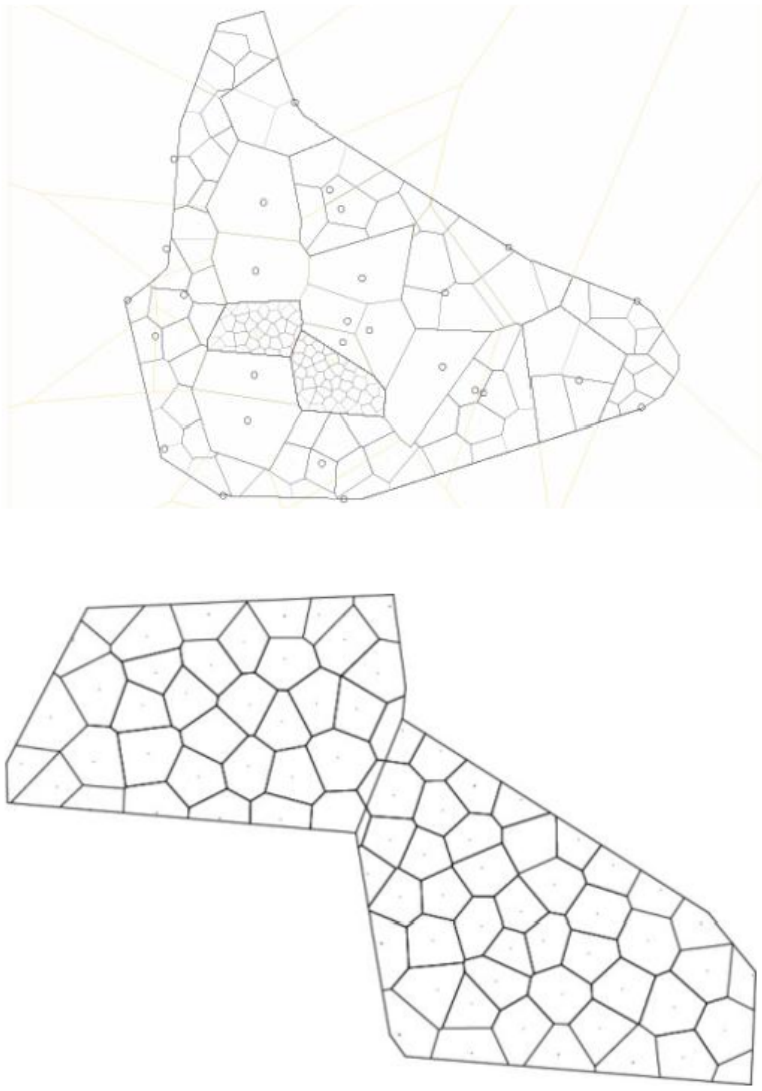

Figure 3. Multi-scale implementation of Voronoï diagram, city scale on the top and neighbourhood scale on the bottom.

reduces the effect of the wind on facades. We will round all the corners of the polygon so that we can extrude a compact and resilient shape.

Music conservatory: One of the most important buildings is the music conservatory. It is unique (see, figure 6). The design is done over a narrow polygonal plot. The conservatory's spaces are music workshops that require acoustic performance to optimize sound environment in the building. We decided to round the four corners of the Voronoï cell, with semicircles where musicians, guitarists, trumpeters and violinists will be housed. Each space has the form of a semicircle oriented towards the place of the master.

Figure 4. The layout of the cultural facility.

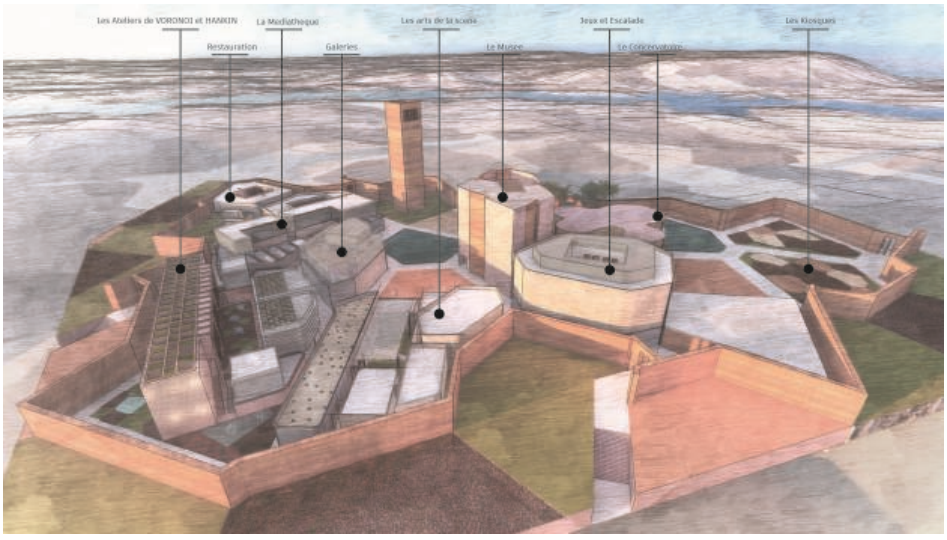

Figure 5. Three – dimensional visualisation of the cultural facility.

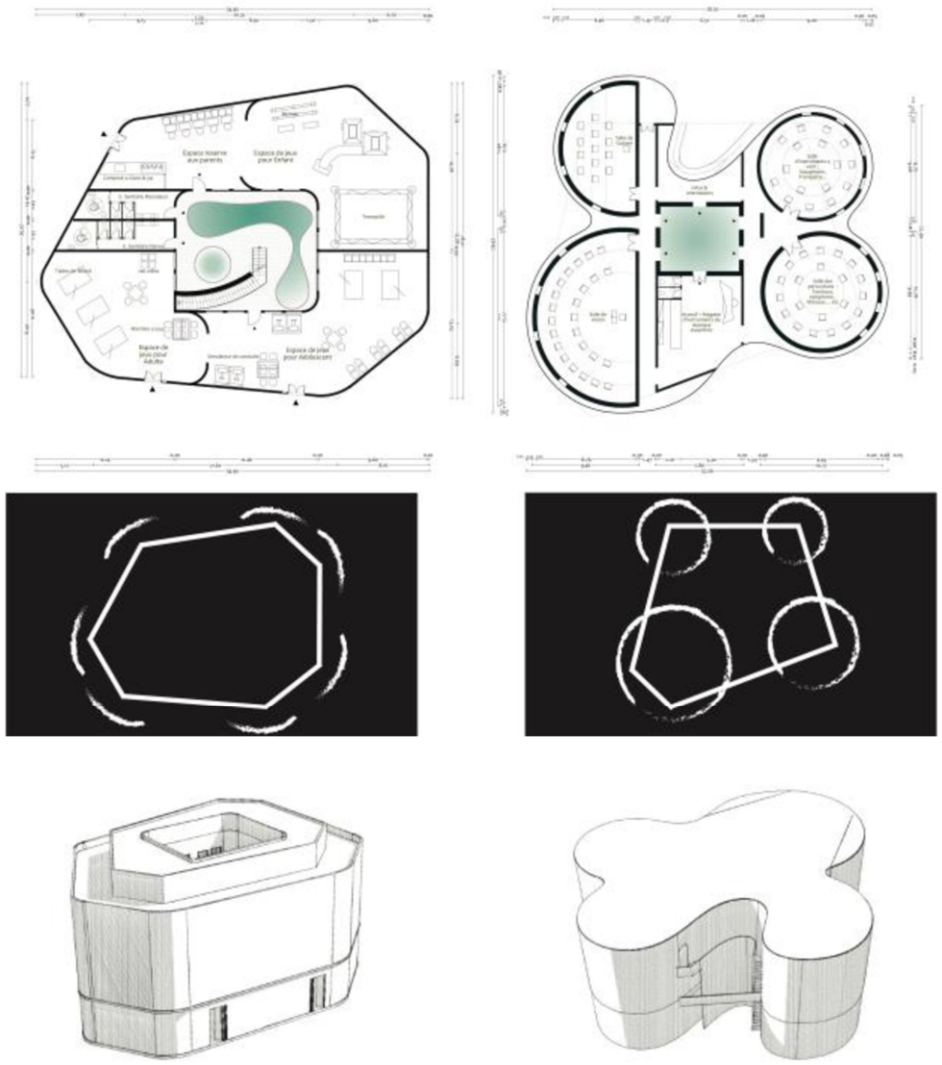

Figure 6. Games building in left column, music conservatory in right column.

- Gallery and worship buildings

Worship building: This Voronoï cell is the cell intended for spiritual functioning (see, figure 7). It will be used for meditation, prayer and meetings between people of different faiths. The layout of this plot reveals a great challenge to bring together a mosque, a synagogue and a meditation space. They are reserved for people of different cults. The concept of this building is to divide it into spaces according to functions that are organized around a large patio.
Gallery: The prism of the gallery occupies a whole cell of our diagram (see, figure 7). Its layout remains almost faithful to the initial shape of the Voronoï diagram. A set of volumes is created in the upper part of the building. Its volumes are defined according

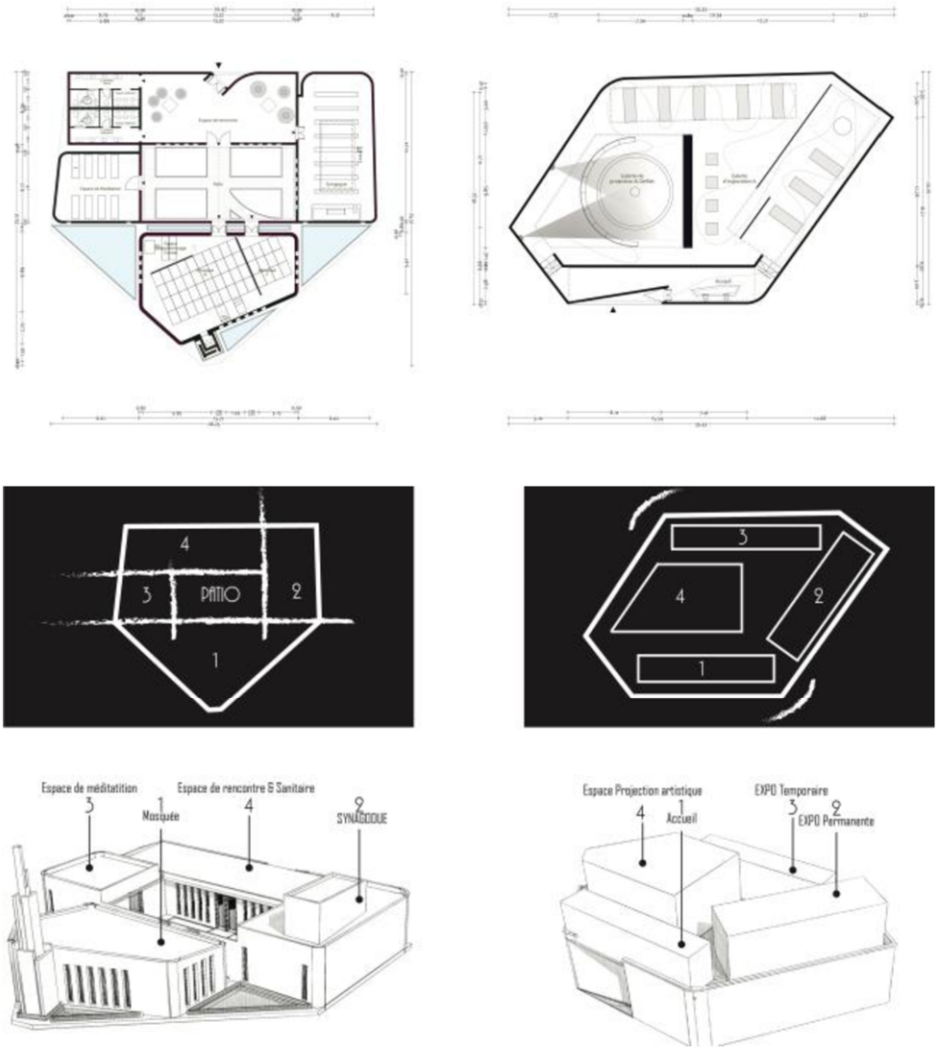

Figure 7. Worship building in left column, gallery in right column.

to the limits of the interior spaces of the gallery. They will be used in particular for lighting, creating a very interesting play of light. Rounded corners to reduce sharp angles are difficult to achieve in construction.

- Cinema and reception buildings

Cinema: The building is reserved for a cinema hall (see, figure 8). The shape of the cell makes it easier to arrange the underground stage of the cinema. The proposed concept curves the three sides of the plot which will serve as a double skin which hides the rigid form of the space. The choice of these curves is made to bring more energy efficiency, this means that, given the reduction in the surface exposed to the weather, it will take less energy to heat and/or cool the interior space of the building.

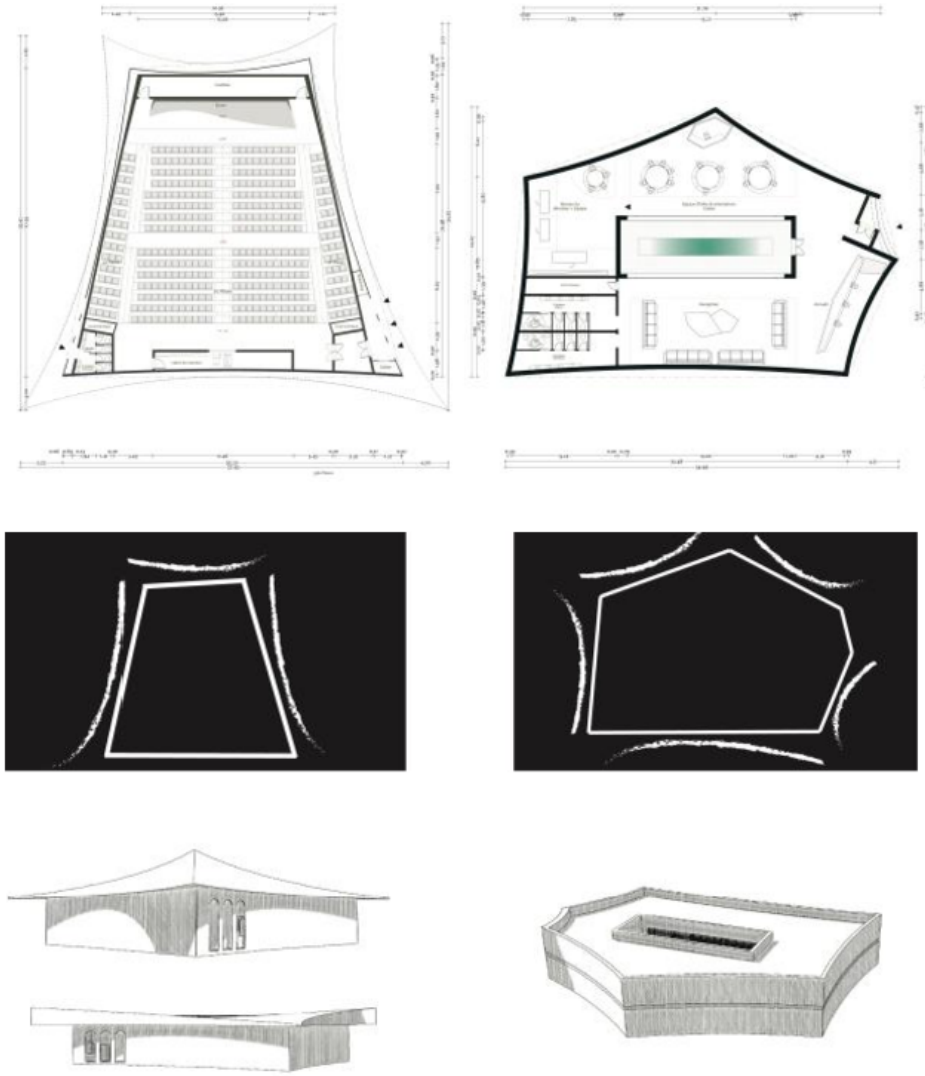

Figure 8. Cinema in left column, reception building in right column.

Reception and orientation building: The reception building is reserved for first contact with visitors to the cultural complex (see, figure 8). A building has a patio, its adobe walls rise to reach the height of the wall. Curved walls designed in the same way as the cinema building and for the same energy reasons, adding a big "bonus" in terms of energy efficiency. The patio has several roles, in this case it will play a very important role in daylighting as well as natural ventilation.

- Workshops

Figure 9. Workshops, layouts on the top and three-dimensional view on the bottom.

The building shelters the most important workshops of the cultural facility. An equivalent of two Voronoï cells were merged in order to handle such an important building programme. The following design step involved subdividing the whole plot of land so as to find the right modules for indoor spaces and the same operations was held for outdoor spaces. Among the building features, the design of an important courtyard, balancing between curved and linear shapes and designing performant double skin facades.

Conclusion

It is essential to explore other disciplines and to produce not only beautiful cities and buildings, but also to promote life quality. The built environment influences the spirit of human kind. The cultural facility consisted of designing a place for cultural dissemination, with the idea of matching negative spaces to buildings and the large landscape "valley" between the cities of Rabat and Salé. Adding to this, the understanding and the integration of contemporary challenges of buildings. The site constitutes the basement of urban and architectural design that emphasizes heritage, sustainability and resilience. The design approach aimed to design a cultural facility in the heart of the Bouregreg valley in order to create a landmark, a rich, complete and sensitive cultural centre for the two twin cities with a desire to be sustainable and to innovate.

Acknowledgement

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