Music to architect time: the Iannis Xenakis' undulating glass panes

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Abstract

In the twentieth century, favourable circumstances gave rise to a variety of junctions between arts and sciences. Einstein's theory of relativity introduced the temporal dimension of space, which had previously been considered uniform and static, and opened up new possibilities for arts to express themselves. Iannis Xenakis broke through the established boundaries and linked Music and Architecture in his work. What interpretation can we make of the experimentation of this collision between these two seemingly distant disciplines? How can the element of the undulating glass panes be interpreted in relation to these movements?

Our reflection began in 2019 with a survey of Iannis Xenakis' undulatory panes carried out at the Couvent de la Tourette as part of Prof. Franz Graf's project workshop at the EPFL. One thing leading to another, we experienced a fascinating relationship between music and architecture in the form of dilation, compression or acceleration of the space felt thanks to the frequency of the concrete posts, throughout our wandering. As we walked through this device, we became the cursors reading the music frozen in the undulating panes at each passage and we were then transformed into both actors and instruments of this music. The end result of this first work was concretely to set the crystallised notes of the undulating sections to music in a piano score and to play it in public. A clear link with the musical composition work of Iannis Xenakis can be felt, particularly through the notions of glissandi and sound continuity.

Could it be that the link between Music and Architecture is deeper than a simple tribute? The concept of the undulating glass panes can be found in one of the greatest monuments of Ancient Greece: the Acropolis of Athens. The optical effect sought, called the parallax effect, makes the interstitial space behind the architectural elements exalt. The colonnade used in the Parthenon appears to vibrate as the visitor moves around it. Its peristyle acts as a filter between two different temporalities: one natural and the other eternal. The grooves take on a mystical quality, vibrating as the walker go trought them, with the same force as the undulating glass panes.

The undulating glass pane then also becomes a threshold between the profane and the sacred, unfolding around the sacred space of the church of La Tourette. Its presence gives rhythm to the temporality of its inhabitants and ritualises their different tasks throughout their day and their life. The architectural element accompanies the individual, collective and spiritual life of the convent. Bringing the proud ancient caryatids into the modern age, the undulating glass pane then architects the human figure through the *Modulor*, making it resonate in the light of a new age. Let us take the measure of this architectural element by considering its origins and its power through what it evokes:

music, space-time and the human being.

1. Introduction

The present work is based on a part of our theoretical statement of master of architecture at EPFL. We humbly attempt to retrace the history of undulating glass panes by proposing a detailed historical and architectural analysis of the ones present at the Couvent de la Tourette.

The analysis we propose is based on a survey of all the undulating glass panes of the Couvent de la Tourette in 2019. The latter enabled us to familiarise ourselves with the device, whose architectural intensity is in sharp contrast to its rationality and simplicity of implementation. Three years of reflection on undulating glass panes have enabled us to arm ourselves with the right tools to understand and interpret their origins, their mathematical genesis, what they evoke about space-time through music and the intensity of the relationships they weave in the architectural domain. To do this, we had to abstract the undulating glass panes to their very essence, define their intrinsic nature and what they represent. We will see that a discreet but nonetheless tenacious link connects the undulating glass pane to the ancient grooves of the Parthenon on the Acropolis in Athens.

When we first encountered the Xenakian architectural device, we instinctively sensed a strong link with space-time. We will therefore introduce the undulating glass panes by inserting them into a trajectory concerning the relationship between the human being and space-time, then into the architectural and musical trajectory of Iannis Xenakis.

Time is an abstract notion, an elusive dimension that human beings have tried to materialise. At first, it is eternity that fascinates, as can be seen in the Egyptian hieroglyphic representations and their constructions linking them to what is most eternal for them: the stars. For a long time in history, the constructions evoked robustness, stability and defied eternity in the image of palaces or other sacred buildings. Let us note here that an embryo in relation to space-time is embodied by the composition of the Acropolis where the buildings do not follow any rule of symmetry, between them. Jacques Lucan, and Auguste Choisy before him, noted a "parallax"[1] effect that the visitor perceives as he moves around the buildings on the Acropolis, bringing time into play in order to grasp the complex as a whole.

It turns out that the way in which we physically represent time depends fundamentally on the conception we have of it. While Newtonian mechanics was the only one known until the 20th century, an upheaval occurred with Einstein's relativity. The very perception of space and time changed, influencing the way in which art, architecture and music were composed. This upheaval was accompanied by a rare decompartmentalization of disciplines between physics and these arts. Exchanges multiplied and it was in this favourable environment that Iannis Xenakis and his personal trajectory intervened, also concerning space-time with creations born of successive musical and architectural abstractions.

Having just taken refuge in France after being expelled from Greece, Iannis Xenakis worked first as an engineer in Le Corbusier's office. His first project as an architect was the Couvent de la Tourette. At the same time, he experimented with musical composition, which had fascinated him since he was a child. Olivier Messiaen, his mentor, suggested that he inject his architectural and mathematical knowledge into his music[2]. Iannis Xenakis' career was born with the composition of *Metastaesis* in 1954, where the musical continuities and discontinuities embodied in his glissandi are reminiscent of the way architecture is composed. The undulating glass panes were born at the same time, with a similarity in the way they were composed with *Metastaesis*. Xenakis' conquest of dimensions begins...

[1] Jacques Lucan, Composition/Non-Composition, p.324
[2] Sven Sterken, Travailler chez Le Corbusier : le cas de Iannis Xenakis, p.215

2. Undulating glass panes

Towards the entrance of the Tourette Convent complex, a perspective opens up to us. We can see the undulating glass panes that let us guess their shape, through the multiple plastic layers of the convent. Silence reigns supreme in the complex, each step resounds like an echo in a mountainous valley. The undulating glass panes seem to be the only sounds allowed in this place: notes crystallized in concrete, iron and glass.

Figure 1: opening to the interior of the convent, near the entrance

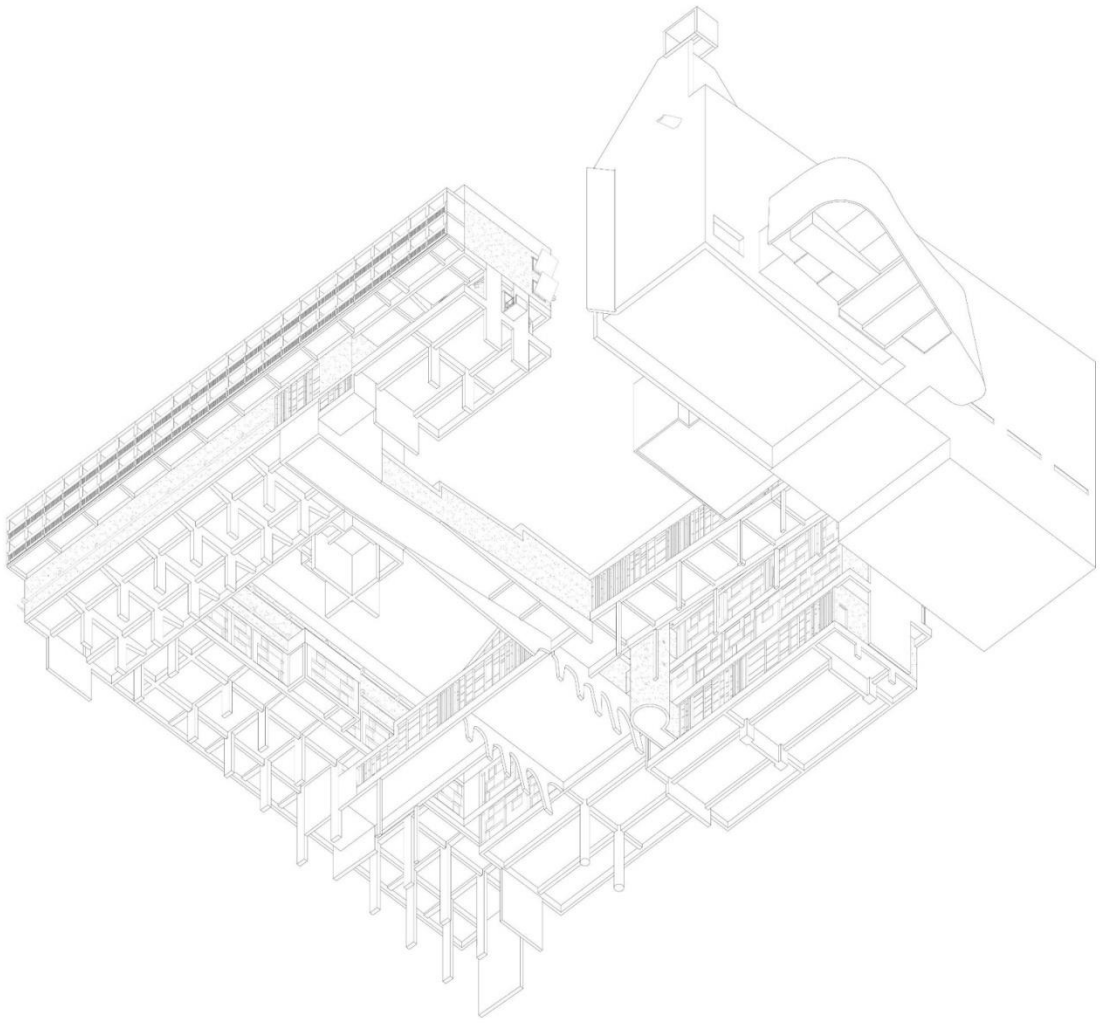

Figure 2: Alice Biber, Marilyn Brühlmann, Tamara Lobo, Abigaël Schaller, Alexandre Gameiro, Mathias Schopfer, Emmanuel Stump, Pierluigi Surano, Envelope – General Axonometry, 2019

Without going into the details of the complete composition of the project, we can nevertheless note the following points: the complex, contrary to what the classical monastic typology suggests, is articulated vertically. The spiritual life is experienced on the ground, followed by the community spaces and then the cells. The cloister, a major element of the monk's resourcing, is located on the roof.

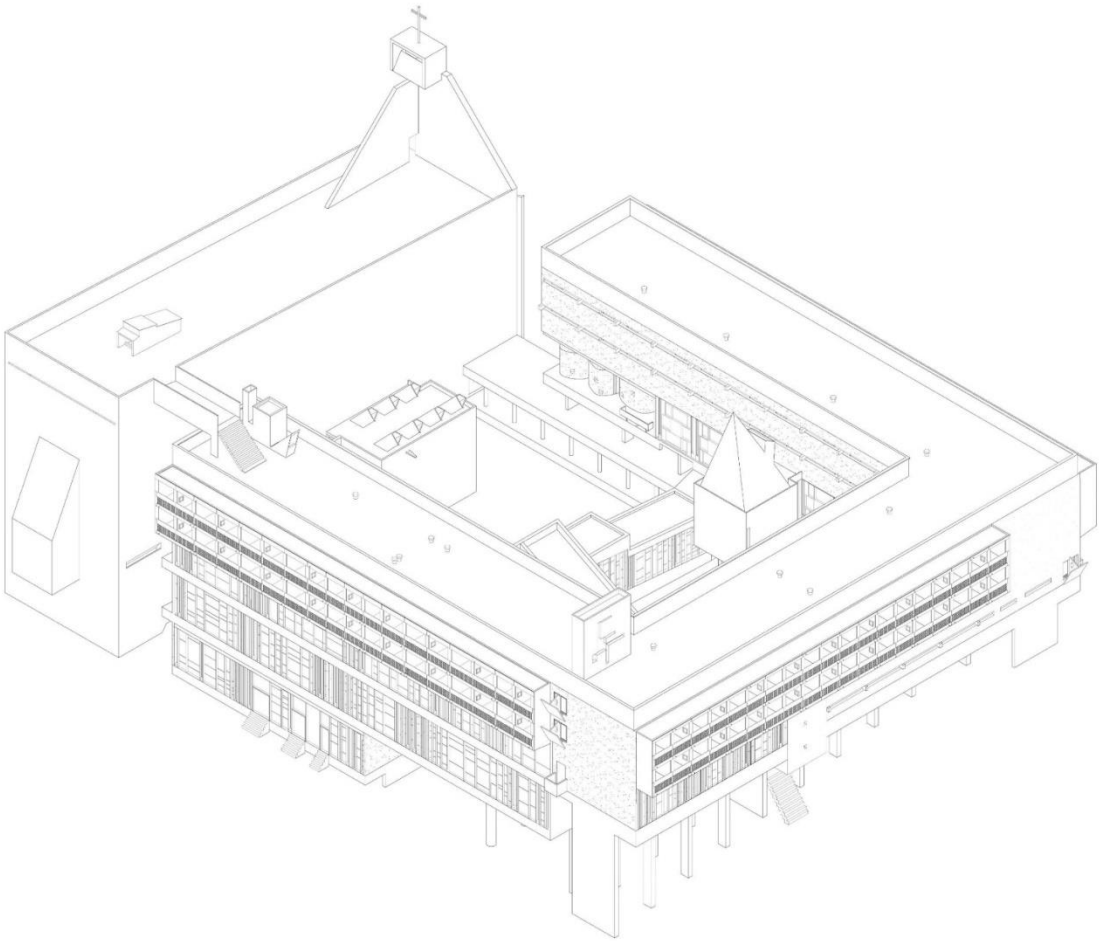

Figure 3: Alice Biber, Marilyn Brühlmann, Tamara Lobo, Abigaël Schaller, Alexandre Gameiro, Mathias Schopfer, Emmanuel Stump, Pierluigi Surano, Envelope – General Axonometry, 2019

Poverty, a fundamental element of Dominican doctrine, is found at every level of the project, both in its constructive and constitutive dimensions. Although modern in inspiration, the building takes as its reference historical complexes, namely the Charterhouse of Ema, in Tuscany, and the Abbey of Le Thoronet, in the south of France[3].

Let's not rush into anything: although medieval inspiration, the Couvent de la Tourette is dimensioned with the help of the *Modulor*, thus making human proportions resonate. Moreover, Le Corbusier spoke of "the workman's touch that leaves its mark" when he defended the poor quality of the building's construction[4].

From a structural point of view, the posts of the undulating glass panes of the Tourette convent are non-load-bearing, although their material and number may suggest otherwise. In fact, the task of carrying the building falls to the various posts set back from the façade. We can justify the use of concrete and glass for the undulating glass panes in order to inspire the rigour and

[3]Sergio Ferro, Chérif Kebbal, Philippe Potié, Cyrille Simonnet, Le Couvent de la Tourette, p.63
[4]Le Corbusier about marks left by the workers *in* Philippe Potier, Le Corbusier. Le Couvent Sainte Marie de la Tourette, p.110

hardness of the Dominican order in the eyes of the walker. The asperities in the element together give off a raw beauty that can be found in ancient ruins left to the four winds. The saddle bars, which represent musical notes, seem to shout while being silent. The visitor then becomes the cursor of the reading, playing the melody to the rhythm of his walk, each post mimicking the dull beat of the metronome. The various asperities of the concrete then begin to vibrate in unison, the light picking up every little flaw as it passes. If in good weather, the imprint of the posts is projected directly onto the ground, the diffuse light resulting of bad weather caresses the device, giving it an ethereal presence.

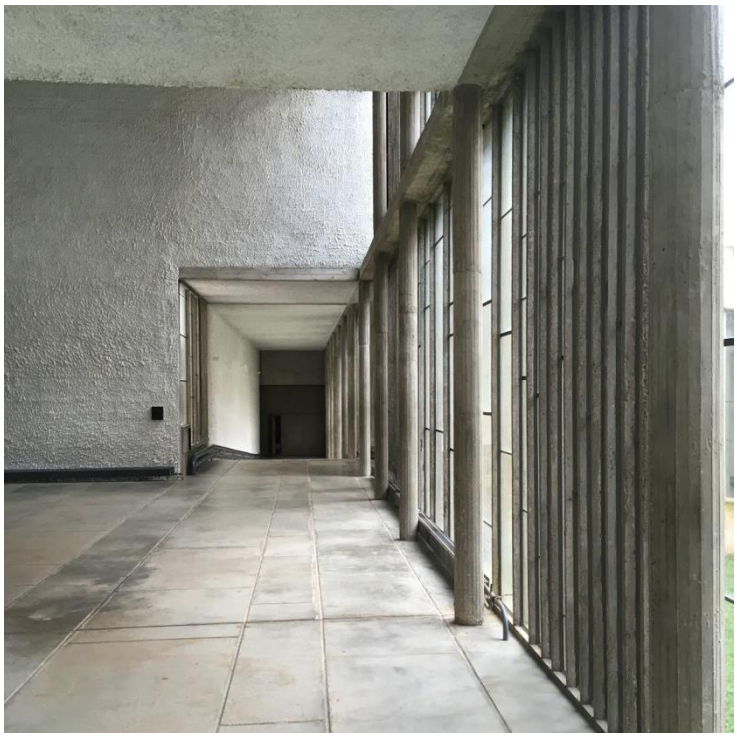

Figure 4: view of the undulating glass panes of the "grand conduit". The roughness of the panes is accentuated by the penetrating light.

Figure 5: close picture of one post

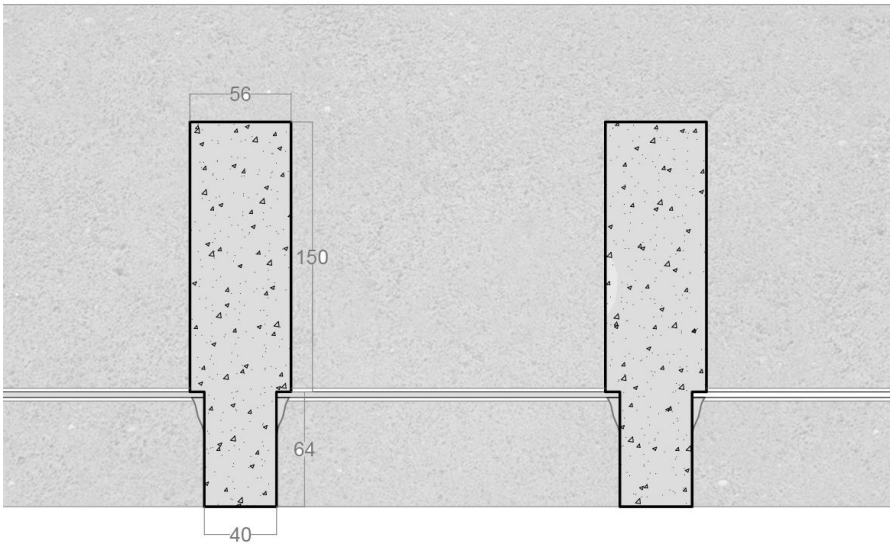

Figure 6: constructive detail of the undulating glass panes

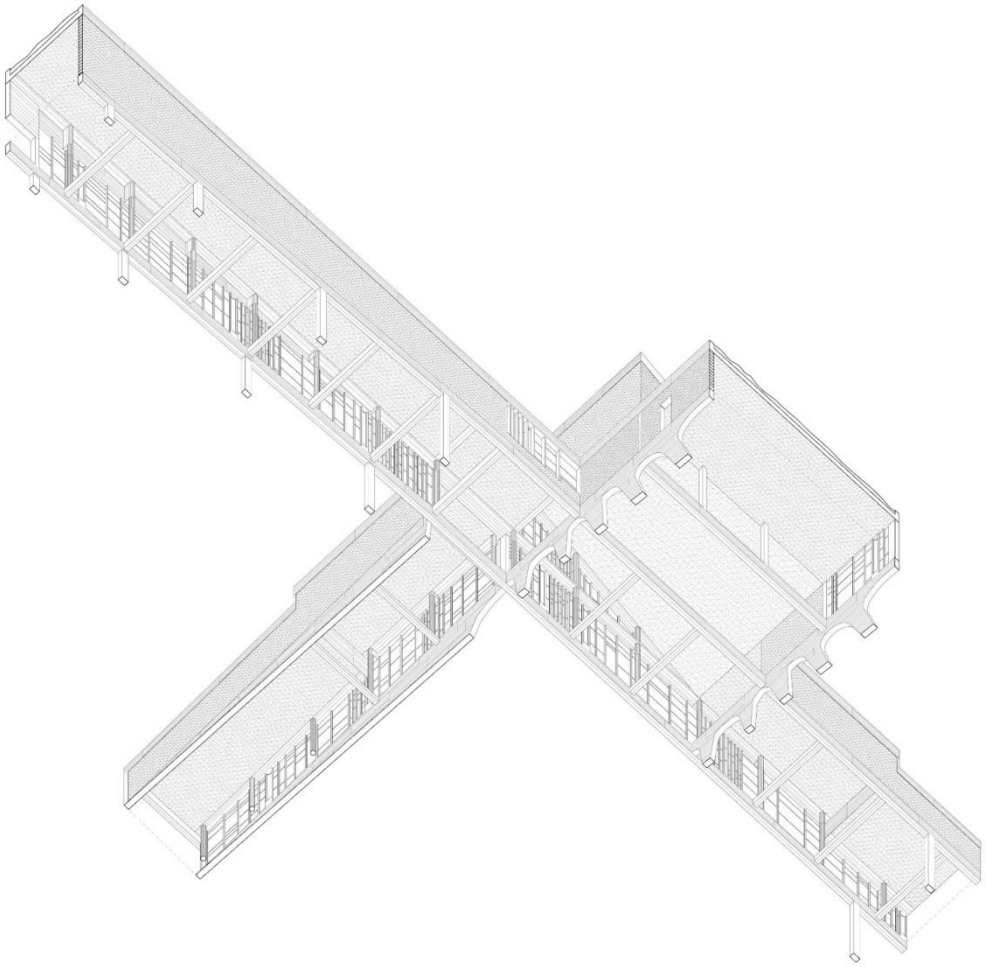

Figure 7: Emmanuel Stump, Couvent de la Tourette – Axonometry of the « conduits », 2019

> "Ainsi, c'est exactement cette plasticité de l'espace musical que Xenakis va transposer dans les pans de verre du couvent. L'opération sera d'autant plus aisée que c'est à l'aide des mêmes graphiques qu'il compose sa musique et ses pans de verre : en 1954, en effet, n'ayant pas encore les possibilités offertes par la combinatoire, le choix des transformations globales du mouvement 'ondulatoire' se faisait simplement à l'aide du crayon et de la feuille de papier, dont il grisait une surface plus ou moins étendue. Fernand Gardien, qui travaillait dans le même bureau, rue de Sèvres, se souvient d'ailleurs que Xenakis, composant et décomposant ses ondulatoires, battait systématiquement la mesure en chantonnant..."
>
> (Sergio Ferro, Chérif Kebbal, Philippe Potié, Cyrille Simonnet, Le Couvent de la Tourette, p.90)

2.1. The origin

The undulating glass panes were born on the Indian construction sites of the new city of Chandigarh, led by Le Corbusier's office. It was originally thought as a pragmatic solution to an ergonomic problem, namely to fill the large openings left by the structure with scraps of glass. Indeed, the recessed structural arrangement and non-bearing curtain wall proposed by Le Corbusier for the City Center buildings is probably unheard of in India. In fact, Le Corbusier is the architect of only the major buildings in the city. He is also responsible for the urban plan and gives global guidelines for the projected buildings, which he will not take care of afterwards. He simply applied his famous 5 points of architecture to them and the local workers took care of the rest, which is how

the Indian glass panes were born. The undulating glass panes can be found on many buildings in the city, whether they are earlier, contemporary or built after Iannis Xenakis' theorisation of them. The process and final object used by the Indian workers, noticed by Pierre Jeanneret, was transmitted to Le Corbusier through his correspondence. Le Corbusier then commissioned his young engineer, Iannis Xenakis, to harmonise and construct a method of composition for this element. With his musical experiments under his belt, the Greek architect first experimented and theorised it at the Couvent Sainte-Marie de la Tourette in Eveux-sur-L'Arbresle before integrating it into the pharaonic Indian project.

It is important to note that the first occurrences of the architectural element are in no way linked to any form of voluntary harmonisation but arise solely from a need for raw material to be rationed.

> "Ce fut pendant cette période calme que Xenakis mit au point l'idée des pans de verre ondulatoire. L'artifice technique lui avait été soufflé par Jeanneret (via Le Corbusier) qui, sur les chantiers en Inde, avait remarqué que les maçons noyaient directement les vitres dans le bâti de béton, sans les huisseries intermédiaires"
>
> (Sergio Ferro, Chérif Kebbal, Philippe Potié, Cyrille Simonnet, Le Couvent de la Tourette, p.32)

> "Bien des artifices sont pour ainsi dire 'testés' à la Tourette avant de s'inscrire sur le projet indien. Les pans de verre, par exemple, bien que le principe constructif ait été découvert en Inde, sont éprouvés à grande échelle sur le couvent avant de s'épanouir sur le Parlement et d'autres édifices ultérieurs ; les systèmes de rampes de Chandigarh également, que Le Corbusier a d'abord travaillés sur le projet du couvent."
>
> (Sergio Ferro, Chérif Kebbal, Philippe Potié, Cyrille Simonnet, Le Couvent de la Tourette, p.32)

2.2. The survey

Our 2019 survey could entirely be recorded in the form of a table of numbers. The different elements were articulated as follows: on the X-axis was the width of the pane measured between two posts and the dimensions on the Y-axis corresponded to the height of the glass, between two bars. Like the architectural element, these rough series of numbers allowed us to reconstitute the various undulating glass panes present in the Convent. It should be noted that the measuring is done from the inside. The constructive detail of the posts is thinner on the inside than on the outside (Fig 5). The role of this work was to try to understand the architectural articulation of the different architectural elements. As a bonus, it allowed us to enter the building itself and to confront it directly with the built ensemble, disregarding the existing plans. Moreover, although the documentation concerning the Convent is abundant, certain details contradict each other in the various drawings.

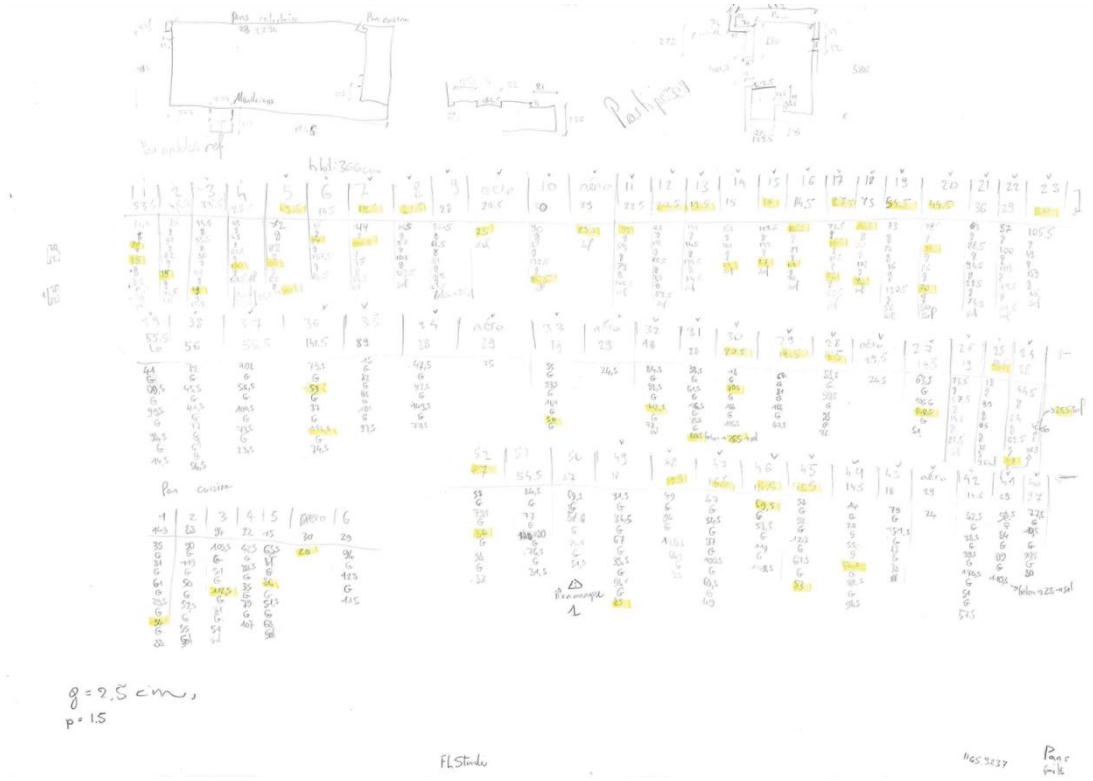

Figure 8: survey sheet of common spaces (from the inside). The values highlighted in yellow correspond to the Modulor values (+/- 1cm)

Figure 9: Emmanuel Stump, Couvent de la Tourette - axonometry "conduits", 2019

As in most of Le Corbusier's post-war buildings, the integration of *Modulor* values into the composition of the project is paramount. However, as shown in yellow on our survey sheets, the

accuracy of implementation leaves something to be desired (Fig. 8 & 10). In these drawings, the colouring of the value indicates the presence of a *Modulor* dimension with a plus or minus 1cm margin. A wider tolerance of 4 cm allows these reluctant values to fit into dimensions inherited from the *Modulor* series.

Of course, the questionable quality of the implementation of the undulating glass panes does not detract from their quality. Indeed, it is very likely that the glass panels were cut after the posts were in place and some had to be cut to fit in. Fernand Gardien's site reports give us a good idea of the chaos that the site represented, particularly concerning the undulating glass panes[5].

Figure 10: survey Notes from the Couvent de la Tourette undulating glass panes

We have transcribed the horizontal dimensions from the inside of the undulating glass panes below. Values that are not part of the Modulor or deviate from it by more than 4 cm are coloured orange. In blue and red you will find the highlighting of the two series of the Modulor.

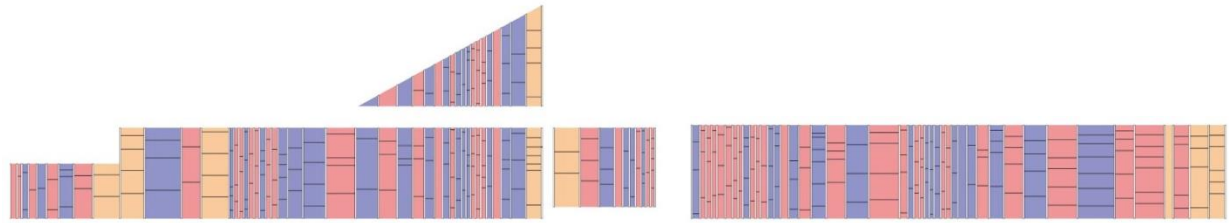

Figure 11: highlight of the « grand conduit » undulating glass pane, according the two Modulor series.

“Grand conduit” read from the South to the North towards the church, integrating the pane in front of the “Petit Conduit”:

25.5 - 15.5 - 22.0 - 29.0 - 33.5 - 45.0 - 54.5 - 72.0 - 104.5 - 92.0 - 141.5 - 74.0 - 107.5 - 14.5 - 16.0 - 15.5 - 14.5 - 17.5 - 17.5
26.6 - 16.5 - 20.4 - 26.6 - 33.0 - 43.2 - 53.4 - 69.8 - [illegible] - 139.7 - 69.8 - [illegible] - 12.8 - 16.5 - 16.5 - 12.8 - 16.5 - 16.5

21.0 - 17.5 - 25.0 - 34.0 - 55.0 - 87.0 - 114.0 - 85.5 - 71.0 - 56.8 - 43.5 - 34.5 - 29.2 - 23.0 - 18.0 - 20.0 - 14.0 - 14.5 - 15.0 - 17.5
20.4 - 16.5 - 26.6 - 33.0 - 53.4 - 86.3 - 113.0 - 86.3 - 69.8 - 53.4 - 43.2 - 33.0 - 26.6 - 20.4 - 16.5 - 20.4 - 12.8 - 12.8 - 16.5 - 16.5

18.0 - 20.5 - 29.0 - 34.0 - 56.5 - 60.7 – end atrium - 102.0 - 72.0 - 56.0 - 29.5 - 22.0 - 19.5 - 18.5 - 13.5 - 15.5 - 15.5 – end little pane
16.5 - 20.4 - 26.6 - 33.0 - 53.4 - [illegible] – little pane - [illegible] - 69.8 - 53.4 - 26.6 - 20.4 - 20.4 - 16.5 - 12.8 - 16.5 - 16.5 – begin church

[5] Sergio Ferro, Chérif Kebbal, Philippe Potié, Cyrille Simonnet, Le Corbusier - Le Couvent de la Tourette, p.50

30.0 - 18.5 - 18.5 - 17.0 - 28.0 - 25.0 - 17.5 - 15.0 - 22.5 - 18.0 - 15.0 - 25.0 - 20.5 - 21.0 - 29.0 - 35.0 - 44.5 - 54.5 - 72.5 - 85.5
33.0 - 16.5 - 16.5 - 16.5 - 26.6 - 26.6 - 16.5 - 16.5 - 20.4 - 16.5 - 16.5 - 26.6 - 20.4 - 20.4 - 26.6 - 33.0 - 43.2 - 53.4 - 69.8 - 86.3

116.0 - 29.0 - 19.0 - 15.5 - 15.5 - 14.5 - 14.5 - 22.0 - 15.0 - 18.5 - 22.0 - 30.5 - 33.5 - 46.0 - 53.0 - 73.5 - 87.0 - 115.0 - 142.0
113.0 - 26.6 - 20.4 - 16.5 - 16.5 - 12.8 - 12.8 - 20.4 - 16.5 - 16.5 - 20.4 - 33.0 - 33.0 - 43.2 - 53.4 - 69.8 - 86.3 - 113.0 - 139.7

73.0 - 114.0 - 60.0 - 71.5 - 62.5 - 58.9
69.8 - 113.0 - 60.0 - 69.8 - -

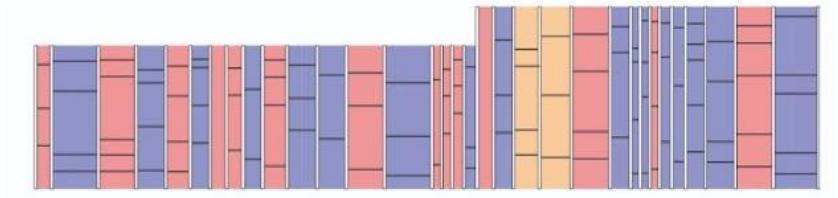

Figure 12: highlight of the « petit conduit » undulating glass pane, according the two Modulor series.

« Petit conduit » from the East to the West:
29.5 - 88.5 - 71.0 - 54.5 - 45.0 - 35.0 - 29.0 - 29.0 - 34.5 - 44.0 - 56.0 - 54.0 - 72.0 - 89.5 - 15.5 - 16.5 - 19.5 - 22.5 - 28.5 - 35.5
26.6 - 86.3 - 69.8 - 53.4 - 43.2 - 33.0 - 26.6 - 26.6 - 33.0 - 43.2 - 53.4 - 53.4 - 69.8 - 86.3 - 16.5 - 16.5 - 16.5 - 20.4 - 26.6 - 33.0

47.5 - 59.0 - 72.8 - 37.0 - 15.0 - 15.0 - 15.5 - 20.0 - 23.0 - 36.0 - 55.0 - 71.5 - 87.5
47.5 - 59.0 - 69.8 - 33.0 - 12.8 - 12.8 - 16.5 - 20.4 - 20.4 - 33.0 - 53.4 - 69.8 - 86.3

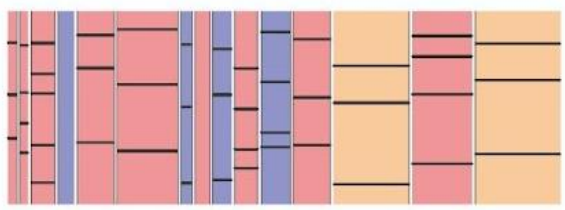

Figure 13: highlight of the Chapter's room undulating glass pane, according the two Modulor series.

The Chapter's room:
18.0 - 16.0 - 45.5 - 31.0 - 71.0 - 116.5 - 21.5 - 28.5 - 36.0 - 45.0 - 56.0 - 71.5 - 145.0 - 115.0 - 163.0

16.5 - 16.5 - 43.2 - 33.0 - 69.8 - 113.0 - 20.4 - 26.6 - 33.0 - 43.2 - 53.4 - 69.8 - - 113.0 - 182.9

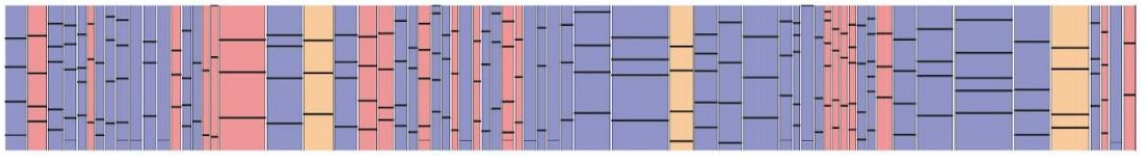

Figure 14: highlight of the Dining Hall undulating glass pane, according the two Modulor series.

The Dining Hall :
53.1 - 47.1 - 37.1 - 30.1 - 21.1 - 16.1 - 21.1 - 23.1 - 29.6 - 31.1 - 31.6 - 30.6 - 24.1 - 22.1 - 21.1 - 16.6 - 17.6 - 116.1 - 89.1 - 74.6
53.4 - 43.2 - 33.0 - 33.0 - 20.4 - 16.5 - 20.4 - 20.4 - 33.0 - 33.0 - 33.0 - 33.0 - 26.7 - 20.4 - 20.4 - 16.5 - 16.5 - 113.0 - 86.3 -

56.1 - 46.1 - 39.0 - 30.6 - 21.6 - 29.6 - 21.1 - 20.6 - 16.1 - 31.1 - 17.1 - 21.1 - 22.1 - 29.6 - 17.6 - 30.6 - 20.6 - 30.6 - 29.6 - 90.6
53.4 - 43.2 - 43.2 - 33.0 - 20.4 - 26.6 - 20.4 - 20.4 - 16.5 - 33.0 - 16.5 - 20.4 - 20.4 - 26.7 - 16.5 - 33.0 - 20.4 - 33.0 - 33.0 - 86.3

143.1 - 58.1 - 57.6 - 57.1 - 88.6 - 30.6 - 16.1 - 30.6 - 19.6 - 16.1 - 17.1 - 17.1 - 17.1 - 21.1 - 19.6 - 38.6 - 56.1 - 88.6 - 143.0
139.7 - - 53.4 - 53.4 - 86.3 - 33.0 - 16.5 - 33.0 - 20.4 - 16.5 - 16.5 - 16.5 - 16.5 - 20.4 - 20.4 - 43.2 - 53.4 - 86.3 - 139.7

88.0 - 94.0 - 22.0 - 15.0 - 30.0 - 29.0
86.3 - - 20.4 - 16.5 - 33.0 - 26.7

The match here is 91.7%.

"L'ondulation des pans de verre peut être décrite graphiquement si l'on

affecte en ordonnées les valeurs du Modulor. Ce graphique nous montre comment, à partir d'une loi de croissance donnée (20-27-33-43-53-70-86-113-140), Xenakis crée des 'symétries', des 'ruptures', des 'accidents' selon son choix. On remarquera également que les éléments sont, de fait, traités en masse, (de même que les glissandi de Metastassis) expériences qui préparent sa théorie stochastique de la composition musicale. A cette composition horizontale des ondulatoires s'ajoute encore une recherche polyphonique des juxtapositions verticales des pans de verre." (Sergio Ferro, Chérif Kebbal, Philippe Potié, Cyrille Simonnet, Le Corbusier - Le Couvent de la Tourette, p.92)

It appeared to us, during our survey and drawing of the undulating glass panes that, although the values of the Modulor are present in the widths of the panes of glass, the heights of the different panes of glass have a random component and are not linked to the *Modulor*, as the authors of the monograph on the Couvent de la Tourette also point out[6].

Of course, some of the dimensions come close to the *Modulor* series, but in our opinion this is a matter of luck. It is likely that during the installation process, the various tiles making up the undulating glass panes were not yet cut. They were cut after all the posts have been installed. It should also be noted that it is easy to come across *Modulor* dimensions which are numerous between 15cm and 43cm depending on the tolerance applied. When these dimensions are exceeded, the correspondence to the model values is rare.

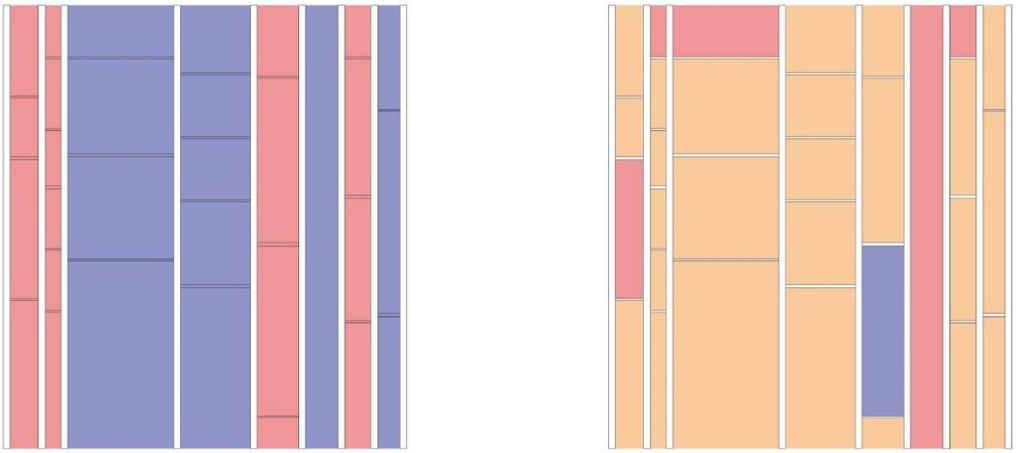

Figure 15: comparison of elements corresponding to Modulor values. The diagram on the left shows the Modulor differences between the posts, while the diagram on the right shows the height of the glass parts (tolerance 1.5cm).

Furthermore, the architectural composition of Iannis Xenakis' undulating glass panes shows the precise location of the concrete posts in the façade. On the other hand, the absence of the saddle bars on these elevations (Fig. 15 and 20) confirms our hypothesis: the saddle bars take on the vernacular characteristics of their Indian counterparts, namely an economic randomness in their layout. Indeed, if we follow a purely rational logic, it is the available glass scraps that would give the heights of the saddle bars.

Basically, the posts have a relationship to time and human dimensions. They fragment the space-time experienced, then, by the human being. The notes embodied by the saddle bars have no reason to be linked to the *Modulor*. For the heights of notes in music have nothing to do with human dimensions.

[6] Sergio Ferro, Chérif Kebbal, Philippe Potié, Cyrille Simonnet, Le Corbusier - Le Couvent de la Tourette, p.84

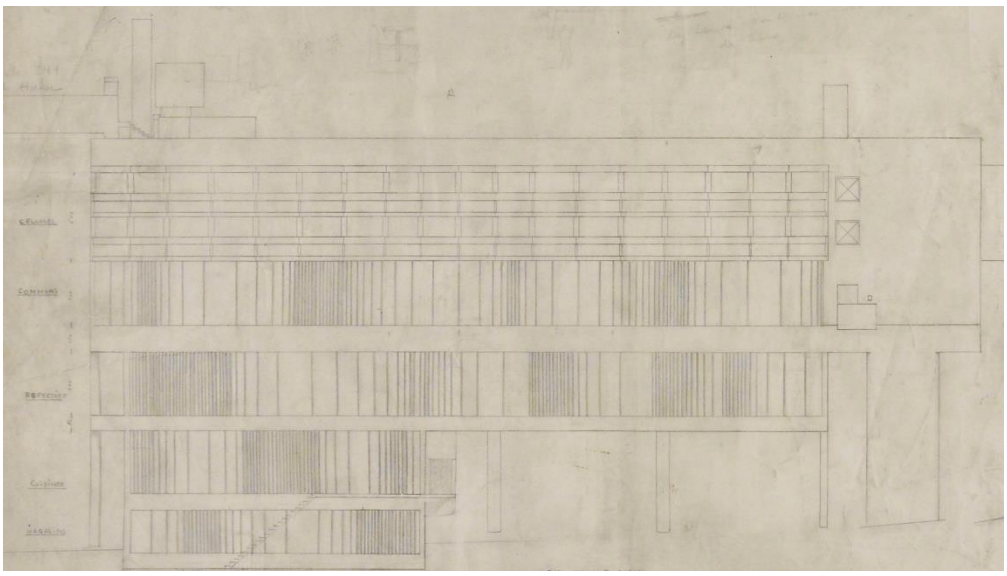

Figure 16: Le Corbusier, Couvent Sainte-Marie de la Tourette, Eveux-sur-l'Arbresle, 1953, Plan FLC 01340, [West facade elevation] (credits : © Fondation Le Corbusier)

In conclusion, it is interesting to note that this composition of undulating glass panes is the result of a reciprocal feeding of music and architecture in Xenakis' creations, starting with Le Corbusier's Modulor. In a transversal way, musicologists and architects find here a common ground for experimentation, breaking down the walls often erected between arts.

2.3. The music of undulating glass panes

During our survey in 2019, the following assumption was made by our group about the reason for the presence of saddle bars in the device in relation to the musical character of the undulating glass panels. We share it with you below:

"Our interpretation of the music of the undulating glass panels focused on a sonorous setting of the graphic score crystallised in the panels, for a classical keyboard of 88 keys. The tempo remains standard, one second per bar, and we have distinguished the musical parts in the "conduits", the atrium and the ones on the exterior façades. In our 2019 survey, we produced the following analysis:

The pane consists of glass panes set into the concrete post and metal and rubber saddle bars, initially the latter were made of foam. The metal bars are 25 mm high and the rubber bars are 14 mm high. Iannis Xenakis' undulating glass panes can be [interpreted] in a piano composition in the following way:

We take the height of the common undulating glass pane (i.e. 366 cm) and divide it by the number of keys present in a common piano. In this way, we obtain a kind of grid in which the concrete posts represent the duration of the piano note and the bars the actual notes. This interpretation makes it possible to transpose the façades of the undulating glass panes into a graphic musical score that can be read by digital music composition software.

The rest of this work was carried out with the help of Mr. Jean Pascal Cottier, an author-composer-performer from Lausanne, [Switzerland].

At the same time as the undulating glass panes, Xenakis composed his first work *Metastaesis* which he published in 1955. This musical piece was composed for a brass and string orchestra. It has a 5/4 rhythm, i.e. 5 beats for one bar on the score. The piece is part of the same movement as pieces by composers such as Pierre Schaeffer and Edgar Varèse. The characteristics of this movement are based on an analytical and mathematical approach to musical notes. The composition focuses on the presence of the notes in the score rather than on the harmony of the sounds as in traditional music. The duration of the piece is 8 minutes. The composition of the façade, at least the one we managed

to implement in our composition software, lasts 8 minutes approximately. According to Mr. Jean Pascal Cottier, the Xenakis façade can be considered as a summary or inspiration of the original piece, reduced to its simplest expression. The composition, hypothetically for piano, imposed a drastic simplification of the original piece, which may explain the heartbreaking feeling that the façade inspired in Xenakis. The piece is intended to be a sonorous ripple of glissandi throughout, a ripple that is impossible to achieve with the façade's straight saddle bars and reinforced concrete posts." (Emmanuel Stump, Mathias Schopfer, Survey report on undulating glass panels, TSAM, 2019)

Iannis Xenakis, Music of the undulating glass panes, 1959

When we returned to the Convent in 2021, it seemed correct to assume that the notes in the conduits had no reading direction defined by the composer: it is the walker who, by wandering, activates them regardless of the direction of his path.

The undulating glass panes in the rooms and common spaces are read differently from those in the conduits. In fact, the user's experience of these spaces only allows him to read part of the overall composition. By observing the façades of undulating glass panes from the outside, the observer can see that the people present in these rooms are all playing the same graphic score in concert, at different speeds. Thus, the western façade, in contrast to the “conduits”, would make the community sing and not the individual.

It is interesting to note that if the saddle bars form notes, the posts of the glass panels can symbolise the different beats of the metronome associated with the composition, thus defining a reading rhythm that varies in time and space. In a similar way to what Einstein's theory of Relativity explains, the posts are "grappled" around singular events attracting them, like stars distorting space-time by their mass. This effect seems to occur in the dining hall where the space between the posts expands when they are on the same level as the robust structural fluted piles (Fig. 18) as the space-time near massive objects physically do.

To close this chapter, let us recall the existence of the aerators, present at relatively regular intervals within the device. As a mechanical ventilation element of the device, their presence could be mistaken with sighs. These moments of silence, which are important in the musical field, allow the musician to catch his breath and continue the piece. The next chapter will give us an assumption for this name.

3. Analysis

3.1. Categorisation of the undulating glass panes

Before looking at the significance of the architectural element, it seems necessary to understand the use of each of the undulating glass panes in the complex. Following the survey, three categories seem to emerge:

- Circulation
- Thresholds and the transition between spaces.
- The representation of collective life.

The glass panels related to circulation are located in the walking spaces, whether vertical or horizontal. We find them in the “conduits” leading to the common and sacred spaces as well as in the staircases leading up to the different wings.

"The holy men no longer turn around in circles, but their procession may now fill these glassed-in conduits with liturgical songs and burning candles.

(Sharon Kanach, Music and architecture: architectural projects, texts and realizations, p.58)

The glass thresholds allow the transition from the profane to the sacred. Comparable to the medieval narthex, they form a filter that separates the religious space from the outside. In the case of the oratory, the undulating glass pane opening to the North makes the transition between the library and the oratory and separates the two spaces by light.

A similar use of this device can be found in the convent church. The two mono-panes separating the chapels from the main space and the monumental glass pane opening to the east use the same principle. The former allows the light to emphasise the sacred and communal volume, while the latter filters the light from the east, giving it its divine character.

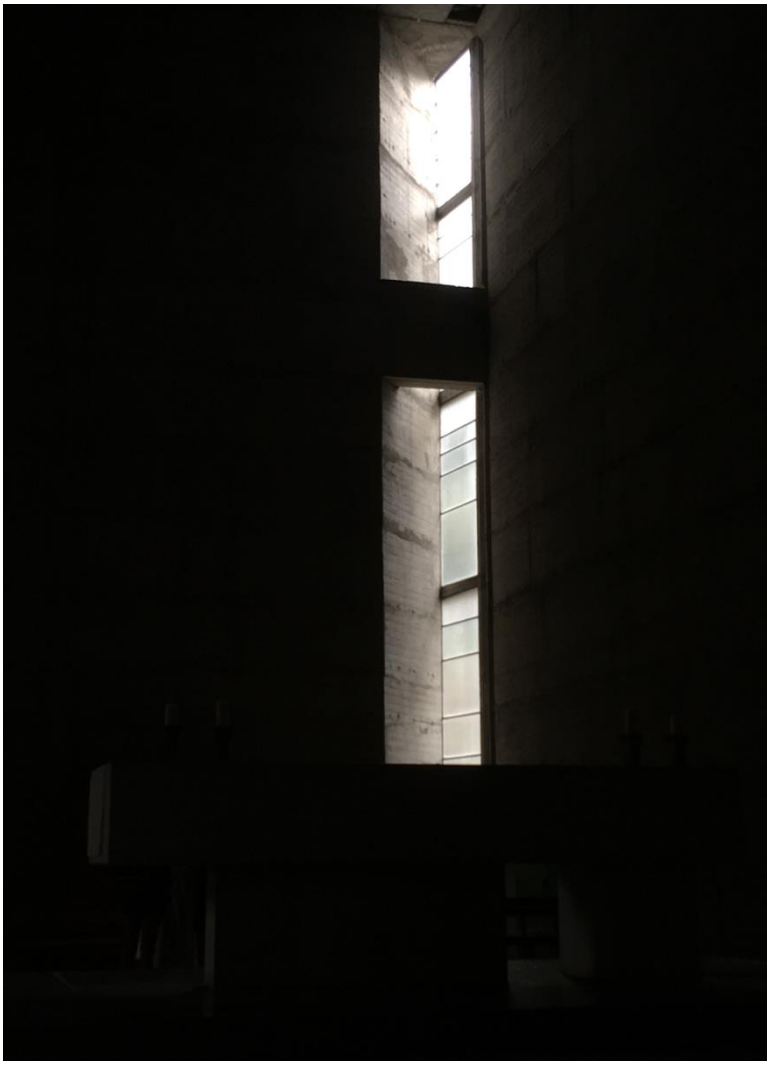

Figure 17: view of the monumental undulating glass pane of the church

The use of undulating glass panes in the common spaces finally reveals that the use of these elements always has a relationship to the staging of human life. Here, it is the community that is highlighted after the strolling and the thresholds. Thus, the spaces of the refectory and the classrooms offer a frontal relationship to the device and a strong contrast between the lightness, even fragility, of the undulating glass panes and the power of the fluted pillars supporting the west wing.

Figure 18: view of the dining hall with the expansion of the sides in line with the fluted pillars

One final element may interest us: the undulating glass pane in front of the spiral staircase in the atrium in front of the dining hall and the chapter's room. Its symbolism seems to be multiple: indeed, it accompanies the faithful when they go to the refectory or the chapter room, acts as a threshold between the ambulatory space of the conduits and the community spaces but also represents the community.

Indeed, in the extension of the opening is the cemetery of the Dominican friars of the chapter, which can be seen at the edge of the forest. It is possible that the architectural element serves to remind the surviving friars of their counterparts and to pay tribute to them.

Figure 19: the undulating glass pane facing the spiral staircase, facing the cemetery

Before starting the next chapter, it seems clear to us to precise that we have not found a different use for the undulating glass panes in convent. However, these different uses allow us to state that an intimate relationship exists between the human being, its proportions and the undulating glass panes. The device is related to music, however, one of its side effects is to ritualise the relationship the inhabitant has with the time and space contained in the place.

3.2. Architectural analysis

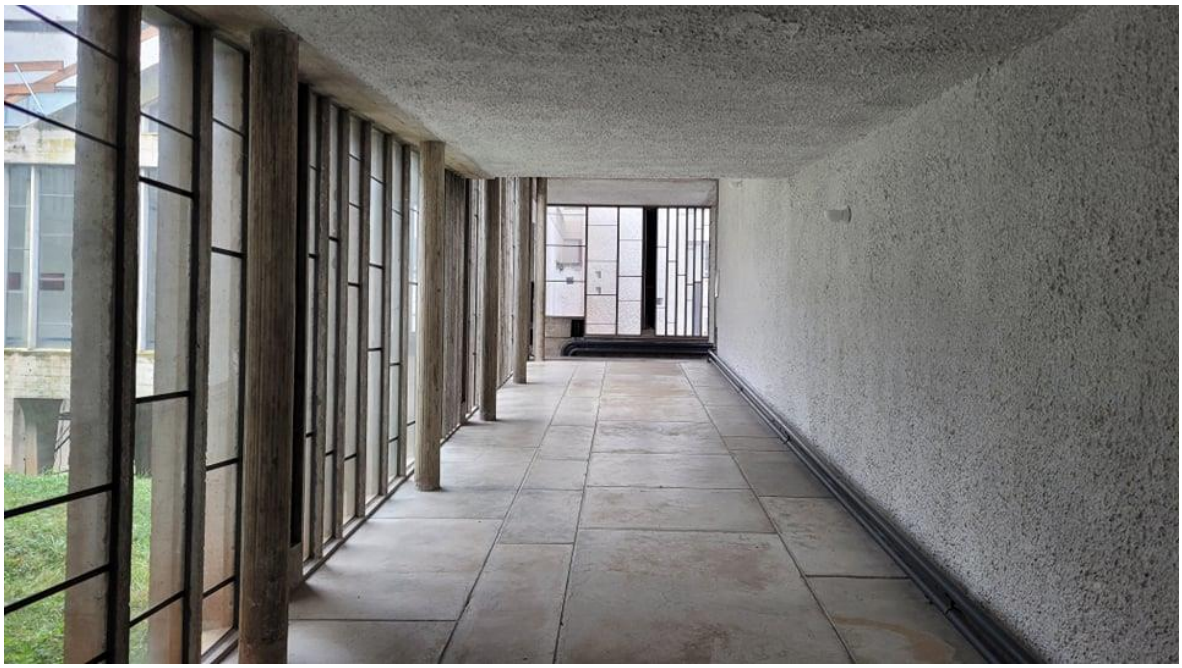

Figure 20: view of the undulating glass pane in front of the "petit conduit"

The pane facing the small conduit is quite crucial for understanding the relationship between music, human beings and architecture in the panes. Linking the large and small "conduit", this element functions as the shifted transition of the graphic score present in the "grand conduit" (Fig.19). The undulation of this pane forms a graphic continuity both for the "grand conduit" as a whole and from the "petit conduit" to the church. The elevations made by Iannis Xenakis as part of the study drawings also demonstrate that this is one and only one partition. By projecting the undulating glass pane against the opposite wall, the visitor, by passing from the "grand conduit" to the small one and vice versa, enters the music and even makes his human proportions resonate with the Modulor contained in the undulating glass panes.

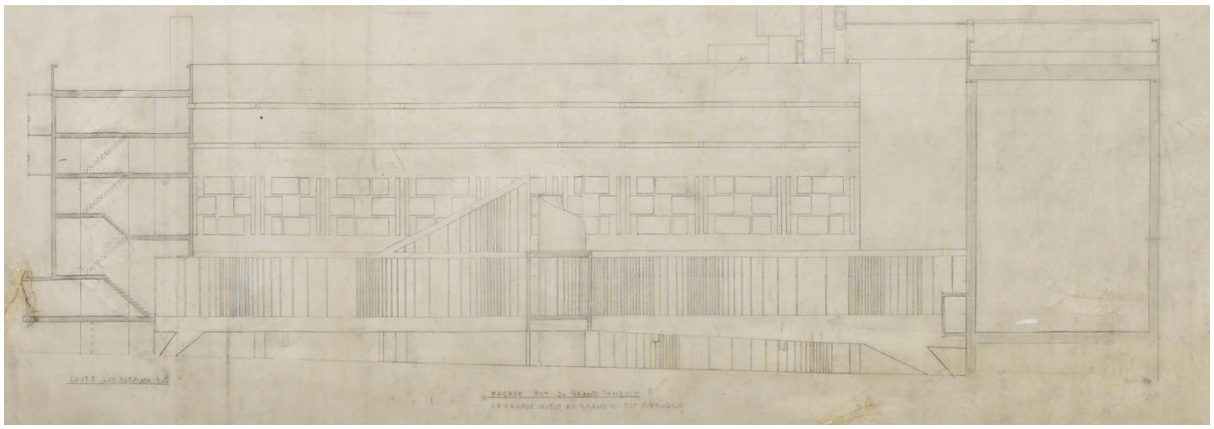

Figure 21: Le Corbusier, Couvent Sainte-Marie de la Tourette, Eveux-sur-l'Arbresle, 1953, Plan FLC 01340, [elevation of the « grand conduit »] (credits: © Fondation Le Corbusier)

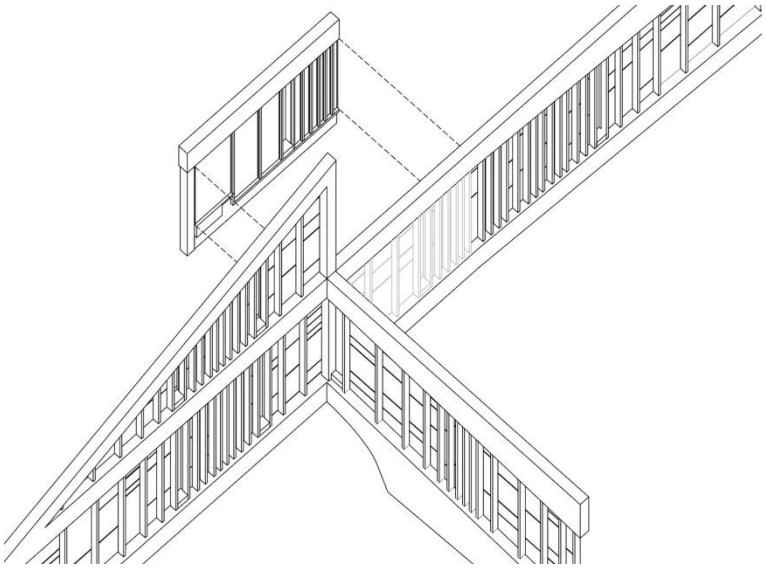

Figure 22: axonometry of the crossing between the "petit" and "grand conduits" with the projection of the pane making the continuity of the device

Figure 23: the corner between the "Grand" and "Petit Conduit"

The “grand conduit” has also its peculiarities either. Its ceiling projections also correspond to characteristic values of the *Modulor*, namely: 226 cm, 366 cm and 732 cm. These measurements correspond, in the case of the model, to: one human being with his arm raised, two human beings on top of each other and finally four human beings on top of each other. The two values of 226cm are found at the beginning of the “petit et grand conduits” coming from the individual cell spaces. Then, we move on to 366cm and even 732. The *Modulor* values tell us that we are moving from individual life to collective and spiritual life.

Figure 24: overall perspective of the “grand conduit”

The rectangular triangle of the atrium seems to extend towards the church, accompanying the community in its spiritual life. Contrary to the western façade, the posts of the two floors are perfectly superimposed, indicating us that it is the same score, on the one hand, but also that the triangular disengagement would allow the score to expand and thus increase the number of notes architecturally, thus provoking a cluster. Indeed, the graphic score progressively increases from 366cm to 732cm, thus admitting more notes while keeping the same number of musical pitches. The triangle and this cluster would then represent the intersection of the individual, the collective and the spiritual.

Figure 25: View of the atrium triangle with the posts on top of each other

It is now possible to include the undulating glass panes of the ducts in the category of thresholds. They act as a threshold between individual, collective and spiritual life.

3.3. Architectural abstraction

Figure 26: Frédéric Edwin Church, Parthenon, 1871

Our theoretical statement on which this article is based is to be used as a basis for our master project. Thus, we have sought to bring the undulating glass panes back to their very essence and primary function in order to, among other things, extract them from the architectural style and the modernist period in which they are embedded. It is through a process of successive abstractions that we hope to define the undulating glass panes of 2022.

Our journey begins with a simple comparison between the architectural and structural device of the ducts and the peristyle of the Parthenon (Fig.27 and 28). The supporting columns of the "conduits" allow the curtain wall and the undulating glass panes. In front of the glass façade, there is always a solid wall, a device comparable to the peristyle of the Parthenon, which made us produce two initial collages to illustrate this intuition which, at the time of its discovery, still seemed weak.

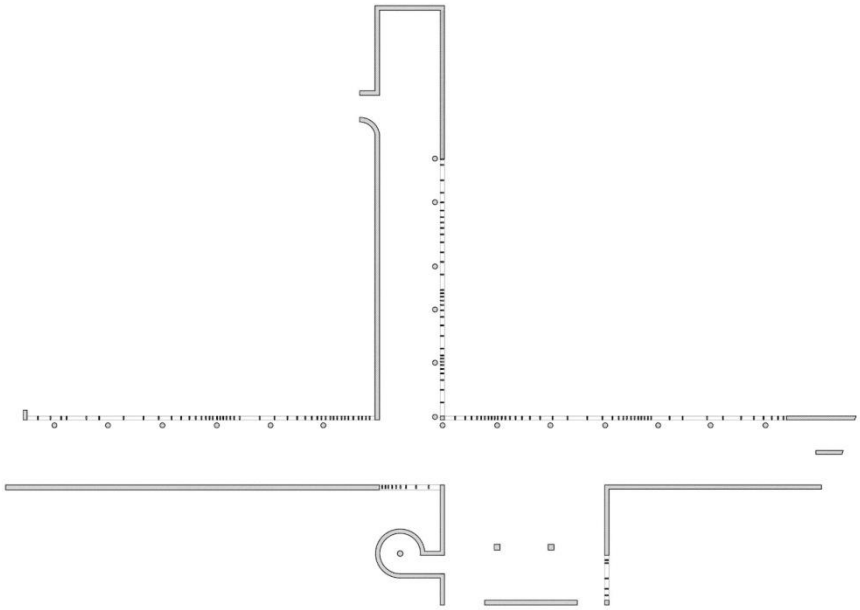

Figure 28: plan of the "conduits" of the Couvent de la Tourette

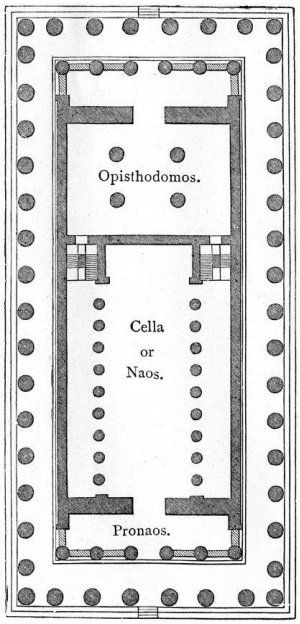

Figure 27: plan of the Parthenon

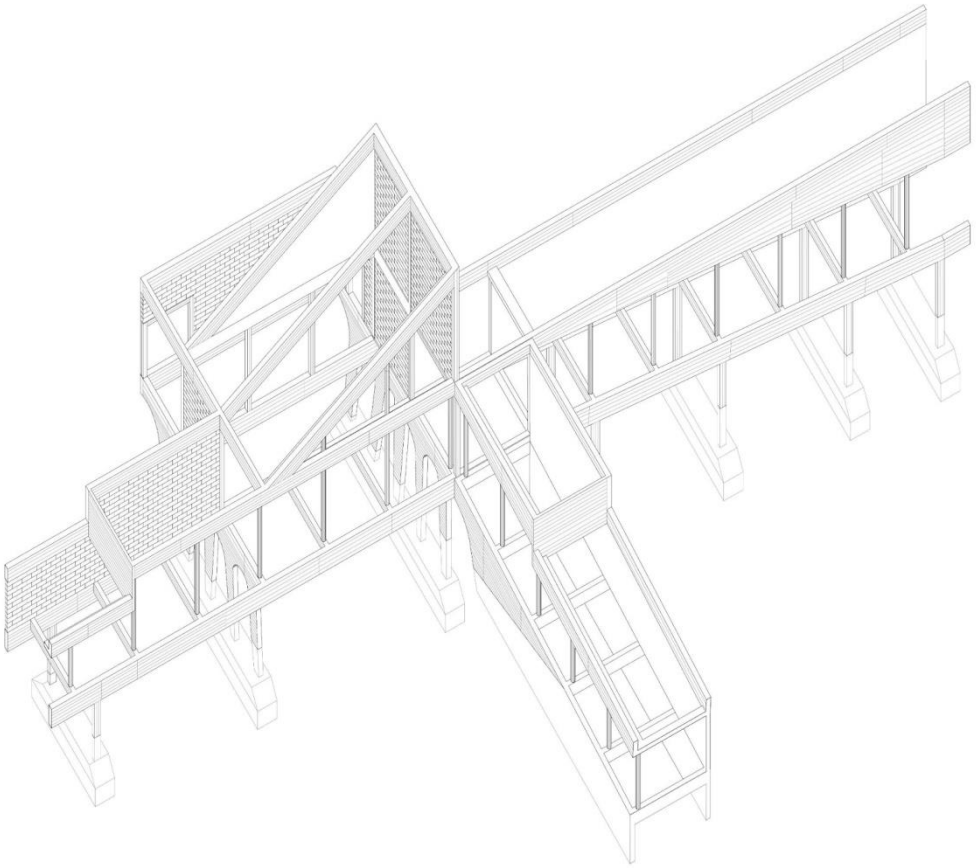

Figure 29: Mélanie Baptista de Sousa, Couvent de la Tourette - Axonometry - conduits, 2019

Figure 30: conceptual collage illustrating our interpretation of the undulating glass pane

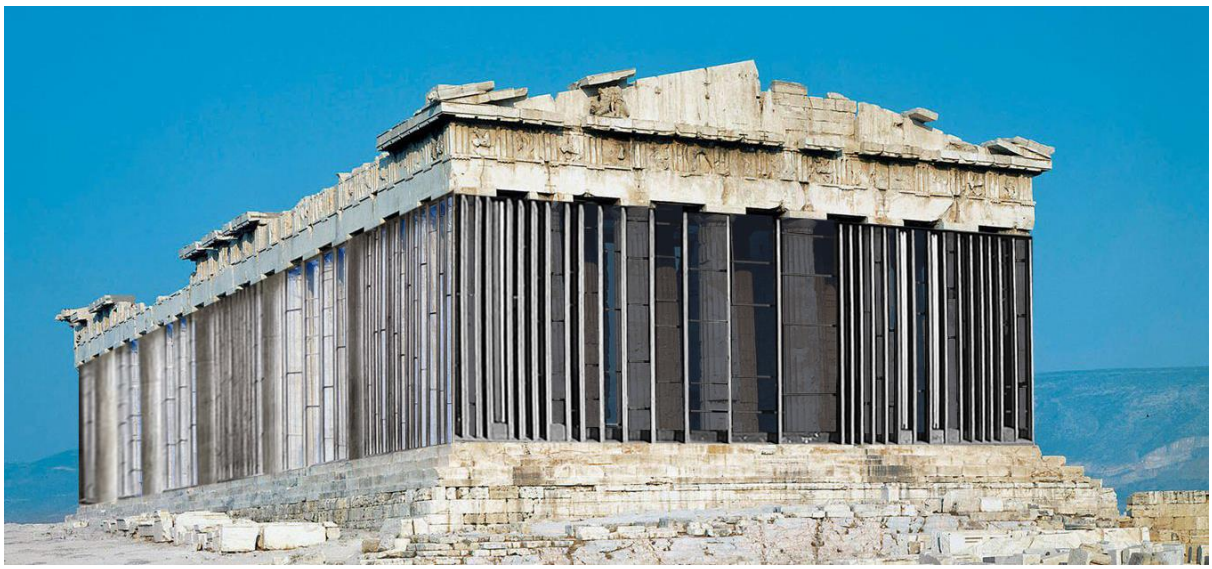

Figure 31: conceptual collage illustrating our interpretation of the undulating glass pane

It turns out that the comparison does not end there. Let's recall here that Iannis Xenakis has Greek origins, has been expelled from Greece and will begin a sort of reconquest of his homeland through several projects such as the Villa Mâche, a project that will be piloted from Paris for example. Then, after the charges against him were dropped, Xenakis composed two Polytopes for this country: firstly the one of Mycenae, and then the one for Athens, which was unfortunately aborted. It is certain that this one would have completed this reconquest. His personal trajectory thus originates from Athens and also tends towards the Greek capital. A similar parallel presented in the introduction can be interpreted with the parallax effect of the Acropolis noted by Jacques Lucan. The Acropolis of Athens is a solid origin of the trajectory concerning architecture and brings into play the notion of space-time. Moreover, Le Corbusier's fascination with the Athenian monument is reflected in the numerous sketches he made during his "Voyage d'Orient" in 1911. He depicts the flutes with an intense vibration which reminds the ones present in the undulating glass panes. The comparison is even disturbing and supports our initial intuition.

Figure 33: Le Corbusier, Carnet du Voyage d'Orient n°3 p.115, 1911, [Sketch of the Acropolis at Athens] (credits : © Fondation Le Corbusier)

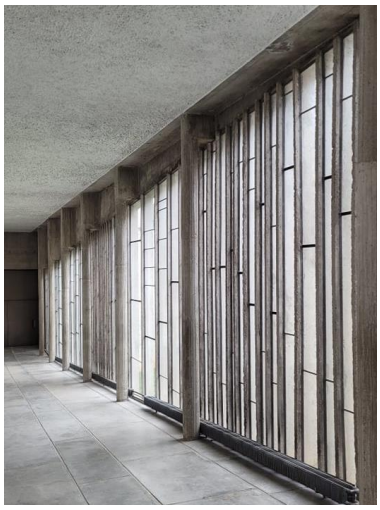

Figure 32: vibrant perspective of the undulating glass panes towards the church

A later reflection in the progress of our work occurred when we were asking ourselves the question of the temporality of spaces for our master project. Is it slow, fast, rhythmic or static for

example? During this reflection, we had the plan of the Parthenon in front of us. The intuition to apply this concept to the Parthenon itself emerged in our minds: the grooves of the peristyle columns can then be considered as a vibrant threshold between two temporalities. The visitor crossing between these grooves passes from the outside, subject to time, rain, and astronomical cycles before entering the sacred space, which has a relationship to eternity. Let us now compare the church of the Couvent de la Tourette with the naos, pronaos and opisthodomos of the Parthenon. These are two rectangles of almost equal proportions. Here again, the same vibration as the Parthenon's grooves, this time in the form of undulating glass panes, takes us from a space literally subjected to time by the rhythms of the posts to an eternal, sacred space where time hits differently. The conduits and the undulating glass panes are like a peristyle unrolled in space that could be wrapped around the rectangle of the church in order to schematically reform the Parthenon's device.

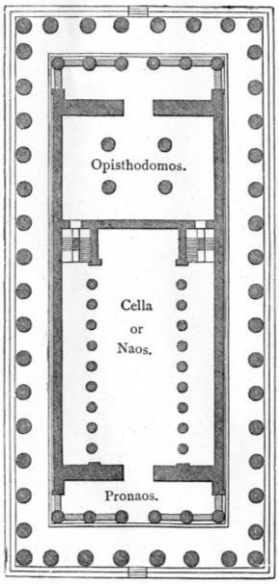

Figure 35: plan of the Parthenon

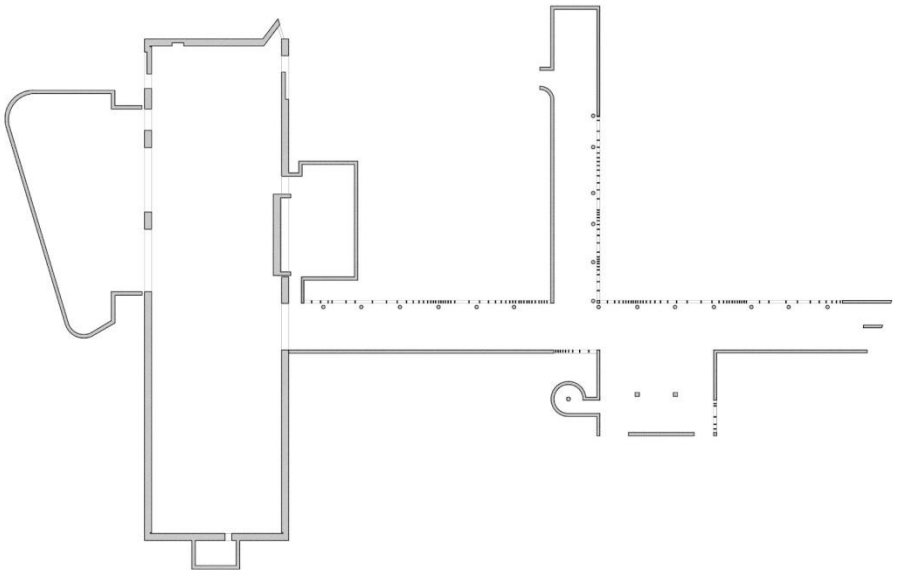

Figure 34: plan of the "conduits" of the Couvent de la Tourette

The undulating glass panes would then be to the modern movement what the colonnade and the peristyle are to the ancient world: a filter accompanying the visitor from one space to another and from one temporality to another.

Figure 36: the Ergastines, detail of the friezes from the Parthénon, Louvre Museum, Paris

To continue the Greek metaphor, let us look at the Ergastines. This bas-relief, preserved in the Louvre Museum, comes from the eastern frieze of the Parthenon and shows a group of Ergastines during the Panathenees. These statues, in the book: "La Métamorphose des Dieux", written by André Malraux, are described as having retained their architectural character of columns through the drapery of their dress, rigid and straight. Thus, in the manner of the symbolic history of the orders, it is no longer characters that are represented in the work but personified architectural elements.

> “Présumons qu’au-dessus du brouhaha des vraies Panathénées, le cortège des Ergastines sembla une procession de colonnes”
> (André Malraux, La métamorphose des dieux, p.72)

> “Le mot sanctuaire ne désigne pas, à Athènes, le lieu où se trouve la déesse, mais l’Acropole même. [...] L’Acropole est une vaste offrande. Ses temples ne sont pas incomparables aux autres par leur architecture, mais par leur ostension”
> (André Malraux, La métamorphose des dieux, p.81)

> “L’arabesque joue ici le rôle transformateur - et non illusionniste - que jouent les verticales parallèles dans le drapé des Ergastines. [...] Les Ergastines sont belles, non comme leurs modèles, mais comme des colonnes - et comme la musique : ce qui exprime le divin.”
>
> (André Malraux, La métamorphose des dieux, p.78)

The Caryatids also present on the Acropolis of Athens have the same characteristics as the Ergastines: they too are the personifications of columns.

Figure 37: caryatids from the Athens Acropolis

Let us now return to the undulating glass panes which, as we have shown, have a very strong architectural link with the grooves vibration of the same ancient columns. Let us also remember that the undulating glass panes are sized according to human proportions and make them resonate thanks to Le Corbusier's *Modulor*. The undulating glass panes can therefore be interpreted as being, like the Caryatids and Ergastines: personifications and modernisations of the ancient fluted column.

Figure 38: vibrant perspective of the undulating glass panes towards the church

Figure 39: Le Corbusier, Carnet du Voyage d'Orient n°3 p.115, 1911, [Sketch of the Athens Acropolis] (credits: © Fondation Le Corbusier)

Figure 40: the Ergastines, detail of the Parthenon friezes, Louvre Museum, Paris

Figure 41: caryatids of the Athens Acropolis

The abstraction is done, the undulating glass panes are a vibration, a threshold and a motif that has human dimensions thanks to the injection of the *Modulor* into its proportions, expressing space-time by fragmenting it, dilating it and compressing it thanks to a musical component. This is what undulating glass panes are and what their 2022 version should express.

4. Conclusion

As we have seen in the course of this work, the undulating glass panes of the Couvent de la Tourette remain both a strong architectural element, guardian of a secular doctrine, and a musical artefact inscribed in a trajectory of Iannis Xenakis and the wider one concerning the representation of time. Indeed, the concept of the undulating glass pane is a two-dimensional transposition inspired by *Metastaesis*, into a graphic and architectural score. The undulating glass panes were used in the vast majority of Corbusean projects before and after that Iannis Xenakis left the office. In fact, the power of the undulating glass panes of the Couvent de la Tourette will find little echo in later projects. The device is now part of the post-war Corbusean motifs, which raises questions about its implementation today. The path we developed in the last chapter seems sufficiently solid to lay the foundations for our personal project, but also for anyone who wishes to evoke the same architectural force and intensity that Iannis Xenakis injected into his device.

Iannis Xenakis' trajectory does not end here and, in fact, has only just begun. In 1958, Iannis Xenakis took up the glissandi of *Metastaesis* as part of the composition of the Philips Pavilion project. Iannis Xenakis then used them to precisely define the isoparametric ruled surfaces

composing the walls of the object. Thus, he moved from a two-dimensional architectural partition with undulating glass panes to a three-dimensional architectural partition developing in space.

Figure 42: Wouter Hagens, View from the exit of the Philips Pavilion, 1958

The conquest of dimensions through successive musical and architectural abstractions continues. His later creations, in particular the Polytopes, share striking similarities to the three-dimensional transposition of the Philips Pavilion. If we compare the latter with the Montreal Polytope, for example, we see that the Polytopes are merely a higher stage and logical continuation of the Philips Pavilion, which is nothing more than a frozen Polytope remaining in three dimensions. The Polytopes are in fact a device of spatialized sounds and lights according to time where architecture is sometimes reduced to simple cables reducing the limit between architecture and music.

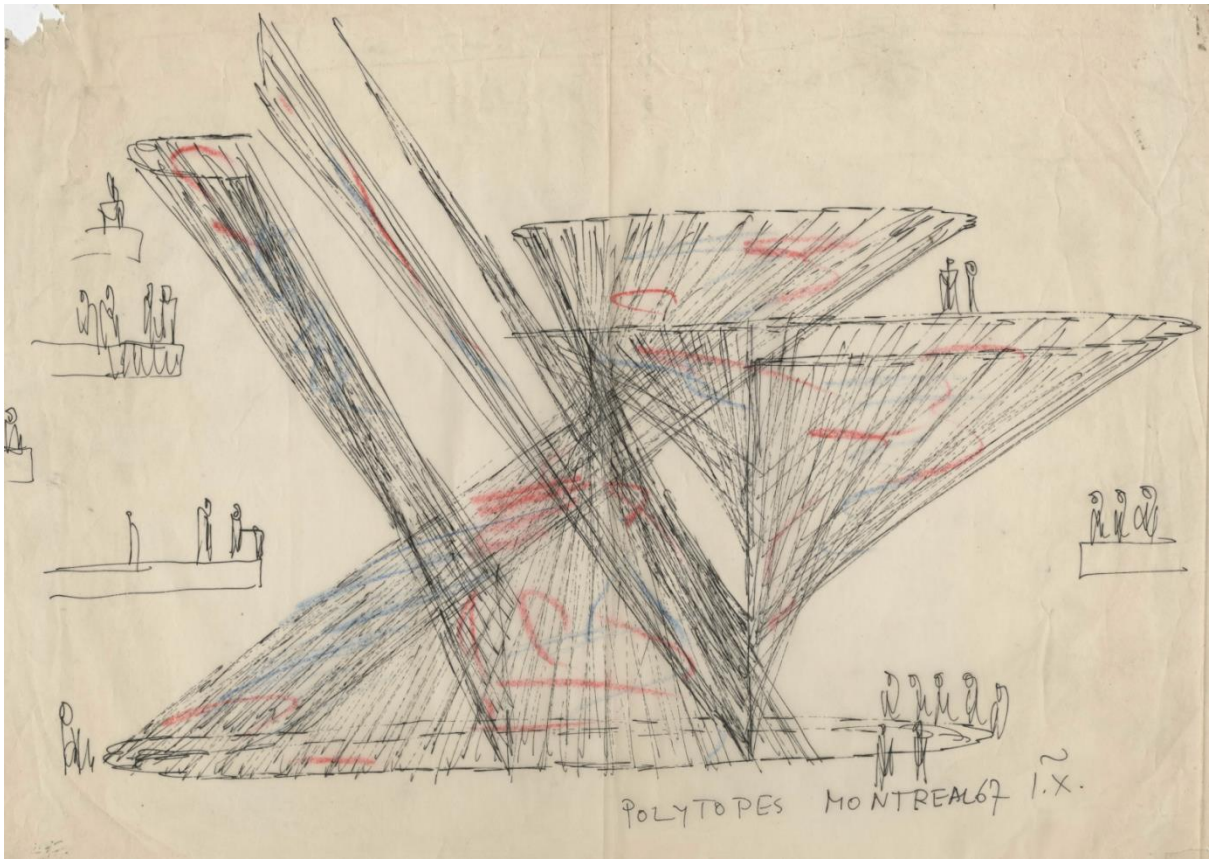

Figure 43: Iannis Xenakis, sketch for the Polytope de Montréal, 1967 (credits : © Famille I Xenakis)

Finally, it should be noted that this personal trajectory involves elements whose strength is remarkable each time: the music, the *Modulor*, *Metastaesis*, the undulating glass panes, the Philips Pavilion, and the Polytopes are, each one of them, accomplished creations. We wish to emphasise that they emerged from one and one person only, one genius, Iannis Xenakis.

Acknowledgments

We would like to warmly thank the staff of the Couvent de la Tourette for their welcome and availability. We would like to thank Brother Charles, architect and Dominican monk residing at the Couvent de la Tourette, for his patience, his listening skills, the interest he showed in our research subject during our discussions and the time he took to inform us about the life of the Couvent and its specificities. Our thanks also go to the various foundations that generously opened their doors to us, in particular the Le Corbusier Foundation and the association Les Amis de Xenakis. We would also like to warmly thank the EPFL library and its team, who allowed us to have all the books necessary to write our work. We would also like to thank Professor Roberto Gargiani for the time he devoted to answering our questions about the Modulor system. Finally, we would like to thank our follow-up team, namely Professors Franz Graf and Eric Lapierre, as well as Doctor Yvan Delemontey, who agreed to follow us on a perilous adventure at the crossroads of the arts and sciences Finally, our gratitude goes to our relatives who supported us throughout our research.

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