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# FUNCTION FOLLOWS FORM ARCHITECTURAL FORM AND SOUND PROPAGATION

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Louis Sullivan's motto "form follows function" has been severely criticized for its consequences on the rigidity of architectural form. In many cases, though, its validity can be proven by its reciprocity. For example in acoustics we notice that sound propagation can be influenced by the form of space. Sound reflections, diffractions etc., change the Sound Pressure Level (SPL) and other sound properties of a given source according to the receiver's position in space. The paper concentrates on this space-sound relation, focusing mainly on open outdoor spaces. Examples of architectural works with an exceptional form (such as Le Corbusier's chapel at Ronchamp, the Kalavryta memorial, or the Athenian citizens' assembly – Pnyx) are examined for their potential to propagate sound due to the acoustical properties created by their form. For this purpose, the use of sound software (Olive Tree Lab 3.0) is applied through the 3D modelling of the above examples and the extraction of 3D mappings of specific sound properties. The main goal of the paper is to investigate (by reversing Sullivan's motto) whether "function follows form".

## 1. Introduction

"*Whether it be the sweeping eagle in his flight, or the open apple-blossom, the toiling work-horse, the blithe swan, the branching oak, the winding stream at its base, the drifting clouds, over all the coursing sun,* ***form ever follows function****, and this is the law*". [1]

Louis Sullivan's motto "*form follows function*" is regarded as a normative law, which is supposed to reflect the everlasting laws of nature. The original phrase "*form* ***ever*** *follows function*" reflects this mentality by including the word "*ever*". "*This is the law*" is emphatically noted right afterward. In architecture this law has an ethical dimension, too. Architectural form should follow function. The criticism against this way of thinking, mainly by postmodern architects and theorists, is based on the strictness of the law itself and its consequences on the rigidity of architectural form. They claim that the quest for form should be freed from any functional restrictions, for the sake of pure expression.

Indeed Sullivan's axiom cannot be justified completely. After all, the form of some natural objects, beings or parts of them does not seem to perform a specific function. Nevertheless, it cannot be totally rejected either. It cannot be denied that we often notice in nature a close relationship between function and form. We see "*the sweeping eagle in his flight"* and we sense a relation to its form. If we consider the "*form follows function*" motto not as an everlasting normative law, but as a guideline for our understanding of the relation of architectural design to aspects of human coexistence, we may find it more helpful.

This paper's approach is to examine the motto's validity through a reciprocal method. We may trace the consequences of a specific architectural form on the way people get together and commu-

nicate. The paper discusses cases in which a specific function derives from, or is related to, a specific form. In order to examine Sullivan's claim, the main question asked is whether function follows form.

## 2. Definitions of Form and Function

For the sake of this main question the meaning of the terms 'form' and 'function' is further examined. 'Form' does not strictly refer to the external image of an object, but to more structural characteristics of space. The in-between, the space between buildings, walls or other architectural elements also has a form. A courtyard has a form; any enclosed space has a form.

'Function' does not strictly refer to economy, ergonomics, efficiency or utility (the Vitruvian 'Utilitas') but can have a broader meaning: it can also refer to how spaces relate to each other and, consequently, to how people coexist and communicate. Communication is related to human senses: vision, hearing and touch. In this paper the acoustical aspect of human communication is examined.

## 3. The acoustic aspect of the human voice

In acoustics we notice that sound propagation can be influenced by the form of space. Sound reflections, diffractions etc., change the Sound Pressure Level (SPL) and other sound properties of a given source, according to the receiver's position in space [2,3,4]. Two people standing in space can hear each other differently, according to their position and the specific form of the space between them. A corner, a street, a niche, a curve, all create different conditions for the propagation of sound. The degree of enclosure of any given space, even outdoor, is dependent on its form and a very important condition for retaining the sound energy within it. Having this in mind we can re-examine some architectural buildings that have an exceptional or unusual form.

Specific architectural examples are examined for their sound properties, mainly Sound Pressure Level (SPL). Three buildings or monuments are the main focus of this paper: Le Corbusier's chapel at Ronchamp, the Kalavryta Memorial and the three phases of Pnyx, the Athenian citizens' place of assembly. All examples are outdoor open spaces that are characterized by some kind of enclosure, even subtle. The use of sound propagation software is applied for this purpose, namely Olive Tree Lab Suite (Version 3.0). Mappings of SPL are created in a 2x2 grid of receivers 1m above the ground. The source is always the same: a human voice at 67 dB(A), which is rather raised. The purpose of the examination is to showcase that the different forms propagate sound differently and therefore they create different conditions for the communication of people.

## 4. Chapel at Ronchamp

The first example is Le Corbusier's chapel at Ronchamp (Fig.1,2) an expressionistic building with strange curved forms. The architect has been criticized, notably by Aris Konstantinidis, of being too concerned with form and that these forms have no function. Konstantinidis claims that in this building "*form follows form*" [5].

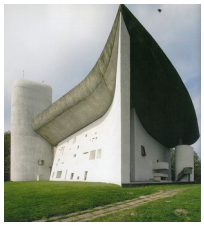

Figure 1: Northeast side of Le Corbusier's chapel at Ronchamp [6].

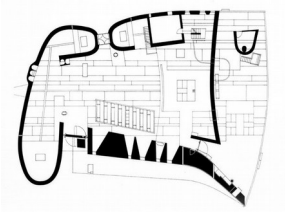

Figure 2: Plan [6].

If we examine though, the requirements given to the architect we see that these forms are not so arbitrary. Here we examine the east side, where the architect was asked to create an outdoor chapel. For that purpose, the usually convex shape of the chancel has been transformed to a concave one. A slight curve together with walls extending from the building's mass and a cantilevered roof create reflections that enhance the propagation of sound (Fig. 3). The priest's voice (regardless of whether it is amplified by electroacoustic means) extends considerably further (Fig. 5). The conditions for an outdoor liturgy are improved. The priest standing in a raised pulpit can be heard by a rather large crowd (Fig. 4).

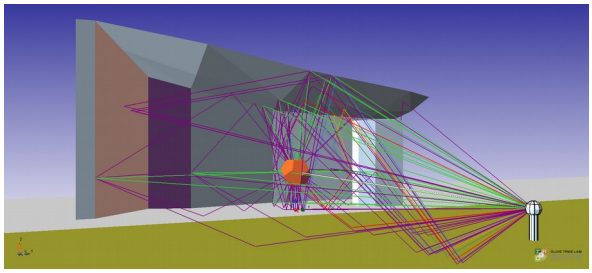

Figure 3: Reflections and diffractions.

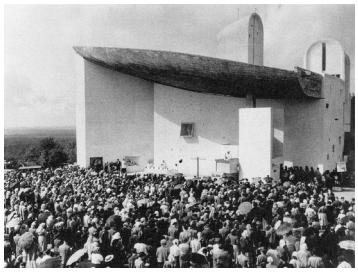

Figure 4: An outdoor mass attended by a large crowd [7].

We cannot be sure that Le Corbusier was aware of such consequences of form for sound propagation. We may recognize, though, such intentions even in his first sketch, where, together with the building's form, he designed the acoustic radiation of the priest's voice [7] (Fig. 6). Le Corbusier was not ignorant of such acoustic properties. In an interview given a few years later he explained the curved form as follows: "*This curve is useful to me, because I create curves of acoustic nature, acoustic landscape … It is an acoustic of space… that receives the four horizons which are different*" [8]. With these in mind we may assume that the creation of form was not just a "*play of volumes assembled under the light*". [9]

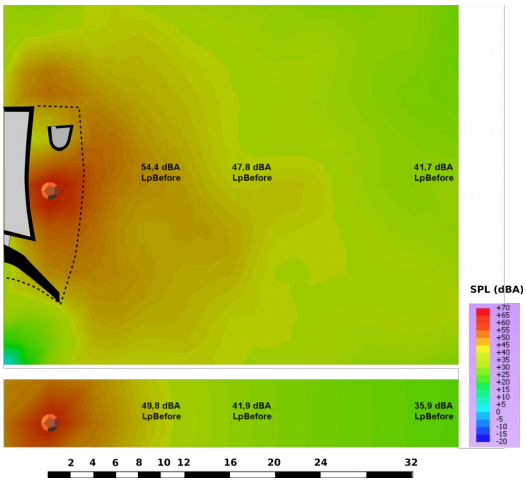


Figure 5: SPL mapping and comparison with the same source in a free field.

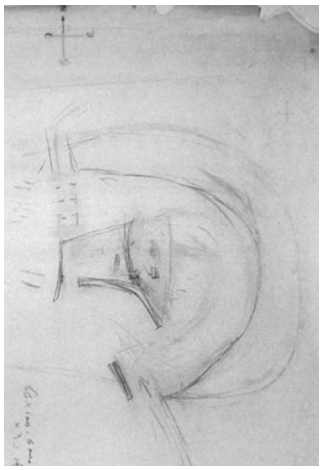

Figure 6: First sketch of the design procedure [7].

## 5. The Kalavryta Memorial

Despite appearing strange at first sight, many expressionistic buildings shape the acoustic field in interesting ways. Even monuments that have no specific 'function', in the strict sense, appear to modify the sound field through their form. The Kalavryta memorial (architects: Ioannis Liapis, Elias Scroubelos and Christos Iakovidis) is a characteristic example. It is built on a hill where in

1943 the massacre of 600 civilians by German troops took place. It consists mainly of freestanding concrete walls of different sizes, shapes and heights (Fig. 7,8). The architects' intention was "*to create a dynamic discontinuous monumental space*"..."*The plastic elements are freely composed in space, they create optical connections with the natural environment, and allow the presence of the historical place inside the monument*" [10]. Even though the monument is open and transparent, the freestanding walls enclose the space. They create reflections that restrain the wave energy inside the monument.

Figure 7: The Kalavryta memorial during the 13 December annual ceremony.

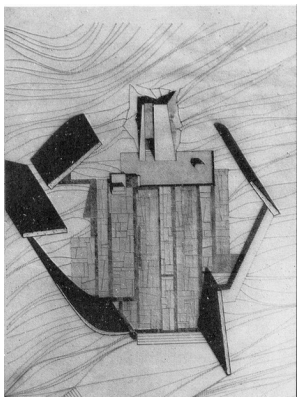

Figure 8: Plan [10].

Many years after the monument's erection the acoustic properties of the space were used to create an interesting sound installation. Every few minutes, a loudspeaker, at the outer side of one of the walls, plays a recording of a narrative of the 1943 events. The adjacent wall reflects the sound waves back into the monument and, additionally, the other walls enclose the sound (Fig. 9, 10). The loudspeaker is not seen but heard. In this way the sound is distant and discrete, and the general feeling is not so imposing. The visitor learns about the past events without being overwhelmed by the monument. We see again that the form of space transforms the sound properties and therefore its potential function.

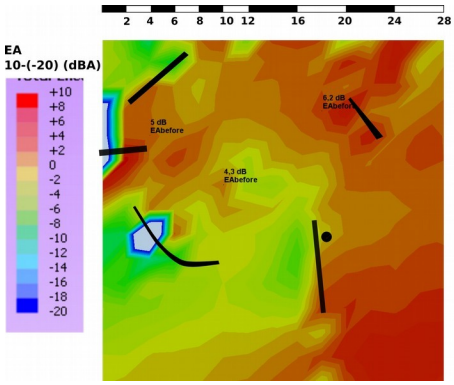


Figure 9: Excess attenuation mapping of a source on the low right wall's outer side.

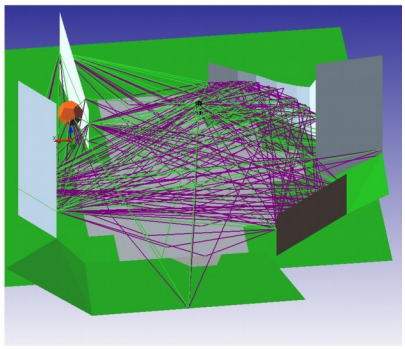

Figure 10: Reflections and diffractions of the same source.

## 6. The Athenian Pnyx

The last example is Pnyx, the Athenian citizens' place of assembly. The monument is here examined not because of its historical importance but because it was subjected to several structural transformations throughout history. We are aware of three phases: (a) the late 6th cent. BC first assembly, probably built during the age of Klisthenis (Κλεισθένης), (b) the phase that was formed after the

404 BC works by the Thirty Tyrans, and (c) the last phase after the 330 BC works [11]. During these phases the shape, scale and orientation of the monument was radically transformed (Fig. 11).

In the first phase the assembly is contained within the chiseled limestone. The curved wall on the south side has a 50m radius. The speaker does not stand in the center of the curve. Behind the speaker, on the north side, a wall is enclosing space. The exact height of the wall is not known, since only the foundation exists. Here we assume that the wall was quite high (3-4m), even though assumptions to the contrary also exist. The far wings of this wall form a 45-degree angle. The ground is made of the same limestone soil. The general dimensions are 40x80m and the place has a 13% inclination (Fig. 12,13).

In the second phase the orientation of the Pnyx rotates 180 degrees. The citizens now turn their backs on the Agora. They stand on an embankment supported by a retaining wall on the north side, which has a curved form and 40m radius. The 'bema' (βήμα-podium) of the speaker stands on the south side and the former retaining south wall is now behind it. The embankment's inclination is much smaller (4.7%) (Fig. 12).

In the third phase the orientation remains the same. The curved embankment becomes even larger with a 62m radius with its center exactly on the 'bema'. Behind the bema the engraved limestone forms a scene that has a wide angle shape. The general dimensions are 67x120m. The inclination is slightly increased (5%). The floor is now made of soil (Figure 14).

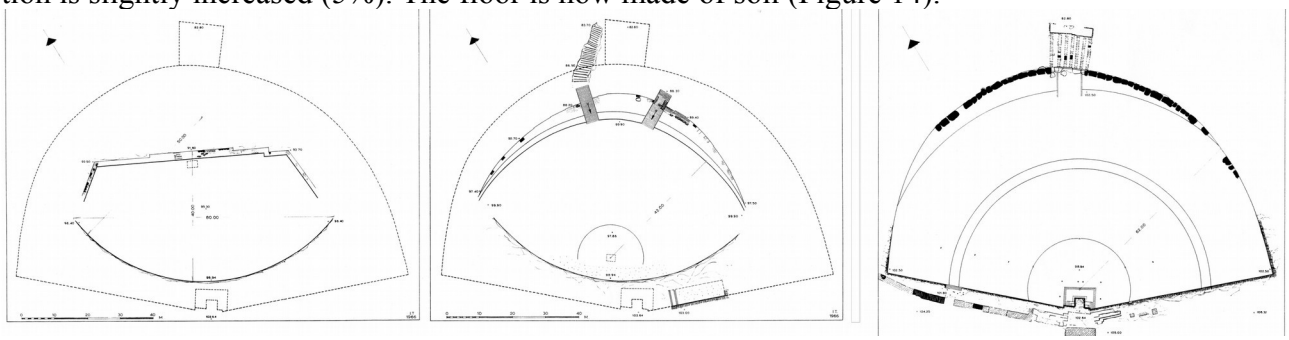

Figure 11: The three phases of the Athenian Pnyx. Left: Late 6th cent. BC; middle: 404 BC; right: 330 BC. [11]. In all plans the third phase is indicated with a dashed line for the purpose of comparison.

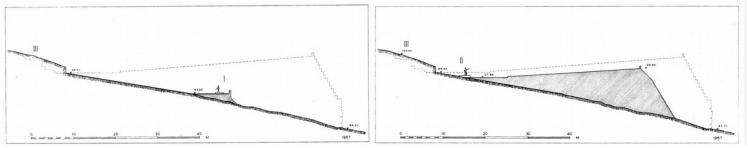

Figure 12: Sections of first (left) and second (right) phase [11]

Figure 13: Model of first phase

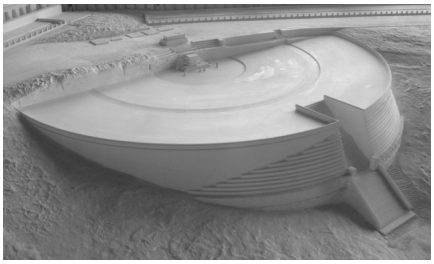

Figure 14: Model of third phase. In both models the north is on the right side of the picture.

The three phases differ from each other in many respects, including their acoustic properties. Here the first and last phases, which display the biggest differences, are compared. In the first phase the

existence of the wall behind the speaker creates early reflections that enhance the speaker's voice (Fig. 15). The engraved wall behind the audience also creates reflections and is responsible for an interesting effect: those sitting in the last rows hear better, because of these reflections (Fig. 16). The scale of the place allows everyone to hear rather satisfactorily.

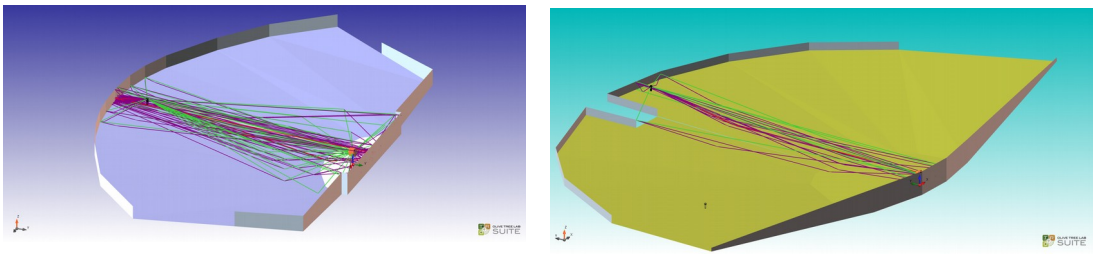

Figure 15: Reflections and diffractions during the first 50 msec after direct sound in the first (left) and last (right) phase of the Athenian Pnyx.

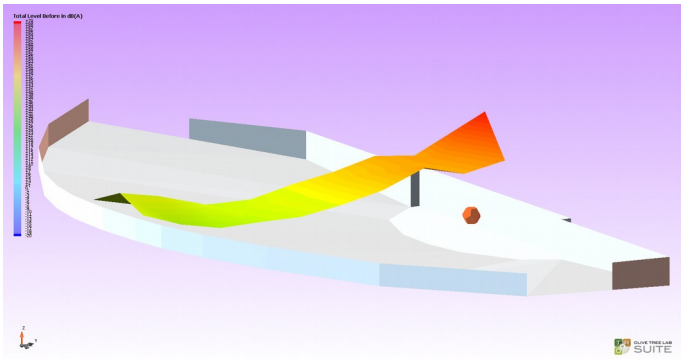

Figure 16: 3D mapping of the Sound Pressure Level of the first phase.

In the last phase, again the back wall behind the speaker reflects the sound (Fig. 15). Its closed shape collects the reflections and increases the SPL. The scale of the space, though, is much bigger. The SPL in the back rows decreases. Additionally the low inclination does not allow adequate visibility and audibility, since the speaker is hidden by the heads of those sitting in front (Fig. 17, 19, 20). The direct sound is unable to reach the back rows. The reflections from the ground floor are also weakened, compared to the ones created by the rocky ground of the first phase.

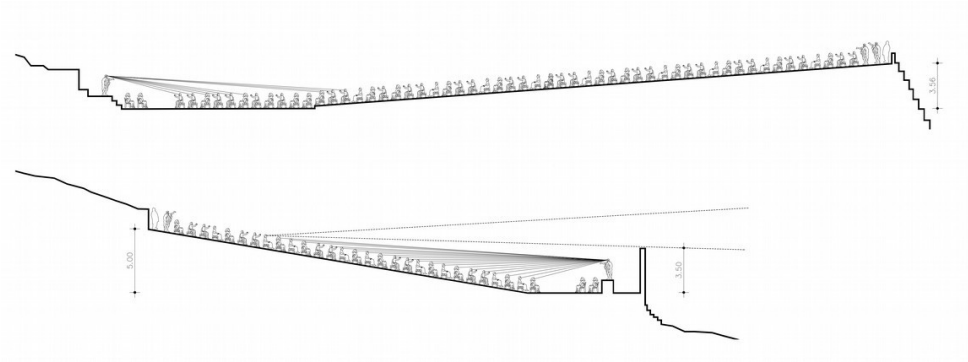

Figure 17: Sections of first (bottom) and last (top) phase with diagrams of direct visibility and audibility of the speaker.

The comparison (Fig. 18) between the two phases does not intend to validate them. It is based on assumptions, which are not completely justified, neither by archeological evidence, nor by the general knowledge of the natural and cultural environment of the ancient city. For example we cannot be sure about the soundscape of Ancient Athens. If the environmental noise was less than 30-35

dB(A), the form of the last phase could be adequate acoustically, since the speech would not be masked. Equally, we can't be sure about the perceptive capabilities of the Athenians. We may assume that they were trained to hear in outdoor space without the modern means of electroacoustic amplification, that nowadays weaken our ability to hear by becoming dependent on it.

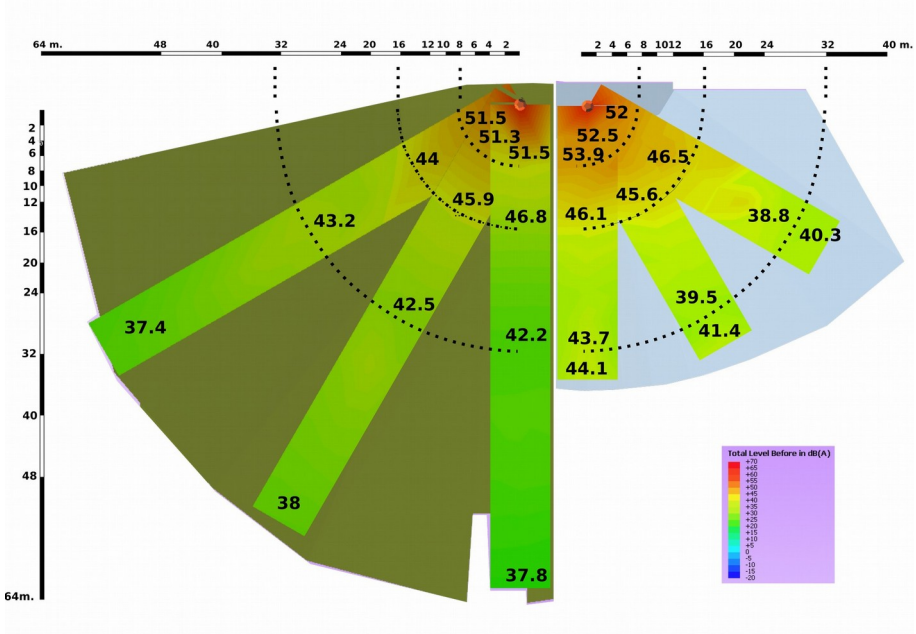


Figure 18: Comparison of SPL of first (right) and last (left) phase of the Athenian Pnyx.

The intention of this comparison is to trace differences between the phases. The goal is to point out the fact that the shape and scale of space changes the potential of hearing and therefore of the ability to participate in an assembly. Definitely the number of people that could attend the assembly in the last phase was higher. Their ability to hear, though, was weakened. The use of the space was gradually abandoned and the Assembly eventually moved to the theatre of Dionysus.

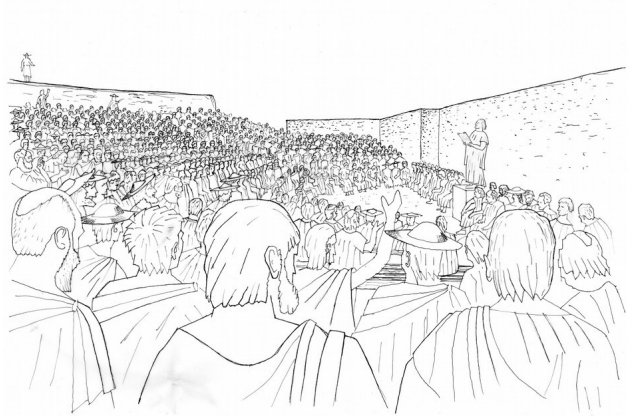

Figure 19: View of the speaker from the audience during the first phase at 15m distance.

Figure 20: View of the speaker during the last phase at 45m distance.

The phases of the Pnyx outline, to some degree, the evolution of Athenian Democracy. It is not implied in any way that it was space alone that shaped its character. The constitution was influenced by factors and events much more important than space. Space is just a vessel, but not just any vessel: it is a vessel of life. The shape of this vessel has a subtle but not insignificant influence on the human interactions within it, and by extension to historic events. This premise is central to this paper's argument.

## 7. Extract: Function follows form

The three examples above support the paper's key thesis: the form of space does influence the communication capabilities of people. This raises important implications regarding the social function of architectural space, the potential given to people to communicate, to speak, hear, see and approach each other but also the ability to conceal and isolate when communication is not desirable. Perhaps Sullivan's motto was accurate in that sense: architectural design must indeed take under consideration, or facilitate, particular functions. However this paper builds on that dogmatic assertion, and adds a requisite social dimension, that is latent in Sullivan's motto: that of the architect's responsibility in a wider sense than just the efficient use of buildings. The form of architectural space is related to the coexistence of people. According to Sullivan's words architecture is and should be "*a fine art in the true, the best sense of the word, an art that will live because it will be of the people, for the people, and by the people*" [1].

As a result of the above discussion, we could extract a less 'heroic' but also less deterministic and normative conclusion, as an alternative to Sullivan's axiom: in some cases the social function follows the form of space. Function follows form. This extract does not constitute an ethical rule, but it can be an important motive and a significant parameter that, it is argued here, may add a further layer of analysis in our systematic knowledge on, and examination of, the form of architectural space – therefore contributing to current thinking and practice.

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