Digitally Conscious Design

From the Ideation of a Lamp to its Fabrication as a Case Study

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This research tries to reflect on the idea of digitally conscious design, from the inception to the manufacturing process of a prototype. A theoretical reflection on the topic is followed by the discussion about the results at two different universities (Alicante and Naples) where students have been proposed a similar assignment: a digitally conscious design of a lamp. In Alicante, the methodological approach was guided by the relation of the ideation process and the use of specific digital fabrication strategies; students were encouraged to develop and rework their designs taking into account the way in which they should be digitally fabricated. In Naples the teaching proposal involved a disciplinary approach; a deep understanding of the digital fabrication processes including the manufacturing limitations of the machinery employed involving a precise geometric control over the design. In both cases, students had to face a real study case of the design and production making use of digital tools. This comprehensive approach implied the consideration of the project as a process making students aware of the difficulties of getting their ideas materialised through digital fabrication and how their designs had to evolve in order to step over the problems encountered in the manufacturing process in different ways.

Keywords: *digital consciousness, digital fabrication, digital ideation, design constraints*

THEORETICAL BACKGROUND

Any creative activity seriously undertaken needs referents produced by others whose work has achieved a distinguished recognition and that could therefore be taken as an example to be imitated. Both, disciplinary knowledge and referents are necessary conditions to develop any creative valuable task as we learn through imitation and those referents nourish our imaginary. Drawing, modelling and more recently programming are the languages we use as architects and designers to produce our designs; not only do we communicate and represent architecture through drawings, models or scripts -in the case of parametricism, we even think and conceive architecture through them.

Antoine Picon (2010) has extensively referred to this shift of cultural and tooling referents in architecture. The historical tension between innovation and tradition (Deleuze 1994), between revivalism or literal reinterpretation of the past and disruptiveness, is the engine of progress. But it has truly been during the last two decades when computers have started to affect not only the way architects design or construct their buildings but architectural language itself. These tools have generated an unquestionable imprint on the aesthetics of the discipline which, for the first time in history, are neither indebted to an architectural past nor to the emergence of new materials nor constructive systems. Bold designs have become somewhat frequent relying on a new aesthetic ever since architects became aware of the extraordinary possibilities that these tools entail. Digital architecture has driven innovation to stages that are expanding the boundaries of architecture, which, in return, is mingling in the milieu of the cross-disciplinary.

However, the question to be posed in the realm of digital design is whether their use is only to make more efficient our design processes or whether the digitally conscious designer should take advantage of all the potentialities of these tools. Terzidis (2006) has pointed out the difference between computerisation and computation in relation to the kind of task we assign computers in the design process. A digital conscious design could be defined as the one that truly takes advantage of the computers' potentials generating a specificity that could not be reached without their use. Obviously, different degrees of digital consciousness may be reached.

A first level of digital consciousness can be achieved through 3D modelling. The control over the geometry is three dimensional instead of based on simple projections which are always a reductionism of the real complexity of space and therefore imply a loss of information in the process (Allen 2009). One of the crucial achievements emerged from the advent of C.A.D. is the creation of a virtual space capable of lodging our three dimensional models. A certain level of complexity in our designs implies the need for this tool to have full control in the design process. Irregularity, as a consequence of complexity, has become increasingly common in digital designs especially with the emergence of parametricism. The realm of complexity and irregularity that these practices allow is unmatched throughout the history of the discipline. This irregularity also implies the need for digitally fabricated elements as their geometric variability is too complex to follow conventional production processes thus following "non-standard modes of production" (Cache 1995). This increasing complexity and irregularity can be observed in some of the state-of-the-art digital designs by architectural practices such as THERVERYMANY or MATSYS.

This research involves two fundamental aspects of the creative-production process. On the one hand, the use of innovative modelling techniques and parametric representation tools, such as Rhinoceros and Grasshopper, make it possible to create 3D models that can be modified according to parameters. On the other hand, technologies for digital production, albeit innovative, also have limitations; overcoming these limits is an opportunity for experimentation and research, as well as a stimulus for the improvement of the tools themselves.

Our students have to be aware of the design implications of this digital revolution afoot and be able to achieve digital consciousness in their designs. Even though contemporary trends in digital design are focusing on the role of information and the interaction between architecture and its dwellers (Saggio 2010), we decided to limit the scope of the assignment to a process from the ideation of the object to its prototyping.

We proposed our students of the Master in Architecture at the University of Alicante and of the Master of Science-Design for the Built Environment Diarc at the University Federico II of Naples to produce a digitally conscious design of an object -a lamp- which they should digitally fabricate as a prototype, engaging them in the whole production process.

In both institutions an initial design restriction was established to guide the student's designs giving them confidence to develop their creativity within a well-established framing. In Naples an initial geometric restriction to direct the design process was set to frame the assignment: every lamp should be based on the geometry of a ruled surface; the class would thus be working on variations of lamps based on this topic. Of these, three were based on the same geometric matrix: a hyperboloid, yet the results resulted very different from each other as the apparent formal restriction became a stimulus for creativity. They were all printed in a home built 3D printer 18x18x18 cm. in PLA (Poly Lactic Acid) taking advantage of the lighting qualities of the translucent type (Figure 1).

Figure 1
Built 3D printed translucent PLA prototype and lighting effects. Students: Miguel Rodriguez, Alejandra Miralles. Prof. Carlos L. Marcos

In Alicante, the restriction implied that the designs had to involve different digital fabrication strategies consistent with the taxonomy proposed by Iwamoto (2009) -sectioning, tessellating, folding, forming and contouring-. This implied reflecting on the essential relations between the ideation process, the digital fabrication and the materiality of the design itself. Some of the lamps were laser cut -those following sectioning fabrication strategies and also the luminescent cube- exploiting the possibilities, in some cases, to use different materials with varying levels of transparency, translucency or opacity to achieve suggestive lighting results. Others were 3D printed in PLA -those following tessellating additive fabrication strategies- exploring the potentials of the chosen material in relation to the use of the lamp itself. Parametric design was implemented in three of them while the other was simply 3D modelled.

DIGITAL FABRICATION AT THE UNIVERSITY OF ALICANTE

At the University of Alicante, the students of the Master in Architecture following the course "Herramientas gráficas para la arquitectura" led by professor Carlos L. Marcos were asked to design a table lamp. A theoretical background on digital culture in architecture was given to students surprisingly unaware in many cases of the progress made by these contemporary trends in architecture.

The 'digital turn' in architectural design can berelated to complexity; Mitchell (2005) referred to it as"the ratio of added design content and added constructioncontent". A digitally conscious design could be regarded as a design which could not have been attained without the assistance of computers. If one critically looks at current winning competition entries most of them could not be regarded as really digitally conscious. Even if the use of computers is evident in the presentation drawings, models and impressive renderings the architectural geometries are more indebted to modern architecture than to truly digitally borne architectural imaginaries. Some architects as is the case of Eisenman, Gehry, Zaha Hadid, Coop. Himmelblau, Libeskind to mention some of the most acknowledged, have made use of computers and their potential to shape their projects achieving in many cases results that are clearly indebted to their digital conception and/or materialisation. The realm of complexity that can be achieved using these tools -especially in the definition of the geometry through scripting languages- cannot be reached otherwise. It is in this sense in which we refer to as digital conscious design; something that also implies geometries based on new imaginaries distinct from any kind of historicism including the modern.

Computational use of computers' implies making use of the intelligence we can introduce in a script, therefore using computers rather as a mate within the design team instead of considering them as simply efficient machines (Terzidis 2006). Accordingly, the course included different assignments to ensure that the students not only made a sensible use of computers to achieve digitally conscious designs but were also shown a varied imaginary of digital architectural designs involving different levels of digital consciousness intended to nurture their imaginary.

Four of the designs developed in groups of two students in Alicante are discussed in the paper. The first is a lamp design inspired by sectioning fabrication strategies which consisted of laser cut and subsequent assembly. In this case only the use of 3D modelling could be regarded as a digitally conscious conception strategy. A simple geometry -a cube- was successively transformed adding layers of complexity through rotation in space, cut, sectioning and varied rotations of the different slices achieving double curvature surfaces during the initial stages. However, the geometry to be imposed to the lamp was up to this point a simple container which had little to do with thinking in terms of lighting or how should it be constructed. Moreover, the design was too obvious and mechanic. To enrich the design a more constructive approach was needed, especially tackling the issues of functionality -a lamp bulb needed to be cast inside and the light should traverse the skin of the object. Steps 8 to 14 (Fig. 3) involve design decisions taken addressing these issues. Thus, a Boolean substractive strategy allowed for the space to host the lamp bulb as well as the ribs that should support the whole structure.

The materiality of the lamp was further developed combining different materials: transparent, translucent methacrylate and some opaque slices to achieve improved material qualities in the design (steps 12-13). Finally, other Boolean operations were implemented subtracting numerous small prisms to the geometry of the lamp to produce diffractive lighting possibilities gaining in the complexity for the light transmission through the skin (step 14). Figures 2 and 3 show the cutting layouts and the assembly process as well as the built prototype lighting effects achieved through the design and the fabrication process, respectively.

Figure 2
Built prototype, materiality and lighting effects. Students: Mateo Linares, Justo Romero. Prof. Carlos L. Marcos

Schumacher (2009) has claimed parametricism to be the 'new global style' of digital design. Although some debate could be held in relation to this statement it is quite evident that parametric design implies a real disruption in the design process swapping representation for codification, on the one hand, and is increasingly becoming a benchmark of digital design in the last years. The other three examples

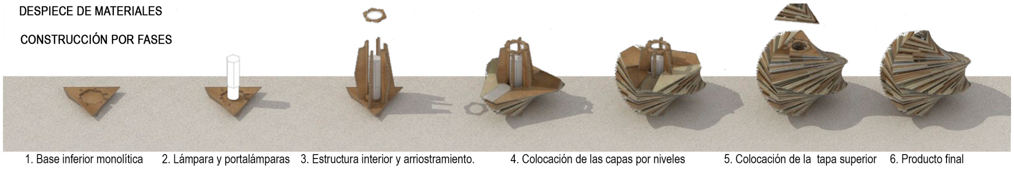

Figure 3
Consrtruction and assembly process. Students: Mateo Linares, Justo Romero. Prof. Carlos L. Marcos

shown here were designed parametrically. The first two are in fact a model of what could be regarded as a digital typology stemming from a same parametric definition applied to different geometries, further developed and altered. Figure 4 shows the design process of this same parametric definition applied to a cube and to a compressed sphere that generate two different prototypes: 'Romeo and Juliet' bound by a common fate. Successive operations of layering and subsequent Boolean subtractions -typically digital strategies- generate the final versions of both designs.

Whereas the rounded shaped lamp uses two different coloured PLA, the cubic design favours the contrasting lighting effects produced by the openings on the mass and the thick layer of translucent material allowing light to be diffused in varied ways (Figure 4). The first of the two involved a more elaborate process of production and assembly as the hollow interior implied the modelling of additional construction ribs necessary to support the geometry while the filaments dried to be later discarded once the model had solidified. It is to be noted that the more 'solid' design of the cubic lamp was much easier to build as no additional ribs had to be added.

The fourth lamp design follows a clear digital fabrication strategy of tessellating and is also inspired by parametric design. Applying subtractive parametric three-dimensional Voronoi definitions to different geometries these were further developed in a subsequent stage in the design process following form finding strategies, something characteristic of open forms or script based formal structures (Marcos 2010). Thus, varying the thickness of the three-dimensional meshes a typology of cubic shaped parametric cages was reached. Varied densities of the meshes applied to the cube faces were tested to choose one that allowed enough light to

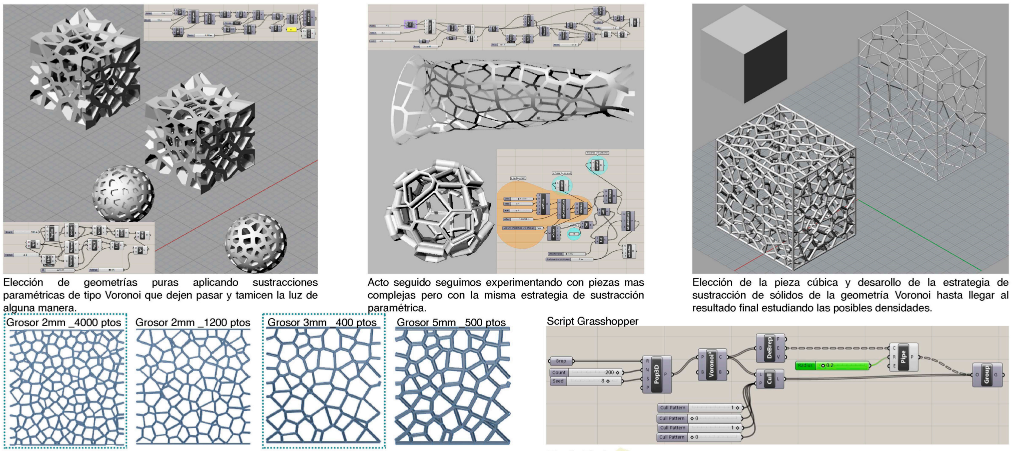

Figure 4
Design process and parametric definition. Students: Sergio Pina y José D. Romcamora. Prof. Carlos L. Marcos

pass through considering the lining of the interior with Japanese paper to produce a warm soft tone against which the silhouette of the mesh might contrast with. Moreover, taking into account the possibility of exploring other kinds of lighting effects, the PLA used in the materialisation of the mesh was luminescent (Figure 5). Thus, once the light was switched off the lamp gleamed in the darkness, something that could be of use, for example, in the design of a night table children's lamp.

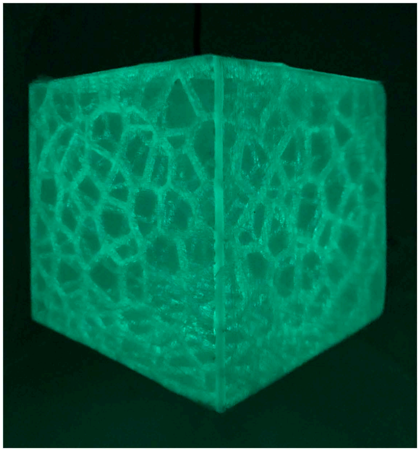

Figure 5
Luminescent lamp lighting effect once switched off. Students: Sergio Pina y José D. Romcamora. Prof. Carlos L. Marcos

DIGITAL FABRICATION AT THE UNIVERSITY FEDERICO II OF NAPLES

At the Modeling and Prototyping Laboratory, led by Mara Capone and Sergio Pone (collaborators Davide Ercolano and Eliana Nigro)- Diarc, DBE - Master of Science in Design for the Built Environment, University of Naples Federico II - the potential of these innovative production processes were tested. Five PLA suspended lamps with LED light E27, E14 were produced: Kasa, Cup, Eureka, Pierlumen and Cream, using AM (additive manufacturing) techniques (Figure 6). The aim of the research was to address and solve all the problems related to building a printable 3D model. It was achieved following a methodological path that began with the analysis of the issues related to the technology used, allowing to define the concept and the geometry of the executive project. Geometric properties knowledge of ruled surfaces allowed to define optimised solutions for the connection joints of the objects produced in several parts, such as in the case of the Kasa lamp design. The main goal was to verify how the geometry is always a very important guideline in the design process, independently of the tools employed, and especially how this apparent geometric constraint may produce very different outcomes.

The five lamps were the result of working with digital manufacturing strategies; they were conceived to be produced and marketed using innovative techniques rather than traditional production systems. We used geometry to identify optimized solutions in relation to limitations associated with the use of RA (rapid manufacturing) techniques: the dimensional restrictions of the 3D printer and the constraints linked to the materiality (angles and supports). The topic of discretization, and therefore the manufacturing in several parts, was addressed in the Kasa and Cup designs, while Eureka, Cream and Pierlumen projects explore the different translucency effects of additive manufacturing.

Building a "printable" 3D model requires attention and, above all, knowledge of the issues involved and the limitations inherent to the manufacturing technology. Thus, the goal was to define an 'optimised' solution that might fulfil the different project's needs: aesthetic, functional and economic. The concepts and the projects were developed following different strategies sharing a common denominator. Far from being neutral, modelling and prototyping tools played a key role.

The executive project is the result of a process in which the steps before printing, modelling and slicing, have included testing in-progress procedures. The slicing step, during which the 3D model was converted into GCode -3D printing instructions- turned out to be a substantial milestone within the process. Depending on the settings of the printing parameters and in relation to the problems encountered, 3D

Figure 6
Suspension lamps in PLA - Modeling and Prototyping Laboratory - DBE - Master of Science in Design for the Built Environment - Professors Mara Capone and Sergio Pone.

models were modified to find geometries suitable for the available technology. The 3D model was divided into layers thus setting some fundamental features that determined the appearance of the printed object. In order to optimise the result, it was necessary to make 3D models according to different setting possibilities, such as layer height, shell thickness, filling density, printing speed and temperature.

Knowledge of the issues involved was crucial to build a printable 3D model and, in some cases, imposed constraints that heavily influenced the design. Some problems such as warping, corners lifting due to the behaviour of the material used that expands and retreats depending on the temperature or the layer separation for PLA prints can be solved by increasing some degrees the extrusion temperature to enhance the mechanical strength of the 3D print without compromising the appearance directly at the slicing and printing steps. The use of the Mudra MK2.5-3D printer implied two initial geometric constraints: the printing plate size (18x18x18 cm.) and the absence of material gaps to avoid stringing, "hairy" printing, which occurs when the material comes out from the nozzle in the case of large breaks.

In order to print 3D models with large "bending angles" using additive manufacturing we needed to provide additional supporting structures. These are needed to support some parts of the model while the PLA filling filaments solidify. In our case, we decided to avoid these supporting structures; this choice was a key element that affected the definition of the geometries to be used in relation to the generation angle. The angle limit, with respect to the horizontal, was determined by an overhang test taking into account the size of the nozzle. Once the limit was established, the projects were redefined to avoid exceeding that angle; thus, the prototypes needed not additional supporting structures.

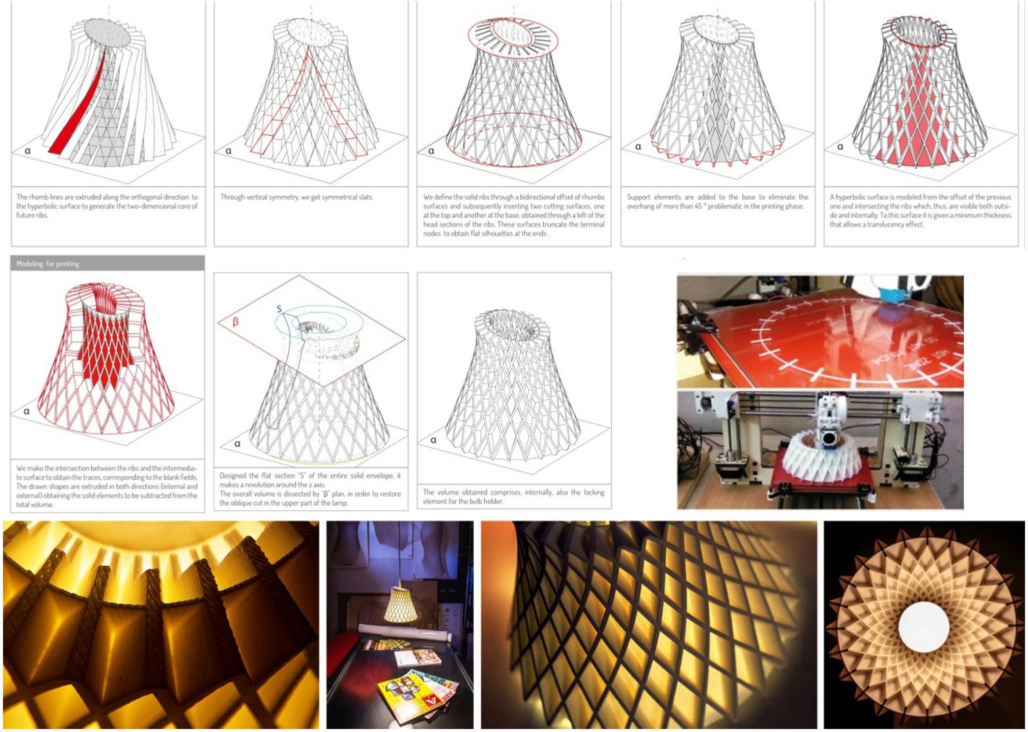

Figure 7
Pierlumen design process and form finding strategies. Students: Giuseppe D'Alessandro, Ornella Fierro, Federica Onorato, Roberta Manzo, Anna Lisa Pecora.

GEOLUX 3 - PIERLUMEN

The GeoLux 3 - Pierlumen lamp (Figure 7) was printed in one piece. Geometry led the design process from the start and problems linked to printing technology were solved considering the geometric features of the surfaces. The lamp is characterized by ribs and the main fabrication problems depended on the modelling of these. Figure 7 shows the design process and different solutions that were studied. A rib grid, following the double order of generatrices of the round hyperboloid, created a matte texture overlaying the translucent surface. The lamp's geometry was parameterised: the application of generative modelling tools allowed to analyse different solutions to achieve the optimal configuration. The key theme of the design process concerned the imprint of these ribs as it was the leitmotif for all the subsequent stages to reach the final design. The lamp silhouette is always generated as a revolution of a curve, a generatrix, that changes shape in all versions to optimise the printing space and the lighting effects, from the classic dome shape to a drop one and finally to the hyperboloid (Figure 8). The implementation of parametric modelling shows how through the use of Grasshopper we were able to monitor the result as well as the importance of geometric knowledge.

Descriptive Geometry is a necessary discipline for researchers and students of design. Although recent scientific production allows us to observe exuberant experiences related to the use of IT technologies in the architectural field, there is a comparatively limited number of in-depth geometric research papers. The automation allowed by many software applications drive students away from learning and deepening on geometric topics whose knowledge enables full control of processes. Some software tools can model free-form surfaces, however being unable to control the proposed structure during the digital fabrication phases. Today's architectural and design software uses different procedures, tools and interfaces to achieve a similar result. Descriptive geometry seems to be outdated through the automatic training of traditional software for 3D modelling, something which does not favour the control and application of theoretical contents that may feed and enrich design as well as research (Casale 2013, [1]). Descriptive Geometry is a necessary discipline for researchers and students of the design area. Although recent scientific production allows us to observe an exuberance of experiences related to the use of IT technologies in the architectural field, there is a comparatively limited number of in-depth geometric research papers. The automation allowed by many software applications drive students away from learning and deepening on geometric topics whose knowledge enables full control of processes. Some software tools can model free-form surfaces, however being unable to control the proposed structure during the digital fabrication phases. Today's architectural and design software uses different procedures, tools and interfaces to achieve a similar result. Descriptive geometry seems to be outdated through the automatic training of traditional software for 3D modelling, something which does not favour the control and application of cultural theoretical contents that may feed and enrich design as well as research (Casale 2013).

Today we are able to witness the birth of an ever-increasing development of instruments for computational and parametric design. These are able to renew descriptive geometry by promoting a more careful study and management of levels of complexity unattainable through traditional approaches. However, only the precise geometric control over the designs may optimise not only the shape but, significantly, the way it may be digitally fabricated with computer manufacturing tools. Moreover, the geometric properties of the surfaces are crucial to find the most convenient structural solutions (Capone, 2012, 53). Therefore, the pedagogical experience proposed at the Modeling and prototyping Laboratory was based on the coordination between this Lab and the Parametric Design Workshop, a course for free training credits, organised by professor Mara Capone, professor Carlos L. Marcos and arch. Ph.D. Emanuela Lanzara, held in Naples.

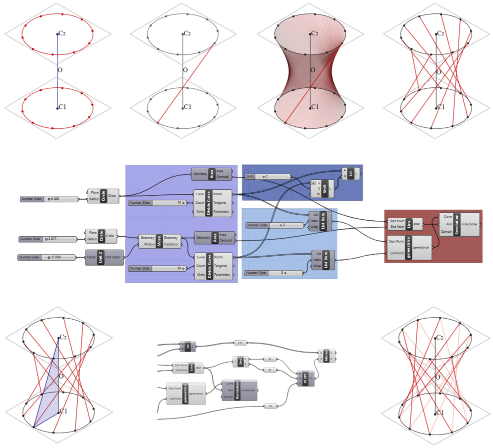

Figure 8
Grasshopper definition of round Hyperboloid genesis. Emanuela Lanzara

Grasshopper's intuitive interface allows to tackle traditional modelling problems more efficiently. At the didactic level, computational design allows students to develop, control and refine their ability to solve real problems by tackling and reducing the limitations and the amount of errors in traditional 3D modelling processes. In addition, 3D printing of student's designs allowed to test and improve their conceptions thanks to quick prototyping techniques.

Product design courses encourage the acquisition of the knowledge and tools needed to enter into the design professional sphere and the possible subsequent marketing of industrial products, offering interesting prospects for social and cultural improvement. Therefore, this experience suggests and encourages the teaching of computational design within institutional courses promoting the fertile symbiosis of traditional disciplines such as Descriptive Geometry with Computational Design.

The introduction to Grasshopper, guided the students in the parameterisation of their modelling of the surface of their lamp's design. To generate the hyperboloid the principles of the genesis of this surface have been translated into a deliberately intuitive and explicit grasshopper definition which allows to separately control the different parameters involved in the geometric configuration of the round hyperboloid. In our case, to manage the shape in Grasshopper, the hyperbolic hyperboloid was generated by the revolution of a straight line around a straight vertical axis (Figure 8).

CONCLUSIONS

Digital manufacturing technologies broadens the landscape of geometries to be achieved as well as the complexity that may be handled. However, the systematic use of certain type of geometries may produce a proliferation of these forms which, while being complex and initially appealing, are now beginning to be repetitive thus undermining the creative prospects made possible through the convergence of C.A.D.-C.A.M. technologies.

It is to be noted that irregularity as a consequence of addressing complexity has become a hallmark of digital architectural design. Our capacity to address complexity has greatly been enhanced through the use of computers, however, it should not be simply regarded as an aesthetical value in itself but rather as the result of enhanced design qualities.

This research shows how a methodological approach related to contemporary imaginaries and disciplinary principles, can stimulate the use of these innovative tools by yielding original results, both figuratively and productively. The Naples laboratory aim was to explore the potential of this innovative expanding process of "digital crafting", a practice which stimulates the definition of new ways to market the design product. The potential buyer could print the prototype himself, using a 3D printer or in a fab lab. This is a major shift that supresses the packaging problem as it can become "virtual". Currently a detailed study to define the possibilities for implementing this prospect linked to the makers world is being studied.

This experience shows that institutional courses on computational and parametric design taught at universities, organized considering the number of laboratory hours required and the choice of appropriate theoretical contents, would allow students -future designers-to handle problems of different complexity related to product design and manufacturing.

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