This research explores the use of graphic techniques to distort the perception of three-dimensional space, questioning the irrelevance of superficial ornamentation in the creation of space. The project starts with a historical and theoretical positioning of the use of superficial ornamentation and aims to bring to digital environments the design and production of such graphic techniques. In order to do so, a parametric tool embedding all the required information in order to facilitate the creation of vinyl decals was created and was finally tested by mostly-unskilled students in an international workshop. This paper describes the development of the parametric tool, its relation to the graphic techniques, and the results obtained during the international workshop.

**Keywords:** trompe l'oeil, sciagraphy, anamorphosis, digital fabrication, vinyl decal

**ORNAMENT & DISTORTION: FRAMEWORK AND OBJECTIVES**

Since the advent of modernism, and triggered by a misinterpretation of Adolf Loos's criticism of ornament, every sort of decoration has been subjected to contempt in Architecture, which has thus been dominated far too long by the paradigm of the absence of ornament (Gleiter 2012). Furthermore, besides a strong tectonic approach, as Kenneth Frampton has argued (1995), modernists presented a major focus on the structural, not the superficial (Picon 2013, Buchmann 1965), in the quest for the new space. Therefore, the more superficial the ornament, the more superfluous and dispensable it is considered, as it detaches from the three-dimensional construction of the space.

With the emergence of CAD-CAM technologies during the decade of the 1990's, ornament has become again a recurrent topic of discussion. In contrast to the first half of the twentieth century, lately ornament has gone through a strong process of revival. The power of digital tools to ease complicated processes of modeling and fabrication in architecture has kindled interest in intricate geometries and wild textures, and has also increased the interest in complex patterns (Gleiter 2012, Picon 2013, Kubo and Moussavi 2017, Gleiniger and Vrachilotis 2009 and Levit 2008). Furthermore, CAD-CAM technologies have enabled unskilled users to produce their own
designs and get involved in the entire process of digital fabrication (Libow Martinez 2013).

During the last years, many design products have explored the possibilities of mass-customization, providing opportunities for end-users to choose and modify the product for purchase according to their own desires. Moreover, open-source culture has facilitated the production of objects with complex design via the proliferation and availability of CNC machines, like 3D-printers or laser cutters, among many others (Martin and Ugarte 2014, Picon 2010). A good example of these synergies is the design and manufacture of vinyl decals for wall ornamentation.

The research project Ornament & Distortion (O&D) revolves around the different topics mentioned above and explores the multiple possibilities for three-dimensional distortion by using vinyl decals - as superficial ornamentation - applying different visual, bi-dimensional techniques. In this way, it questions the irrelevance of superficial ornament in the configuration of space. The project possesses a twofold academic focus. On one hand, from a theoretical perspective, it intends to establish an intellectual framework on how superficial ornamentation highly contributes to the creation and articulation of space. On the other, from a more pedagogic approach, it aims to expose amateur, non-skilled students to CAD-CAM technologies and digital fabrication environments, in close relation to descriptive geometry and technical drawing. This paper, however, focuses on the more practical side of the project, and the development and use of the digital tools required for the production of distorting vinyl decals.

The research project was structured in different steps or phases. First, different graphic techniques that produce spatial distortion were identified and studied in depth in order to understand their rules and applications. Afterward, the necessary parametric tools were developed in order to enable the digital production - from modeling to fabrication - of vinyl decals, using the above-mentioned techniques. Finally, an international workshop with design students was organized in order to test the tools.

**GRAPHIC TECHNIQUES FOR SPATIAL DISTORTION**

During the first phase of the project, it was necessary to identify the different graphic techniques that can distort the perception of space, questioning the modernist statement of ornamentation’s irrelevance and its superfluous role in the construction of space. Three such techniques are *trompe l’oeil* (which creates a non-existent three-dimensionality in a planar or three-dimensional existing space), *anamorphosis* (which creates a non-existent bi-dimensional element in an existing three-dimensional space), and *sciagraphy* (which creates a non-existent shadow projection from an existent or imaginary element in the existing space). These three techniques establish relationships between viewer, space, and objects in space that break the rules of human perception, therefore twisting/questioning the understanding of spatial recognition.

In the field of contemporary art, there are some renowned figures that explore the use of such techniques in order to question the perception of space.
Among many others, some of the most remarkable artists are the Swiss artist Felice Varini (in the use of anamorphism), Damien Gilley, from North America (trompe l’œil), and Regina Silveira, from Brazil (sciagraphy) (Fig. 1). For example, to produce her installations, Regina Silveira relies on her deep knowledge of descriptive geometry and technical drawing skills. For many years, Silveira has developed herself, by hand, the necessary blueprints for her visual illusions (Fig. 3). The drawings are later digitized in order to be produced on a bigger scale. In many cases, the illusions are fully printed in continuous vinyl foils and later stuck onto the required surfaces, completely covering the space and not restrained to the geometry of the shadows she creates. On the other hand, Felice Varini makes use of a beamer to project the figure he intends to use directly onto the real space in order to create an anamorphosis. Afterward, he contours the projected shapes in situ, creating an outline to be painted as the last step (Fig. 2).

As observed, the techniques displayed to produce installations with the different distorting techniques remain at a very handcrafted and low-tech level. A digital gap still exists, one which the O&D project wants to bridge, both optimizing and expanding the possibilities of such techniques, by bringing them closer to CAD/CAM environments. Furthermore, despite the fact that there has been previous research dealing with the development of digital tools to produce such distortion techniques in a CAD/CAM environment (Di Paola, F., Pedone, P., Inzerillo, L., Santagati, C. 2015), the O&D parametric tool, with its unique interface, will allow production of all three techniques (trompe l’œil, anamorphosis and sciagraphy), whereas the pre-existing tools are limited to one technique at a time.

PARAMETRIC TOOL DEVELOPMENT
Once the techniques were identified, their geometrical rules were examined to find a common ground and the possibility to create a parametric tool that enables their application in 3D-modeling digital environments. A digital parametric tool was created with Grasshopper, to be used in the 3D-modeling software Rhinoceros (Rhino), integrating the use of the three different graphic techniques mentioned. The parametric definition has embedded all the different requirements, limitations, and necessary elements to operate the different geometrical steps needed to create a projection on the modeled space for any of the three techniques. That projection was then used...
to cut a vinyl decal that could be applied to that very space. Thus, the process of design and fabrication totally digitalizes, leaving only the final installation of the decals to manual intervention (Martin and Ugarte 2014), a step that nevertheless has been simplified, by avoiding the time-consuming *in situ* contouring and painting as in the case of Varini’s work, or reducing the vinyl application as in many of Silveira’s installations.

The parametric tool in Grasshopper consists of five different components in order to follow the specific conditions that were determined (Fig. 4). The first component - entitled “Space & Illusion” - relates to the two main elements involved in the creation of the optical illusion: the space (a) that is going to be used to create an illusion or distorting effect and the design of the illusion (b) that is going to be created. These two preliminary elements must be modeled in Rhino by the user and, to work with the generated parametric tool, have to be linked to the first component of the Grasshopper definition where indicated (“Space” and “Illusion” independently).

The three illusions distort the perception of a space by using graphic projection techniques; therefore, there is an important relationship between the viewer and the space observed, which translates into two reference points (“Viewer Point” and “Target Point”) that have to be connected to the second component in the interface - “Viewer and Target Settings.” These two main points must be fixed in the Rhino model: “Viewer Point” refers to a specific point of view in the space (c) and “Target Point” to a vanishing point of the projection (d). Between them, a projection line is created, a sort of trajectory along which the distortion design will be projected into the space.

Once the points (“Viewer” and “Target”) and the two geometries (“Space & Illusion”) are linked to the parametric tool, the third main element of the definition - “Projection Generator” - will create the intersection between the space and the illusion design (e), producing a projection contour line.

The fourth component of the parametric tool - “Projection Parameters” - is meant to control and better adapt the projection of the illusion into the space. The component allows the user to fix the dimensions and location in the space of the illusion, which is initially linked to an extra element located in the Rhino space (f): the “Projection Frame.” The location of the projection is related to the position of the illusion’s geometry within the “Projection Frame.” The “Projection Frame” is a rectangle that belongs to the Rhinoceros model and is also connected to the first component of the Grasshopper definition automatically. The projection frame is parameterized and located in the projection line that links the two above-mentioned points. The size of the projection is controlled by the “Projection Size” slider that adapts the size of the parameterized frame. The location in space of the parameterized frame is controlled with the “Distance from the Viewer” display, which determines the limits of the illusion within the space, regulating the depth of the projection in relation to the “Viewer Point.”

After adjusting the three-dimensional projection
of the illusion by means of the fourth component of the Grasshopper definition, the fifth one is in charge of isolating the three-dimensional projection and flattening it. These drawings are then ready to be part of the last step of the digital fabrication process, as they will be used to cut the vinyl decals with a CNC vinyl-cutter.

The development of a parametric tool that allows the creation of installations using trompe l’oeil, anamorphosis and sciagraphy in a digital environment boosts the possibilities of the creators and optimizes the process in many different ways. First of all, the ability to produce an entire digital model of the space and the desired projection enables the user to simulate and test the effect of the installation. The parametric tool provides an opportunity to produce changes quickly and easily, and to adapt the design - for example, changing the desired geometry, or adjusting the viewer’s point of view or the vanishing point - as well as to substitute the space where the illusion is going to be created.

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The possibility of preparing the installation remotely (and in advance) also permits the creator to delocalize not only the preparation, but also the production. For example, in contrast to the regular procedure that Felice Varini follows - painting the anamorphosis in situ, by means of digitally fabricated vinyl decals it is possible to completely delocalize the production process. Besides the flexibility this brings, it also reduces the installation time, which in many cases can result in a relevant reduction of costs.

The introduction of the CAD/CAM fabrication process and switching to the use of vinyl decals for those techniques that did not yet use them also optimizes the process in terms of material use - which also reduces costs. First, exchanging the use of paints - which Felice Varini and Georges Rousse use in their anamorphosis - to vinyl reduces the lasting impact of the installation in the supporting space. Some decals may have trouble sticking to some surfaces, but the quality and the variety of vinyl products have increased lately, allowing for their application onto very difficult surfaces. For installations that exceed specific dimensions, the use of vinyl may be difficult, but vinyl decals allow for an easy and clean removal, with little impact on the support surface, reducing possible extra costs for cleaning and repairs.

Even in comparison to artists that have used already vinyl decals for their installations, such as Regina Silveira or Damien Gilley, the application of the new parametric tool allows for a material optimization. The possibility of precisely producing the cutting contours of the geometries that are going to be applied on the space enables the reduction of the material that is going to be used. Instead of producing full foils to be applied, the required geometry can be outlined and divided in independent smaller elements to be cut following the requirements of the manufacturing process - the maximum dimensions of the cutting machine and the vinyl sheet. However, this procedure requires more precision, in order to calculate the different elements in which the overall geometry is divided.

As shown, bringing the design and production of distorting graphic installations to CAD/CAM environments, together with the use of vinyl decals, introduces a wide range of possibilities for optimization. Benefits include flexibility in design and material optimization, which can translate not only to an enhanced process of creation, but also to relevant cost and time savings in the entire process of design, production and assembly.

INTERNATIONAL WORKSHOP
Once the necessary tools in a digital environment to produce anamorphosis, trompe l’oeil, and sciagraphy were established, the next step in the O&D project
was to test their application by unskilled users. In
the summer of 2017, an international workshop with
more than 20 students from different design pro-
grams - architecture, interior design, product design,
and fine arts, among others - took place in the School
of Architecture of the Polytechnic University of Valen-
cia (UPV), Spain.

The schedule and content of the workshop were
highly demanding, and during four days, the stu-
dents were exposed to an extensive theoretical con-
tent - with lectures about the historical origins and
possible applications of the different techniques,
about descriptive geometry (to understand the rules
behind the graphic techniques), and about CAD/-
CAM technologies, from a general description of
common terms and possible applications to the more
specific use of the parametric tools developed for the
occasion. The first two days were devoted to the-
etorical content and digital training, producing ex-
amples of the projections both with AutoCAD - as
a drafting tool generating the projections following
the required geometrical steps - and with Rhinoceros
- which, together with Grasshopper, turns the pro-
cess fully digital and partially parametric. Most of the
students did not have previous experience with the
modeling software Rhinoceros. On the contrary, all
of them were used to working with AutoCAD.

During the third day of the workshop, the stu-
dents were divided in groups of three or four partici-
pants, and were asked to design the application of an
anamorphosis in a rectangular room into which they
could also place other elements to enhance the inter-
action of the installation with the three-dimensional
space. Unfortunately, due to time constraints, it was
not possible to explore the use of trompe l’oeil and
sciagraphy as well. The students had to design the
geometries they wanted to apply for the anamorpho-
sis and produce a model of the room (Fig. 5). Having
followed the instructions about how to use the tools,
the students were to obtain the cutting contours for
the decals to stick onto the surfaces. Instead of using
a vinyl-cutter, due to the reduced scale of the proto-
types, the students laser-cut the stickers. The fourth
and last day was devoted to the finalization of the
models and the documentation of the results, taking
photos and recording videos of the illusions.

Among the seven groups, one was capable of
producing three different models, making use of the
three distortion techniques. In this case, this was
the only group in which the three participants were
not only relatively skilled with AutoCAD, but above
all, had a deep understanding of descriptive geometry.
This group, contrary to what was asked for, used
drafting techniques in AutoCAD rather than the para-
metric tool to produce their projection drawings for
trompe l’oeil and sciagraphy (Fig. 6), using the para-
metric tool only for the anamorphosis. The proce-
dure they followed in AutoCAD would normally take
much longer than the one using the parametric tool
when the latter is mastered, but the low level of ac-

Figure 5
Different results of
the Student Work.
quaintance with such tools made the process much harder, inverting the expected time expand (Lynn. 2004. 65).

It is worth mentioning that the students received very little input in terms of the quality of their designs, as the instructors had to be focused on solving all the practical problems the participant encountered while using the modeling software and the parametric tool. Most of the designs were only slightly supervised and therefore, some of them lack interest or present a low relationship with the distortion of the perception of space. This last issue may be explained by the fact that some students had backgrounds unrelated to spatial practices like architecture and interior architecture.

Figure 6
Sciagraphy produced by the students

CONCLUSION
As digital environments have increasingly become part of contemporary architectural production (Iwamoto 2009, Picon 2010), the relevance CAD-CAM technologies have acquired in education has increased as well, sometimes displacing more traditional fields of knowledge due to restrictions on teaching times and tight academic curricula. The Ornament & Distortion research project, framed in an educational context, aims to bridge digital environments with many other disciplines relevant to the field of architecture and design, namely history, theory, descriptive geometry, and material sciences, among others.

Unlike the high level of specification that many Architecture and Design programs follow - understandable up to a point, due to the high complexity of digital fabrication and computational design - the O&D project pursues a more holistic approach (Evermann 2017). The aim of the project is to expose students in the beginning semesters to digital environments and fabrication processes, promoting the culture of learning-by-making from an early stage while exploring other fields and subjects.

During the four days of the O&D Workshop, the students were exposed to and experimented with CAD tools and processes, becoming familiar with terms like CAD-CAM, CNC machines, algorithms, rapid prototyping, etc. They also got a deeper insight on what digital technologies can bring to the architectural production, managing to establish a continuous and efficient workflow. Above all, the students observed how digital technologies do not simply ease complex design processes, but also help to articulate knowledge and ideas, and are very powerful tools that require extensive skills. Digital design enables the expansion of architectural possibilities from design processes to fabrication and assembly (Chaszar and Glymph 2010), but by growing in importance and wide spreading in academic curricula, it could prevent students from learning the basic skills in which upon many digital tools are based - for example, the O&D parametric tool. The power of easing processes may optimize architectural production, but it can also hinder the education and training of future designers, used to powerful tools and ready-made solutions that lack the depth and spectrum of tedious and more handcrafted design processes. Therefore, the gradual implementation of computational design is relevant for the future of architectural studies, not only to be ready for upcoming industrial challenges, but also seamlessly to intertwine basic and traditional knowledge with the most cutting-edge technology.

SUMMARY AND FUTURE DEVELOPMENT
The O&D project was developed during the Spring 2017 semester at Berlin’s International University of
Applied Sciences, which also organized the International Workshop in Spain in collaboration with the UPV. During this semester, the theoretical and historical research was conducted by Prof. Martin and the digital tools were developed, producing small prototypes in order to test them and get them ready to work for the International Workshop. The parametric tools used during the workshop were functional, but not yet fully optimized. For example, the fifth component described in the text is not developed yet, and the students had to obtain the projection contours themselves, as the current tool does not isolate them. Another possible development would be the capability of the tool to break the shapes into different sections that adjust to the maximum fabrication sizes regarding material and machine limitations.

Also, a second workshop to further explore the capabilities of the parametric tools, the creativity and learning process of students, and the potential of the distortion techniques was planned in Berlin during 2018. Unfortunately, the development of Berlin International and the move to different facilities postponed the workshop. However, once Berlin International is established in the new facilities, the workshop can have a more impactful result due to the spatial features of the building, where the students will be able to produce 1:1 vinyl decals.

Finally, to reach to a higher audience and contribute to the open-source culture, the website www.ornamentanddistortion.com was created. All the theoretical research, the parametric tools, the results from the workshops, and information about new activities can be found on the website.

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REFERENCES
Buchmann, M 1965, Ornament ohne Ornament?, Kunstgewerbemuseum der Stadt Zürich, Zurich
Gleiniger, A and Vrachliotis, G 2009, Pattern: Ornament, Structure, and Behavior, Birkhäuser, Basel
Libow Martinez, S and Stager, G 2013, Invent To Learn: Making, Tinkering, and Engineering in the Classroom, Constructing Modern Knowledge, Torrance, CA
Picon, A 2013, Ornament. The Politics of Architecture and Subjectivity, John Wiley & Sons