Nexus Network Journal

Domestic prototypes co-designed through experimental 1m3 topological cubes

--Manuscript Draft--

Manuscript Number:	NENJ-D-17-00047R2
Full Title:	Domestic prototypes co-designed through experimental 1m3 topological cubes
Article Type:	Research
Funding Information:	Ministry of Education, Culture and Sport from the Spanish government (FPU15/00791) — Mrs. VIRGINIA DE JORGE-HUERTAS Universidad de Alcalá (UAH/EV 852) — Mrs. VIRGINIA DE JORGE-HUERTAS
Abstract:	This paper shows a prototyping project carried out with students of the 1st Architecture course at the University of Alcala (UAH), Madrid, Spain. The project starts with the development of a 1m3 prototype associated to a micro domestic space for each student, which generates 45 micro architectures. The main objective for all students is domesticity. Students interpret their domestic intimate space developed in a matrix of 100 x 100 x 100 cm. The aim of this paper is to test the learning process on domestic layout through a prototyping approach. This workshop is based on 25 previous references going through a co-design learning process and design thinking to the translation and experimental approach of 10 prototypes construction on a 1:1 scale. This paper focuses on the learning process carried out with the DPM (Diagram, Plan, Model) methodology and patterns generated by the students' architectural projects through the development of prototypes.
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Author Comments:	Thanks for the revisions which has been essential to improve the research.
Response to Reviewers:	COMMENTS FOR THE AUTHOR: Reviewer #1: Specific points: Dendogram drawing is now better explained, but it is still not clear how did you form the cluster to measure the distance between each pairs? How did you convert variables into numerical values for cluster analysis? You need to provide more explanation about that process. Data collection and analysis are now better explained. For the scope of this work, inclusion of questions 9 and 10 from the questionnaire are sufficient for better understanding of the analysis. ANSWERS: The variables were converted into numerical values applying the Likert scale 1 to 5. The concepts analyzed are qualitative and quantitative. (City, year of construction, geographical, location, country..)

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	The general database has several concepts but we take into consideration in the final analysis only the following ones measured to create the Dendrogram: The first one "If it is a module or a cube"; the second one measures if the project allows groupings (yes or not, so a binary answer 1 or 0); the third one is the "Use" or "the programmatic approach" of the project where general "residential" is 1, equipment is 2, a domestic space is 3, a specific equipment related to "productive programme" such as Kitchen is 4 and Furniture is 5; the forth one is if it is a Prototype or not; the fifth one measures if it is built or it is a theoretical approach; the sixth one is the scale of the project, Likert scale, being 1 the littlest one, scale XS and 5 the biggest one, scale XL. So XS (1) S (2) M (3) L (4) XL (5); the seventh one is "If the project allows change which is measured in an also binary 0 or 1 (yes or no) answer." With all this parameters we create a database taken from a bigger one of 110 projects. With this concepts we create the cluster analysis for the Dendrogram using the program Statgraphics Centurion XVII that allows us to organize and measure the distance between pairs or cluster association depending on the level or relationship about the parameters given, the projects with the parameters are analyzed and specified before. We include a table with the six parameters measured as an example : ModuleAllow PrototypeBuilt Allow or cubegroupingUseor theoreticalor notScaleChange Pao nomad girl 015111 1 Casa E-1027 101113 1 *The source of Information of these variables came from texts, plans, sections, facades, volumes, models, visits on site and prototypes Corrections: Figures: Original name of Villa Savoye is corrected in text but not yet corrected on fig 1 and fig 7 This has been corrected. 1. Introduction: Citation/Reference is needed for the Rudolph Laban's theory (1966) (Line 37) This has been corrected. 6.References: Some author names or author order list need to be checked and corrected. 1: Michael Reb (Instead of Webb) This has been corrected. 2: Bojan Tepavčević and Vesna Stojaković (instead of Vesna Stojakovic and Bojan Tepavcevic). It should be corrected also in the text citation (section 3) This has been corrected. 3: Sanders Elizabeth (instead of Elisabeth) This has been corrected.

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Domestic prototypes co-designed through experimental $1m^3$ topological cubes

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Domestic prototypes co-designed through experimental 1m^3 topological cubes

Abstract

This paper shows a prototyping project carried out with students of the 1st Architecture course at the University of Alcala (UAH), Madrid, Spain. The project starts with the development of a 1m^3 prototype associated to a micro domestic space for each student, which generates 45 micro architectures. The main objective for all students is domesticity. Students interpret their domestic intimate space developed in a matrix of 100 x 100 x 100 cm. The aim of this paper is to test the learning process on domestic layout through a prototyping approach. This workshop is based on 25 previous references going through a co-design learning process and design thinking to the translation and experimental approach of 10 prototypes construction on a 1:1 scale. This paper focuses on the learning process carried out with the DPM (Diagram, Plan, Model) methodology and patterns generated by the students' architectural projects through the development of prototypes.

1. Introduction

The interaction of multiple agents in the architectural design process, the scale of projects and issues related to domesticity and flexibility, among other factors, make the complexity in the design stages higher. Authors such as Kiatake and Petreche (2012) mention that this complexity, which increases to the extent that a design process is in more advanced states and any change in the initial parameters or alteration of possible solutions requires a greater effort, is related to a greater displacement of the research to be known that occurs in the initial phases of the design process (concept of design, capacity of interpretation or planning), where the levels of abstraction, interpretation and generation of ideas are high compared to the final stages of the process.

The programme to be developed is based on a domestic space established in a reference in the Netherlands from the seventeenth century (Rybczynski 1986). Different approaches to the *domestic cube* have been carried out before, from the square grid-based design Roman villas from XVI century (Pinho and Xavier 2013) to the primitive hut of Marc-Antoine Laugier in the XVIII century. This primitive hut with six two-dimensional faces that create a three-dimensional space respond to a human problem: a floor to isolate from the ground, walls to protect from the air and a roof to protect from the rain as well as movement actions according to Rudolf Laban (1966) and his theory of the icosahedral ergonomic and choreographic space.

The starting point is the topological cube that could be framed from analysing Sol LeWitt's incomplete open cubes (LeWitt 1974; Rozhkovskaya 2015) to Giorgio Scarpa and John Hedjuk (1960) with the 9 x 9 grid problem with his students at the Copper Union. By taking into account three points, the *primitive hut*, the *topological cube* and 25 references, students are said to create a domestic space based on a 1 x 1 x 1 m prototype, scale 1:1. Milligan (2006) describes the concept of *experience prototyping* as an attitude, an interdisciplinary interaction between design, economy and experiences. Pieter Jan Stappers (2007) has written about prototypes as the designing act of creating prototypes being in itself a potential generator of knowledge.

To achieve the objectives of the course, the teaching process is based on experimental learning (Dym et al. 2005), that means, a hybrid learning process based on three points. Blended learning (De Jorge-Moreno 2012), social constructivist learning theory (Minneman 1991; Cialdini 2005) and an *atelier* based on workshop classes such as cooperative learning and group work are analogous terms that describe "students working together in a group small enough that everyone can participation a collective task" (Cohen 1994) mixed with some specific master class.

The concepts *design thinking* and *co-design*, along with the applied methodologies DPM (Diagram, Plan, Models) and PBL (project-based learning) allow for understanding the development of the project

encompassed in an experimental learning process. The concept of design thinking is characterised as a process of thought that is compensated between the qualitative and the quantitative focus; one is linked to creativity and intuitive thinking and the other to standardisation and objectivity. It encompasses a set of skills such as decision-making, thinking as part of a team, the ability to handle uncertainty or reason and communicating in different design languages (Dym et al. 2005)

Authors as Sanders and Stappers (2008) used the term co-design as the "collective creativity as it is applied across the whole span of a design process". In co-design, different experts come together, such as researchers, architects, engineers, designers or developers, and potential customers and users—who are also experts, that is, *"experts of their experiences*" (Sleeswijk et al. 2005)—to collaborate creatively.

The objective of this work is both related to the co-design of guided prototypes and an analysis of the degree of comprehension and creative thinking development of architecture's students, through strategies of collaborative and proactive learning based on problem-solving. The development from the initial idea of the concept to the final prototype by means of experimental learning processes and mixed methods of research could contribute to an increase in the acquisition of skills of compression, abstraction, interpretation and conceptualisation of the architectural principles in projects.

The paper is organized as follows, section two shows how references are assign to the students and introduce the methodology. The third section shows the main results followed by the final exposition. Finally, the fourth section contains the conclusions.

2. Methodology

2.1 Description of references for projects students' domestic spaces

In order to develop the prototypes, 25 architectural references (fig. 1) were provided to guide students. The choice of these references was initially based on different concepts analyzed from a database of 110 projects elaborated by the authors of this work. Among them are the architect, with the year or the country as descriptive factors. From the qualitative point of view, special attention was paid to: whether it was a constructed project or not, whether it was a single experimental prototype, whether it was an ergonomic changeable space, whether it was modulated dwelling or was a cube, or finally if it allows grouping. At the quantitative level and by means of a Likert scale, factors such as the scale of the assigned reference are analysed, with XS being the smallest and XL being the largest (XS, S, M, L or XL). The degree of mutability was evaluated. The references were grouped according to the hybrid program or use of the reference. Finally, the degree of possibility of change and mutation of the given reference was evaluated.

From the creation of the mentioned variables and by means of a cluster analysis, an exploratory analysis was carried out to determine the process of association of the references. Different combinations of variables and techniques were used. Although there were no significant changes, the choice of six variables (module or cube, allow for change, use, prototype or not, clustering and scale), the most remote neighbour method and squared Euclidean distance were chosen. These guidelines are in order to obtain a complete chain of the 25 projects. Fig. 1 shows the dendrogram of the references. It is a graphical representation of the result of the tree-grouping process. Its construction is done, so that 1) in the lower part of the graph the 25 projects are arranged, 2) the joints between projects are indicated by three straight lines. Two are directed at the projects that are joined and are perpendicular to the axis of the projects, the other is parallel to this axis, situated at the level in which they meet, 3) the process is repeated until all the projects are connected by straight lines. If we cut the dendrogram into a given distance level, we obtain a classification of the number of groups existing at that level and the projects that form it. As can be seen in fig.1, there are three groups, where the Pao of the nomad girl of Toyo Ito with Kazuyo Sejima, next to the Teatrino of Aldo Rossi and the references of the group Archigram, are the references that form the group that is nested in the end and therefore has less of a relation to other projects or constructed works.

Fig 1. Dendrogram of the 25 references. Source: own elaboration.

2.2. Research participants

The participants, as already mentioned, were first-year students of the project I of the Architecture course, 2017 at the University of Alcalá. The students could choose their attendance in the subject via two versions workshop and non-workshop. Surveys were carried out at the beginning and end of the project in order to determine the degree of understanding of the activities to be carried out to materialise the prototype, with special interest in the conception, interpretation and abstraction phase from the assigned references. Likewise, the surveys allowed for analysis of the degree of satisfaction of the students during the project and to know some characteristics of theirs. Table 1 shows the technical characteristics of the surveys.

<**T1.** Characteristics of the sample>

Regarding the demographic characteristics of the students, 58.14% are female. 86.64% of the total number of students chose architecture as the first study option, 20.45% have a familial architect and 31.82% have previous knowledge related to the career (professional training or architectural studies).

In order to supervise the students' performance level, whose results we will be shown later, the development of their activities was controlled according to their degree of satisfaction and understanding of the project. Some authors, such as Blumberg and Pringle (1982), mention that a person's performance level is a function of their ability (intelligence and individual abilities), motivation (intrinsic and extrinsic) as well as the opportunity to perform (constrain their performance).
In these surveys, we also obtained evaluation of students' comprehension degree about domestic space, as well as other information regarding whether the students' knowledge or attitude to architecture have origin before joining the university or not, as it will be discussed later.

2.3 Instruments and Procedure

The learning carried out in the project has been experimental and holistic; this is the ideal to be able to generate a connection between learning and the creative process. Authors such as Heron (2008) argue that this learning is a sum of four concepts. Two of them come from Aristotelian learning. The thought related to intellectual statements, together with the practical related to resolutive aspects. The other two concepts are the ability to imagine, related to ludic dreams and visions, and feeling as an active method. These last two concepts include *feelings* in learning to understand the creative process (Welford 2004).

In order to understand the develop in which this study was conducted, fig.2 presents the process of creating projects carried out at a sequential, temporal and repetitive level through Diagrams, Plans, Models (DPM) methodology. The students' work process is based, on experimental learning, defined as an interaction between empirical works and works related to the constant revision of the literature (Dym et al. 2005). This learning took place during the four months that the project lasted (from February to May 2017).

Fig 2. Gantt diagram and project

The process was carried out in three phases—# 1, # 2, # 3 in the lower part of the figure, we show the beginnings and ends of the phases.

Development of the phases:

Phase #1 and global perspective

In the month-long phase # 1, students worked in pairs. At this time, they were asked to create an individual online blog (https://grupotallerblog.wordpress.com/proyectos-1/) along with the collective work. Fig.3 shows different phases and activities with sequential time criteria.
In phase # 2, which lasted for a month and a half, work occurred individually, allowing us to get to know the progress of each student with his project and translation of references.
In phase # 3, the duration of which was a month, the work was in teams. This process of collaborative work brings with it the interrelation of ideas and work processes to achieve the objectives, improving the organisation of the process, putting ideas in common and improving communication when working in teams (Steen 2011).
As for the strategies carried out in the mixed work in the workshop, the following stand out. On the one hand, the workshop was based on lessons supported by classroom work, attendance at exhibitions and discussion. In addition, punctual master classes were held each time a new phase or concept was established. In addition, individualised tutoring was given to classes as additional time.

Fig 3.. Phases and activities of network project

One of the most relevant strategies was the practical work requested from the students for the final construction of the prototypes. In this part, there are three key points. First they were asked to carry out the DPM process throughout the project, in all its phases, in a repetitive way. This was done and internalised by working with the DPM three consecutive times. Fig.4 shows the result through the models after the development of diagrams and the development of plans, was parallel to the basic structure of the project to deepen it during the 4 months of work. The DPM process was repeated by increasing the metric scale and therefore the level of development, with both of the plans and diagrams as the models. This work was turned over each week to their blogs. This online space allows for control by the teacher when the number of students is large (De Jorge-Moreno 2012).

Fig 4. Class 11. Photography of the second competition. 04/04/2017. Source: own elaboration.

Phase #2 references in the process of developing prototypes

In this phase, a series of questions were asked to extract strategies from the references and to export them to the translation of prototypes. The questions led to the 1:1 scale development of domestic prototypes. The references and their developments in the projects will be approached in the following section in relation to the prototypes. Subsequently the 10 prototypes built will be analysed. Finally, four patterns (Alexander 1966) will be presented in the process of the final domestic topological cube.

On the one hand, this phase provides a theoretical base of references for the students (fig.1). This has the aim of facilitating the implementation and development of spatial capacities in variable and experimental domestic environments, which in turn with strategic associative capabilities improves their learning through the final construction of prototypes on a scale of 1:1.

The translation of the initial reference given is transferred to the plans, models and prototypes through some guidelines previously given to the students. Asking questions is fundamental in the design process (Dym and Little 2003)

The prototype *filters* started from the reference to the "*Villa Savoye"* of Le Corbusier. The prototype was based on the distribution and maximum optimisation of the space to create a comfortable place for the users, related to their ergonomics. In turn they valued the versatility of the space, obtaining a cyclical space and one of continuous change like a chessboard. The basic programme was a village and the programme introduced in the prototype is based on the domesticity transferred to the public space.

The prototype *sand and perceptions* obtained from its reference perceptual factors like the filters through which it passes to a series of movable panels, arranged in racks. The student personal perception was "a filter the existing reality linked to psychiatric centres".

From the prototypes *Mr. Gym*, *Blue Garden* and *Wormhole*, based on the reference to the Pao (portable tent-house) of the nomad girl of Toyo Ito (Ito 2000), different translations are extracted. One of them, *Wormhole*, extracts the versatility of the "Pao" both for its shape and its weightlessness. The students also analyse the envelope that takes your prototype as a space "that protects you in specific moments". They define their space as an envelope where the user can introduce themselves and create new experiences inside. The organic form allows it to acquire the versatility of change and adaptation to the body as a second skin. This project is abstracted from the cubic geometric form of the 1 x 1 x 1, meaning the volume together with the topological and non-formal relationship of the base statement.

The prototype *Blue Garden* obtains from the previous analysis of Pao of Toyo Ito, the light, transportable and ephemeral architecture. In turn they are inspired by Japanese architecture and culture in terms of values such as care and importance with the nature and lightness of their interior modulations of traditional constructions. They propose a project based on the combinatorics of portable garden-lounge, whose grouping with other prototypes generates an experimental domestic space.

The prototype *Knotted* whose base project is the Casa NM, obtains from its reference the introduction of counting in a minimum space with the necessary possibilities and functions. His project is limited to the cube of 1 x 1 x 1, fixing some knots as shown in fig.5 with three openings that allow for the creation of various configurations with the same slats. This prototype allows for a configuration based on the combinatorics of the incomplete open cubes of Sol LeWitt (LeWitt 2001).

Fig 5. Students working on the Knotted prototype. Source: own elaboration.

The *Set-mesh* prototype is part of Jaap Bakema's Square L-type system reference, a module system of 6.3 x 6.3 allowing for diverse groupings of space. The reference of Bakema is a work of houses for the reconstruction of damaged areas after the second world war. This project allowed associations that were both horizontal and vertical.

Among the associations from the reference to the prototype, in groups of 4–5 students, a total of 10 groups and 45 students concluded that the most determining factors are the distribution of spaces and perception and the user's perception of the projects when interacting with them. However, the parameters that most influence the students when it comes to conceiving the space are those of flexibility, and lightness in the portability and versatility of the space, as will be analysed later.

Phase #3 Co-design of topological cube prototypes

At this point of phase # 3 of the project—the prototyping—was exposed. The process of co-design was realised taking into account the topological concept of the space of the prototypes. That is, the study of qualitative properties developed with transformations of space (Tepavcevic 2014). In the second phase, about 45 initial variants of the 1 x 1 x 1 cube were created, as shown in fig. 6, based, on the one hand, on the previous references given and, on the other, on the evolution of the students' creative thinking, together with the guidelines from teachers. From this point, the last phase of the design of the prototypes on the 1:1 scale was made.

Fig. 6 45 raised options of the cube linked to a micro domestic space. From the 25 initial references given previously and in the combinatorics between work teams, the last design phase was passed. A: Perimeter exterior, B: Structure, C: Volume interior, D: Folding, E: Axis, F: Topology.

Finally, 10 of 45 prototypes built were selected in a competition for their level of development and didactic possibilities. As Jan Stappers (2007) has described prototypes as: *"the core means by which the designer builds the connection between fields of knowledge and progresses toward a product. Prototypes serve to instantiate hypotheses from contributing disciplines, and to communicate principles, facts and considerations between disciplines. They speak the language of experience, which unites us in the world. Moreover, by training (and selection), designers can develop ideas and concepts by realizing prototypes and evaluating them...The designing act of creating prototypes is in itself a potential generator of knowledge (if only its insights do not disappear into the prototype, but are fed back into the disciplinary and cross-disciplinary platforms that can fit these insights into the growth of theory). (p. 87)"*

In fig.7 we can observe the influence of the 25 references given; as can be seen, two references have a significant nodal density, thus indicating the important predominance in the development of students' work. On the one hand is the house Clota by Benedetta Tagliabue and Enric Miralles, a work built in 1991 in Spain. The main influence of this project on students was the central skylight. This element allows by its geometry and arrangement of angles the entrance of light into the interior space. In addition, the use of the masonry without coverings in Clota House inspired them in their final prototypes, leaving the material seen without any coverings, architectural finishes or paintings.

On the other hand is the Pao of the nomad girl, a project realised in 1985 by Toyo Ito and Kazujo Sejima. It is based on a circular base envelope and a possible development based on triangular structures. This project had a final influence on 12 students (fig.7). It also encouraged the final development of 3 of the 10 selected prototypes of the same reference. This leads to the conclusion about the possibility of the factors mentioned above. In the case of the nomad girl's Pao, it is an experimental prototype: it has an XS scale, and is a visionary project whose objective is to give visibility to a factor that today is still present—domesticity and its evolution or experimental progress. In addition, the Pao has the possibility of generating changes or combinatorics.

The third and last phase was prototypes. In fig.7 we can see how the references (marked with a triangle), the students (marked with a circle), and the prototypes (marked with a square) generate a new work-network. The fusion of references by each of the students creates an atmosphere of interconnected work for the construction of the prototypes, and illustrates that they are enriched by the contribution of the references that come together when members of other references are grouped together to form the prototype team (see prototype *Blue Garden*). The grouping of students belonging to different initial references promotes the acquisition and natural hybridisation of concepts carried out in the final prototype. This is the case of the prototype *Observatorium* or *Set-mesh*, whose students come from 4 different references, and which reflects this interaction in the final prototype, both in its form and in its base concept.

<**Fig 7.** Network of references, students and prototypes >

2.4. Data collection and analysis

In this section we bring the results obtained from the pre and post-surveys to the students. The pre-survey included a set of architectural subject items (domestic spaces comprehension, experience, previous knowledge, relations with familiar architect). For the degree of comprehension and satisfaction we used a 5 Likert-scale ranging from Low (1) to High (5). The items for comprehension/satisfaction were: what is the degree of comprehension or satisfaction of the work you are doing?. For architectural subject: what space of your house is dispensable or essential? What space does not currently exist in a house? Would you invent it?, and so on.

The descriptive analysis of Table 2 shows the degree of compression and satisfaction. The values of understanding and satisfaction are high and show how both evolved between surveys.

<T2. Degree of understanding and satisfaction>

In order to know in depth, the relationship between the degree of comprehension and satisfaction in the different surveys carried out, given the relationship of these factors to the performance already discussed above, an analysis was carried out in greater depth than the one shown in the Table 2, where only the value of the mean is taken into account. Fig. 8 shows a graph illustrating the complete distribution of the four variables by means of a box plot and graphic in the form of a violin according to the surveys. In the central part of each graph is the detailed box plot, indicative of the range and extreme values of the distributions. In the external form, you can see the kernel distributions. Clearly, a shift of the values of comprehension and satisfaction of the second survey (light grey violins) can be seen in the higher levels in relation to the first.

<**F8:** Violin graphs of the degree of understanding and satisfaction of the surveys >

Regarding the features reflected by students' characteristics, 32% have previous knowledge of architecture, due to relationships with a relative, friend or previous study and 90% of them chose an architecture degree as first option. Regarding evaluations related to domestic space, 90.84% define this as domus-casa. Dispensable spaces: living room, dining room, hallway; essential or more frequently used spaces: bedroom, bathroom and kitchen.

Concerning the development of outdoor spaces and whether having them inside the house or not, the responses are very divided. 80% of them show around 20 different choices, where the highest percentages focus on swimming pools, sports areas, gardens and co-working areas.

3. Results and exposition.

The 10 prototypes developed in fig.9 are grouped into four patterns (Alexander 1977). On one side are the prototypes that maintain the cubic configuration from the beginning to the end of the process. In this section three prototypes are entered: *Knotted* (1), *Mr. Gym* (2) and *Set-mesh* (3). On the other hand are those that occupy the volume initially given in a 1 x 1 x 1 cube but are expanded by organic forms, complex geometries, or topological relationships of the space to be explored, that is, a non-metric concept of space (Stojakovic 2014). These are the prototypes *Wormhole* (7) and *Movements* (8). A third group would conform to those prototypes that maintain the perimeter base of 1 x 1 in some of their "faces" and develop an open form based on the use assigned by the students. In this group are the *Botellódromo* (9), *Filters* (6), *Blue Garden* (5) and *Observatorium* (4). A fourth group is formed by the *Playgrounds* project (10). This prototype creates four spaces by intersecting two planes.

<**Fig 9.** Development of 10 prototypes >

There is a choice of 4 among the 10 prototypes. The first prototype, *Set-mesh*, is associated with pattern # 1 cubic Euclidean geometric space, maintaining the cubic form from the initial phases of the process to the final execution on a 1:1 scale. It proposes a prototype based on a mesh, influenced by its reference to Jaap Bakema, and two framed quadrants of 1 x 1 wood allowing the axis Z to vary according to the needs of the user. A series of slats of 1m long adjustable according to the needs of the user are arranged. Fig.10 shows this strategy created to allow for multiple dispositions with the same 1 x 1 matrix.

<**Fig 10.** Pattern 1. Prototype Set-mesh. >

The second prototype, *Movements*, (fig.11) is associated with patterns # 3 and # 4 expandable coplanar projective space and folding space. The concept *folds* has been studied for the geometry of space, testing with different materials the same folds. Both the origami (folded paper art) technique and the architectural kirigami (paper cut art) technique were tested by students on scale models under the influence of the Toyo Ito reference and Japanese culture. The Spanish architect Emilio Pérez Piñero, who designed and built from 1960–1971 coplanar deployable structures and removable and retractable domes, worked experimentally on a 1:1 scale, and referred to the process carried out in the preparation of models and later drawings. In many cases, he first produced models and prototypes and then drew them. This pattern has been contemplated in several prototypes such as *Botellódromo* and *Movements*.

Fig 11. Pattern 2. Prototype *Movements*.

Wormhole, the third prototype (Fig. 12), is associated with pattern # 2 topological space. This project starting from a volume of 1 m^3 led to an organic structure, and generated a mirror of the concept "squaring of the circle" (Duvernoy 2008.) The prototype is associated with topological relations of space (Stojakovic 2014). The sensation of metamorphosis (Kafka 1966) or of a second skin and ergonomics, leads the students to create a path of 6 linear metres, folding to 50 cm after folding, as seen in.9. This prototype allows for the possibility of generating multiple paths and arrangements, both horizontal, diagonal and vertical, given the flexibility of the proposed curves.

Fig 12. Pattern 3. Prototype *Wormhole*.

The prototype *Playgrounds* (fig.13) is part of the capsule *Living pod* (Greene 1967) of the British group Archigram. This prototype is transformed into the intersection of 2 planes, creating 4 spaces. The associated programme is the recreational spaces to 4 generations—a game for all ages. Each space is interconnected contiguously by means of micro visual perforations or hollows to pass the hands to another geometric space of parallelepipeds or flat pyramids.

Fig 13. Pattern 4. Prototype Playgrounds.

The final exhibition with all the prototypes is based on a matrix or a game board (chessboard). The game strategy allows for a constant change of elements. The board acts with a double function. First, it takes the domestic space to the public space, the street, taking advantage of the particular function of each prototype. Second, it creates another domestic space that shelters projects, always thinking about the comfort of the user. The process of realisation, both of the prototypes and of the exhibition, was carried out via co-design and collaboration between the teachers and students. In addition, brainstorming and tutorials were carried out with the faculty's architecture laboratory and the provider. The main objective of the exhibition is based on the interconnection of prototypes in the same space. This approach was proposed by the teachers as a possible strategy for the final association of cubic spaces (fig.14).

4. Conclusions

The main results show the evolution of the learning process and the architectural projects of the students, through the development of prototypes, in which it has been possible to identify four patterns: cubic Euclidean geometric space, topological space, expandable coplanar projective space and folding space. Also in the development of prototype construction, the incorporation of models to different scales from 1:100 to 1:10 has been relevant to the development of prototypes on a 1:1 scale. This allowed first-year students to internalise three important concepts of architecture, mainly in experimental housing and its distribution of spaces adapted to change, together with mathematics. First is the united concept of *scale* and proportion, linked to the ergonomics of the user in a domestic micro architecture as a base point. Second is the incorporation of geometry and form from the distribution of spaces to development in the constructive detail. Third is the concept of groupings by applying the 1 x 1 x 1 cube and its subsequent association to a game board (fig.14).

The proposed project with its conclusions and hypotheses should be tested and refined with more case studies of different contexts and prototyping dimensions. Exploring new sets of scales and grouping is also expected in future research. Furthermore, a possible extension to this work could follow several lines. A potential path could be carried out on the basis of the cube but using a material other than wood, or the same volume and different geometries. Applying a similar approach working with metric, dimensions alternative to 1 m^3 as a standardized "a priori" measure could be applied, for example, a threshold of a door of 80 cm or the minimum radius required for a space to reach with universal accessibility, 150 cm, can also be an interesting extension.

Fig.14 Final grouping based on the diverse flows of domestic space and activities: intimacy, privacy, quotidian function, familial relations, eating, washing, sleeping or any activity associate with home.

5. Acknowledgments

On the one hand, thanks to the 45 students of The School of Architecture (ETSA-UAH) of the University of Alcala (UAH) for their effort and hard work. On the other hand, thanks to the teachers of "*Grupo Taller UAH*", FINSA Madrid (Finsa 21) and technical assistants.

The experimental project has been financed by an innovative teaching project from the Institute of Education Sciences, University of Alcala (ICE UAH), called *Development of spatial capacities by applying the 1 m^3 cube in variable and experimental domestic environments*. Link to the project course: Http://www.virginiadejorge.com/teaching and https://grupotallerblog.wordpress.com/proyectos-1/

The project is based on the first part of the ongoing Ph.D. research on experimental housing and its thresholds of the first author. It has been possible thanks to the funds of an 4-year excellence pre-doctoral contract (FPU-MECD) of the Ministry of Education, Culture and Sport from the Spanish government. All images and photos shown here are by the authors.

The authors thank the comments and suggestions by the editor and the reviewers who have helped to improve this work. The responsibility for any mistakes made is solely the responsibility of the authors.

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Table Click here to download Table PID 2017_tables_R2.docx

<**T1.** Characteristics of the sample>

	Technical characteristics of the study
Analysis unit	Students of 1st year of the School of Architecture of the University of Alcala, atelier group ("Grupo Taller UAH").
Geographical scope	University of Alcala-Madrid
Population	54 students enrolled in the 2017 course
Sampling type	For convenience
Sample size	45(83,3%) students
Sampling error/ confidence interval	5,9%(95%); p=q=50
Measuring instrument	Individual survey
Date embodiment	February- April 2017

Source: Own elaboration

<**T2.** Degree of understanding and satisfaction>

Ítem	Survey #1	Survey #2
Degree of understanding (average DE)	3,82	4,21
	(1,11)	(0,61)
Degree of satisfaction (average/DE)	3,91	4,23
	(1,27)	(0,65)

Source: Own elaboration

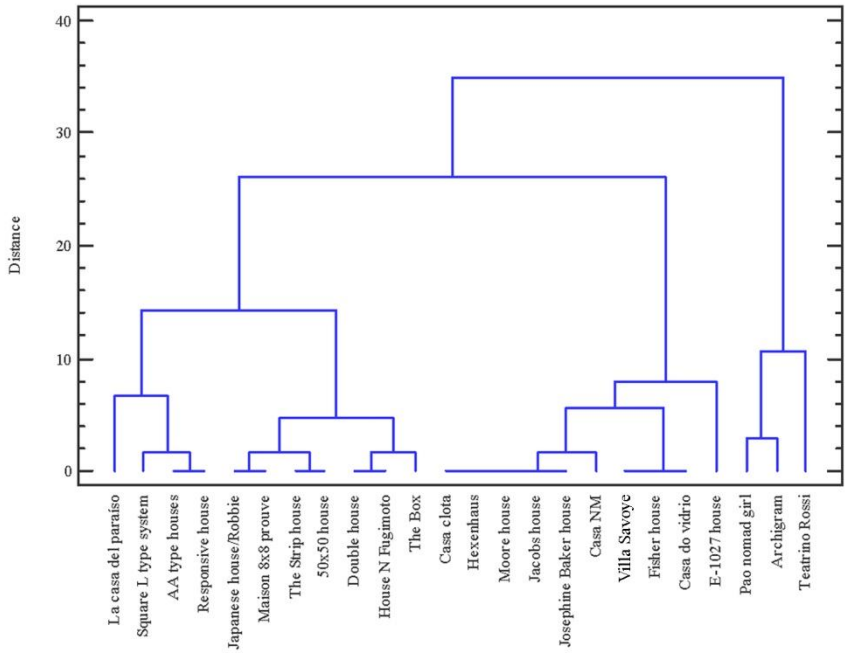


Fig 1 Dendrogram. Farther neighbour method. Euclidean square. Source: own elaboration.

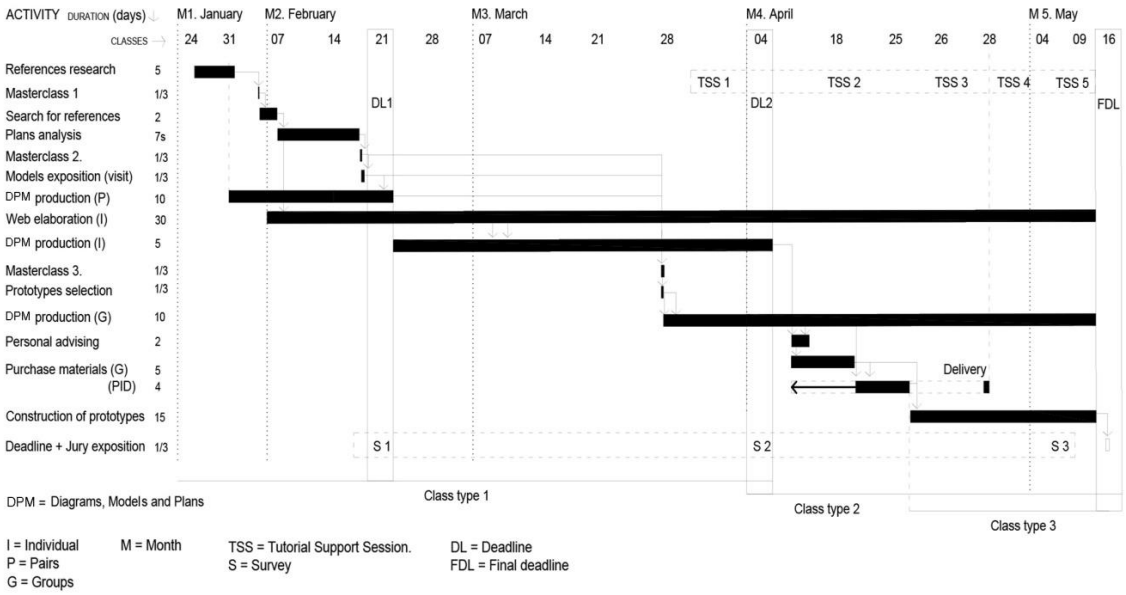


Fig 2. Gantt diagram and project

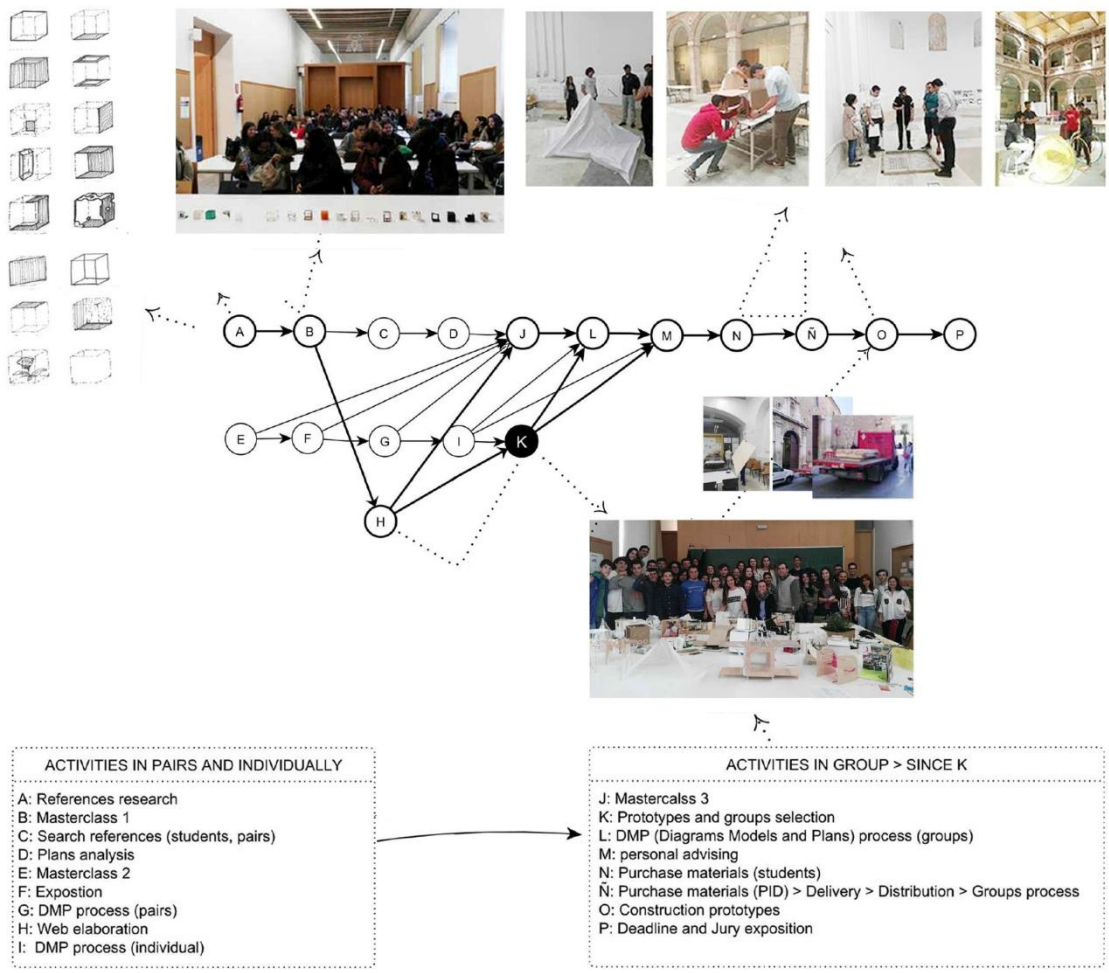


Fig 3.. Phases and activities of network project

Fig 4. Class 11. Photography of the second competition. 04/04/2017. Source: own elaboration.

Fig 5. Students working on the Knotted prototype. Source: own elaboration.

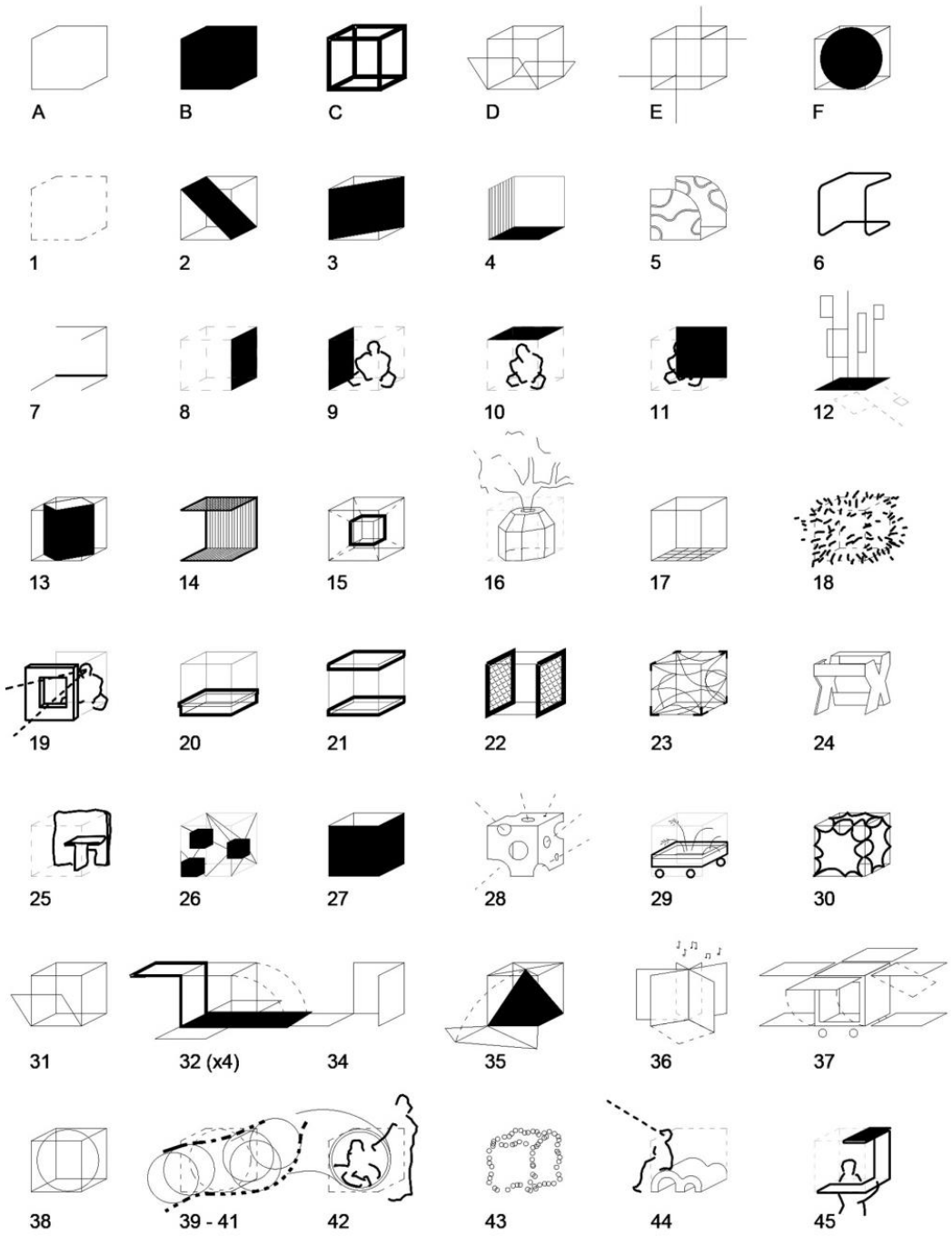


Fig 6. 45 raised options of the cube linked to a micro domestic space. From the 25 initial references given previously and in the combinatorics between work teams, the last design phase was passed. A: Perimeter exterior, B: Structure, C: Volume interior, D: Folding, E: Axis, F: Topology. Source: own elaboration.

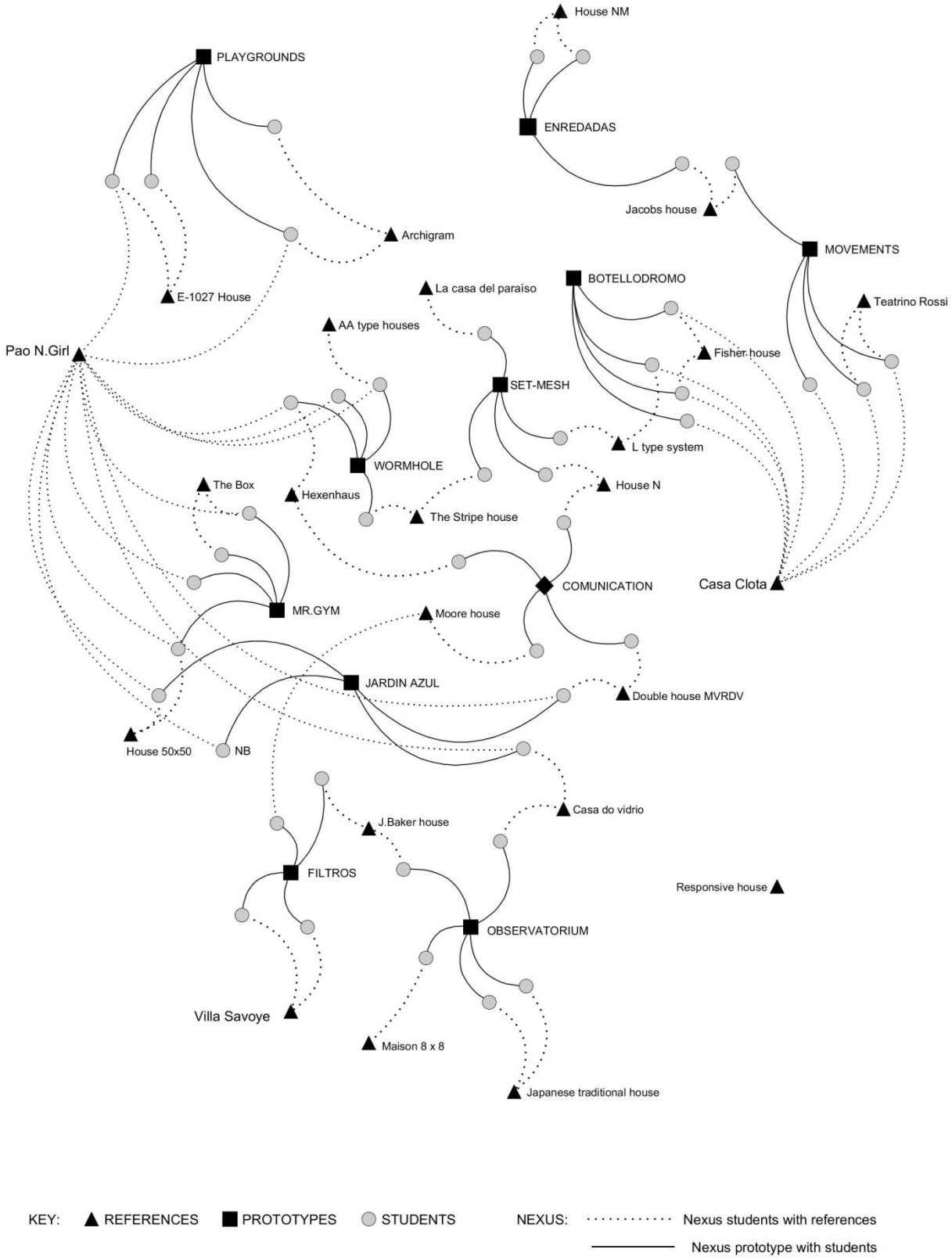
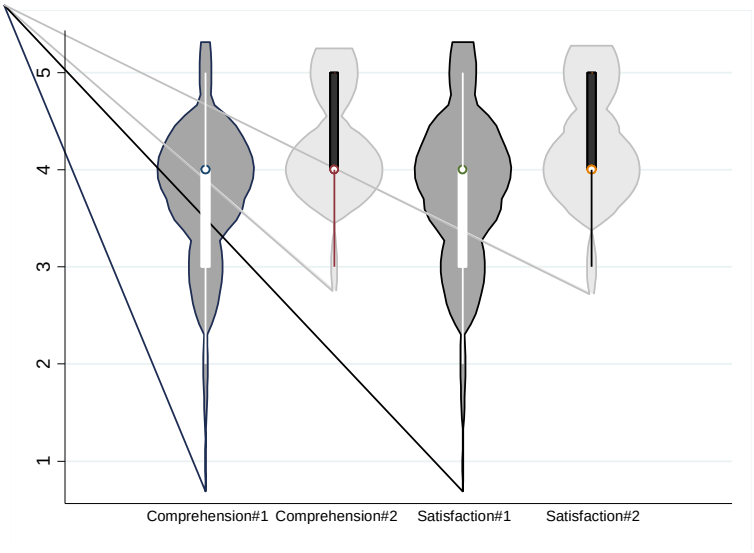
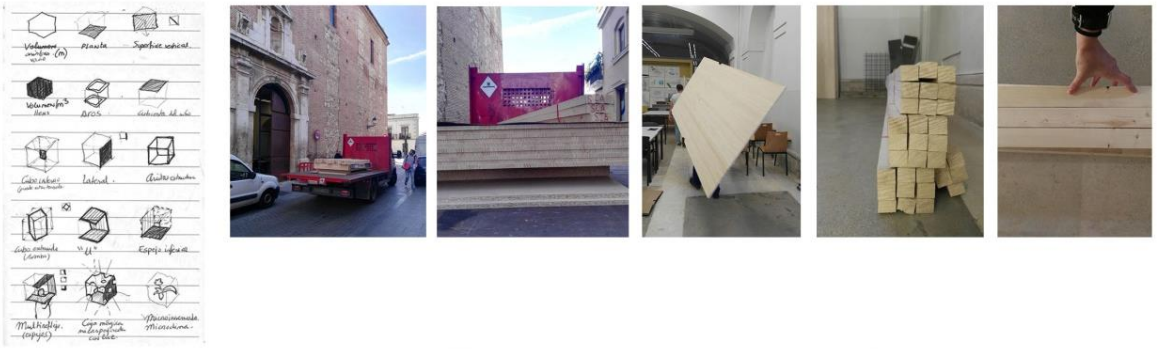


Fig 7. Network of references, students and prototypes. Source: own elaboration.

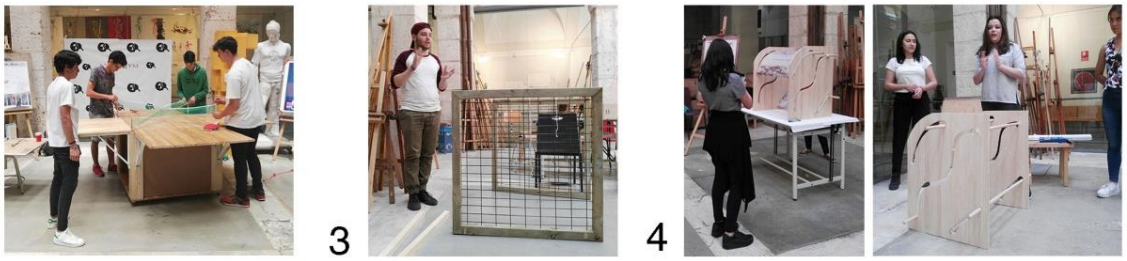


<**F8:** Violin graphs of the degree of understanding and satisfaction of the surveys >



Starting point.

1 Knotted



2 Mr.Gym

3 Set-Mesh

4 Observatorium

5 Blue garden.

6 Filters.

7 Wormhole

8 Movements

9 Botellódromo

10 Playgrounds

Fig 9. Development of 10 prototypes. Source: own elaboration.

<**Fig 10.** Pattern 1. Prototype Set-mesh. >

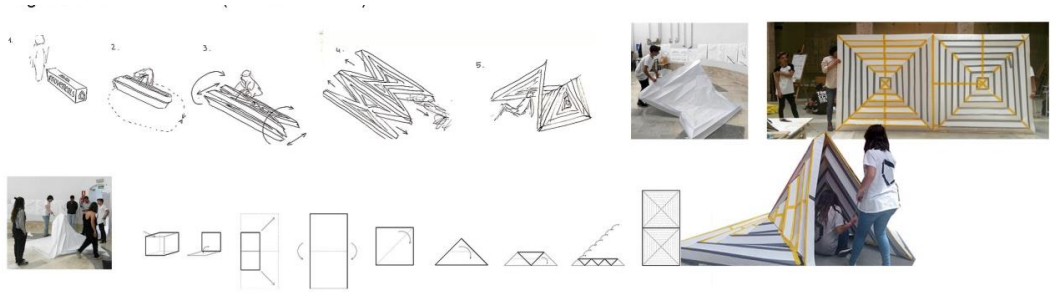


Fig 11. Pattern 2. Prototype *Movements*.

Fig 12. Pattern 3. Prototype *Wormhole*.

Fig 13. Pattern 4. Prototype Playgrounds.

Fig 14. Final grouping based on the diverse flows of domestic space and activities: intimacy, privacy, quotidian function, familial relations, eating, washing, sleeping or any activity associate with home.