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CAD-CAM AND CNC TECHNOLOGY IMPLEMENTATION FOR A SUSTAINABLE REFURBISHMENT OF HISTORIC DISTRICTS. A CASE STUDY FOR BILBAO

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Abstract
After having researched a construction system based on CAD-CAM and CNC, we come to the conclusion that this system is appropriate for implementing it in refurbishment processes in old buildings. More precisely, refurbishment in buildings erected before industrialization with wooden structure and masonry facades in dense and historic city quarters. The main goals of the construction system are the recyclability of all elements, energy savings, bioclimatic performance, economy, accuracy and safety in the building site and simple procedures to write the project documentation.

The old quarters accessibility is often a handicap for implementing standardized components. In this case, the structural panels can be elevated to the floors with a reasonable physical effort for the worker, using the staircase, instead of an electric elevator.

Moreover, the heterogeneous personal economical resources of the neighbours in the building, is often an added problem for executing overall refurbishment of buildings. This system allows to make partial refurbishments and can work in different phases.

The new program layout planned for the buildings or apartments solved with the common refurbishment technologies and systems, requires an added slab of 20 cm for the drainage piping system. The application of the system can avoid this.

The construction system is adaptable to any geometry. In this way, there is no problem to applying the system on non-orthogonal plots. Using a CAD-CAM coordinated system the structure is easily adaptable to irregular geometries and dimensions.

During the first industrial era, in the historic city centre buildings, the insertion of plumbing system in a wooden structure building was rarely successful. The wooden structure near these plumbing facilities, is almost always rotten or damaged. The proposed construction system offers a solution for this problematic.

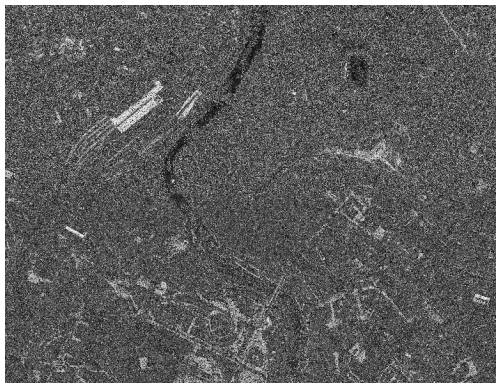
Normally such historic buildings don´t have a correct insulation. The system allows a bioclimatic performance of the whole building.

Keywords: CAD-CAM technology, historic district refurbishment

1.-INTRODUCTION: Research framework

1.1.-Urban context

This research is limited to the refurbishment of the Old Quarter of Bilbao. The urban shape of this part of the city was shaped between the 12th and 13th century. They used the so called ``Gothic Plot´´ to organize the structure of the city. Those plots are four meters wide and fifteen meters long. The front of the plot faces the street and the back of the plot to a "carcava" or gully (two meters wide medieval back street). In the beginning the buildings were two or three stories high, and they had a courtyard or a garden in the back side. But at the beginning of the 14th century, the whole plot became occupied by the building. Nowadays, the buildings have five floors, they form blocks and sometimes they share an inner courtyard. That means that the central area of each separate building has no sunlight. The current buildings were built around the year 1800, that is before the industrial era. Since then, they have been constantly modified. They are commonly divided in apartments in the first to the fifth floor and a commercial use space in the bottom floors.



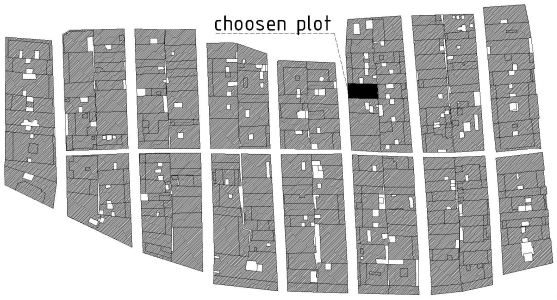


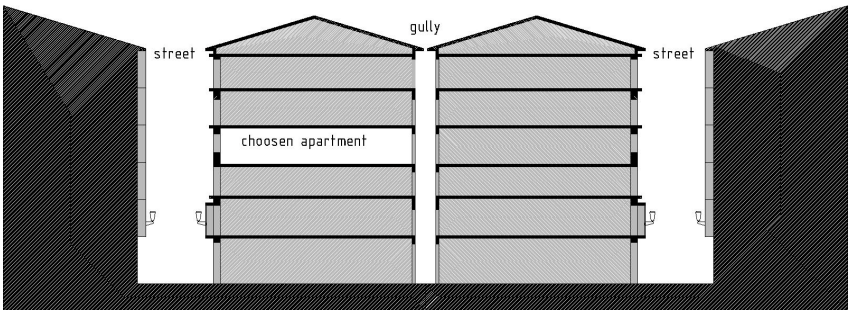
Figure 1and 2: *Orthophoto of the Old Quarter of Bilbao and location of the plot where the research has been made .*

1.2.-Built context

The buildings are built using a timber framework (beam and column structure). The floor structure is made up with rafters and boards. The last bay facing the street is filled with two feet brick masonry or stone wall. The bay facing the gully is closed with a one foot wide brick wall. The inner distribution was built with one quarter feet wide brick walls. Normally, the layout was the same in all floors. This distribution often ties the wooden framework and sometimes collaborates as a structural piece. The goals of this research are to create a tool for the refurbishment of those buildings and to repair the pathologies in the wooden structure.

1.3.-Property context

The property of those buildings is divided in two parts: The common use property and the private property. The common property is made up of the facades, roof, structure, common installation supplies and staircase (and the lift, in the few cases it exists). The private property concerns the inner area of each apartment and its installation system. The refurbishing works will be different if they are focused on the common part or the private property.



Figures 3 and 4: *Cross section and facade of the chosen building.*

1.4.-Technology

The tool created from this research, will be used in the following context:
-The architect or the designer uses three dimensional Computer Aided Drawing software.
-The fabrication or the different elements of the refurbished building is made using Computer Numerical Control machinery. This means, that the technology is available in the industrial companies nearby Bilbao.

1.5.-Materials

The Refurbishment System created from this research uses mostly plywood or laminated wood. Steel for reinforcement purposes will be used when necessary. Wood is available in the Basque Region and it covers the 30% of the territory land-surface. Timber industry is quite developed both for construction and for furniture. Steel working is also a developed industry.

2.-Why Refurbish the Bilbao's historic district.

2.1.-Environmental improvement

The buildings included in this research have needs to improve their thermal and acoustic insulation. Those building have five times less insulation than the required for new buildings by the Building Code (``Código Técnico de la Edificación´´).

Calculation of a Thermal insulation Resistance .

WALL

-Stone wall 60 cm wide.

- Superficial Resistance of the enclosure in contact with interior and exterior air.

Rsi = 0,10 m2 K/W
Rse= 0,04 m2 K/W

Layer n°	Material	Thermal resistance e(m)	λ	R
Int.	Rsi =1/hi			0.10
02	Stone wall	0.6	3	0.2
Ext.	Rse =1/h_e			0.04
			R_T =	0.34

Energetic demand limitation

Test if U < $U_{max.}$	U1 =	1/ R_T =	2.94	<	U_{max} =	0.53	NO

Figure 5: *Calculation table: Thermal Insulation Resistance of a 60 cm stone wall .*

2.2.-Lack of land surface for building residential areas
In the last fifty years, the use of land for urban purposes has reached the 65 % of the total municipal area of the municipality of Bilbao. The Basque Region of Biscay (NUTS-3) is a Predominantly Urban Region. There is an evident lack of land.

2.3.-Empty dwellings or in disuse
The proportion of empty houses in the target neighbourhood doubles the one in the rest of the city. 616 apartments out of 3.206 are empty nowadays. That's near 20 %. Reasons are multiple but mostly, it's because these apartments don´t offer enough facilities. As it has been said before, these buildings are 200 years old. Within the empty houses, not all of them have sufficient comfort, such as heating, hot water or even a kitchen and shower. Another fact is that these buildings don´t have an elevator.

It is common for some apartments in the building to have been newly refurbished and others don't even have a shower. This is a consequence of the property system mentioned before. Refurbishment is necessary to turn all the empty space into proper and dignified dwellings. The local administration has made a subvention program for refurbishment, and it has been working with it during the last 25 years.

3.-Problems for Refurbishment in the Old Quarter of Bilbao

3.1.-Project
The council's office for Planning asks for a project whenever an apartment is going to be subject of new layout transformations. The ancient layout usually has up to four rooms, two of them usually lack windows. The kitchen and the bathroom usually are attached, both in the back side of the apartment.

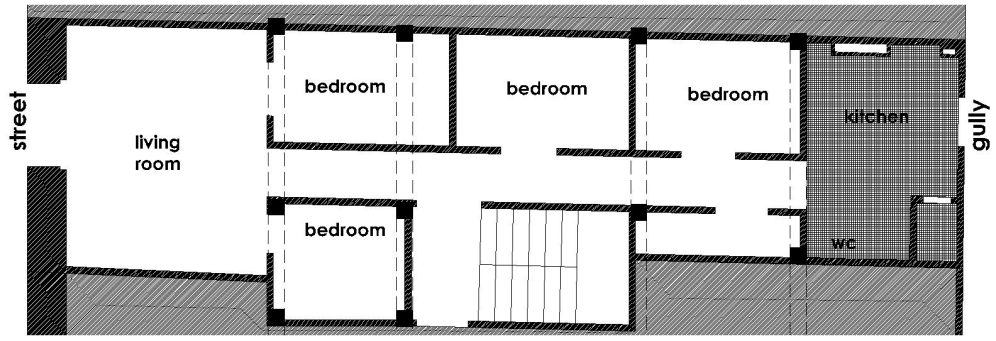
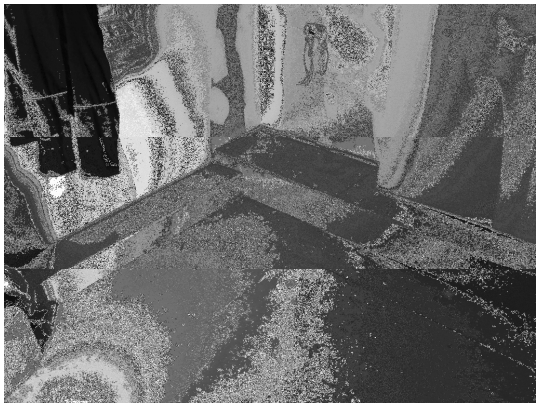


Figure 6: *Apartment´s floor-plan before refurbishment was made.*

The project must fulfil what the Local Plan -regarding technical and hygiene requirements- requires for a standard or basic home. Such apartment needs a space for living room and kitchen, a bedroom and a complete bathroom. The kitchen needs forced ventilation to the gully and not the main facade. All the spaces must have natural light and ventilation, except the bathroom, which can also work with mechanical air renewal. There are apartments within the Gothic plot which are four meters wide and fifteen meters long, with only two windows, one to the street one to the gully. The main drainage pipe of the building is usually in the back of the building.

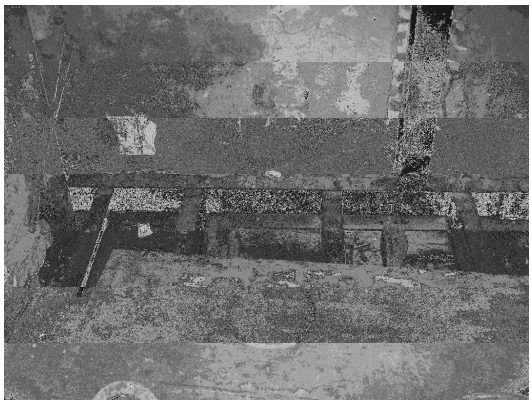
During the industrial era, in the end of nineteenth century and in the beginning of the 20th, the plumbing system was inserted. The location of the system was always close to the gully. In order to keep the budget low, the kitchen and the bathroom were close to this plumbing system. During the project design process, in order to fulfill the local requirements for a basic home, the architect or designer ``needs´´ this area attached to the gully for placing the bedroom or living room. Otherwise, the bedroom will have no natural light or ventilation. Therefore, the bathroom is moved to the centre of the floor-plan. The displacement of the bathroom requires more room for the drainage pipe and also a longer one. The local building regulations oblige the placing of the private pipes and their connection to the main ducts within the apartment that they serve. In consequence, a step will have to be built in order to attain a correct evacuation of black waters. That is, the bathroom level is usually higher than the rest of the home. This is a common procedure to avoid installing mechanical pumps that often do not guarantee a continued use.

Figures 7 and 8: *Fecal pipe and its stair.*

3.2.-The rotten structure

As the demolishment is being carried out, the structure is unveiled. After 200 years, the wooden framework near humidity sources is usually rotten. The moisture sources are the plumbing system and the rain water in the back gully. This plumbing system, mostly built with steel pipes, has been worn out over the years. This system used to pierce or go through the flooring, so the wooden structure near the pipes is always rotten. During the refurbishment period the rotten framework must be reinforced.

Figures 9 and 10: *Rotten structure and typical steel reinforcement.*

3.3.-Neighbors
During the refurbishment process, it is almost inevitable to disturb neighbours. The property division between an apartment and the one below, is often a 2 centimetres wide wooden board and a 2 cm wide plaster board. Considering that near the gully the wooden board is almost always rotten, it's quite easy to make a hole -sometimes in consequence of rubble falling down-.

3.4.-Accessing the building site
Narrow staircases are an impediment for transporting material to the apartment. The proposed systems should deal with pieces in suitable dimensions for transportation purposes. A small scaffolding is commonly used but its has to be compulsory certified and signed by an architect -which will add on to budget-. Another limitation is that imposed by the pedestrian zone regulations. Cars are only allowed from 8.00 to 11.00 am.

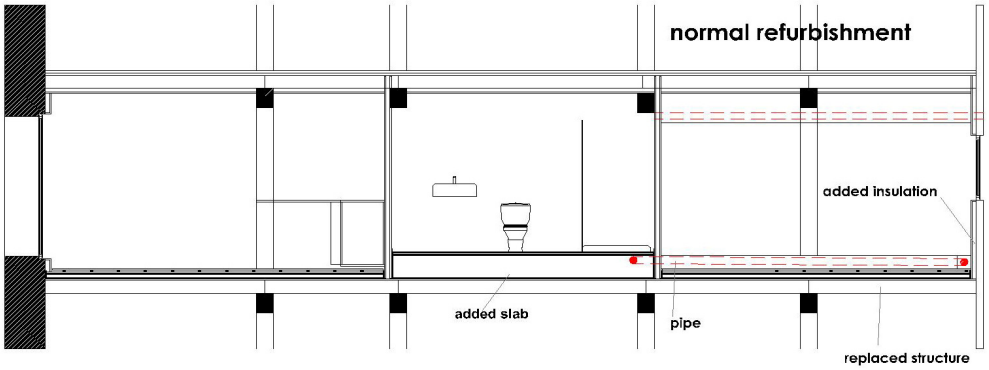


Figure 11: *Cross section of an apartment refurbished with common technology.*

4.-Research methodology

The research is made with the aim to define and prove a Construction System for Refurbishment in Old City Quarters using CAD-CAM and CNC. Currently, the research is in the design and test of building elements phase. Both design and testing are made by computer. The next phase will be creating prototypes to test them in a real situation. Defining each part of this construction system is compromised by the research itself and by the outputs obtained with the prototypes.

4.1.-Approach to the construction system
The main goals of the construction system are the recyclability of all elements, energy saving, bioclimatic performance, economy, accuracy and safety in the building site and simple procedures to write the project documentation. Adaptability to geometries, and different building situations.

4.2.-Generic design, first approach
As it is has been said before, the system will be adapted to any building in the Bilbao Old Quarter. But first, a generic design has been developed. This generic design will be focused in:

Common layout level
-the structural reinforcement and the new structural framework
-the enclosure system, and specially the thermal and acoustic insulation

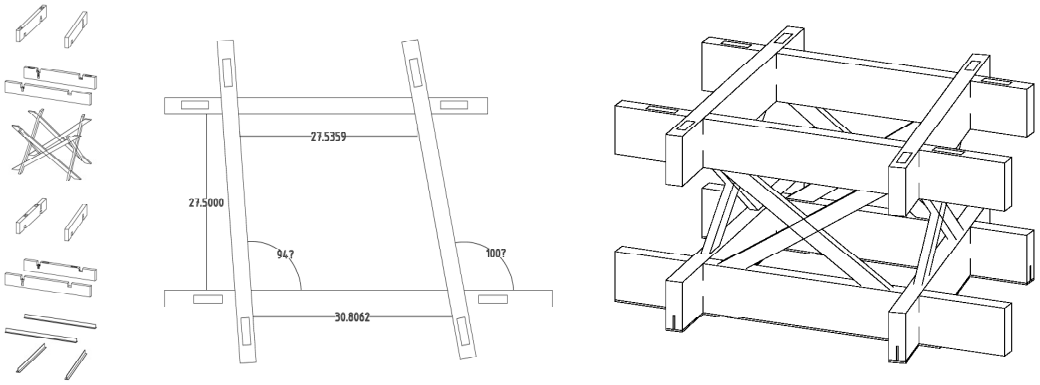
Private layout level
-the partition system, should be as adaptable as possible. The system is flexible in partition and in installations.
-providing space for the installation system

The Construction System will be modified and improved during the research process.

4.3.-Checking the generic design by computer simulation
A test with a three dimensional CAD model, will check some features of the system. The outputs of the simulation say that the structural behaviour of the system is correct.

With the 3D model, we can also check that the different pieces of the system can be produced in the CNC machine. This way, the cutting proposed for each element is based in state of the art technology, without wasting material.

4.4.-Conclusions and definition of the generic design
Once the results of the simulations are finished, the generic design can defined. The research is in this phase now



Figures 12, 13 and 14: *Pieces and Scheme of the structure made in CNC.*

4.5.-Projecting and building the prototype
Once the design is finished, the Construction System should be tested in real situation. For this purpose, a collaboration with local administration is needed. It seems quite difficult that a private owner of an apartment will expend money in a Construction System that it is not even proved. So, a public refurbishment work will be needed to apply the prototype in real case.

4.6.-Testing the prototype
The prototype will be tested structurally, thermally and acoustically. But the timing of the fabrication and building process as well as all the facts that could enlarge the budget will be also studied.

4.7.-Conclusions and final report for the application of the Construction System
After testing various prototypes, the System will be ready to apply in all the cases. A handbook or manual to use the Construction System as a designers tool can be designed. After the research, the system will be considered as a language or as a tool that both the designer and the builder will use. A computer plug-in could also be developed. This plug-in could be useful for the following:
-as data base offering frequent solutions.

-to adapt the construction solutions to the different geometry cases that will be refurbished.
-to calculate the needs of the structure and insulation.
-to generate documents for the project, such as budget report etc.
- to coordinate the designer and the manufacturer.

5.-REFURBISHING WITH CNC

5.1.-Building with CNC. The context nowadays.
CAD (Computer Aided Design), CAM (Computer Aided Manufacturing) and CNC (Computer Numerical Control) have been mostly used in industry more than in construction. Shipping industry, automotive industry are quite used to such tools. Within construction area, the furniture industry and the timber industry are the ones that have developed their own know-how.

There has been a more developed use of the CAD-CAM and CNC technology in new building constructions than in refurbishment processes. Particularly, when the designed form's complexity cannot be solved with traditional technology. It is also applicable when the budget is too high.

One of the earliest precedent in architecture for using CNC-CAM technology is professor Mark Burry's approach in 1.993 for the Sagrada Família church in Barcelona, which required a forehand research to reach Gaudi's original design. The next step was to make a 3D parametrical model using advanced CAD to define the future stereotomy. Then a polystyrene prototype was erected. And finally, the lateral and central naves, the 7 meter wide, 35 meter high Rose window screen wall for the West Transept were erected with just 10 mm tolerance.

Another examples are Frank O. Gehry's projects. The forms he designs, ``need´´ somehow to be built with CAD-CAM technology. The Guggenheim museum in Bilbao, finished in 1.997, is one example. Here, the main structure was made in steel, a material that is malleable and can be cut in CNC. The same architect, with the assistance of Thomas Bock used concrete pre-cast elements in the ``Neuer Zollhof ´´project, located in Düsseldorf (Germany). In this project, the polystyrene-formworks were produced by CNC-milling machines.

Recently, the CNC technology are being developed in timber structure buildings. These are a few of the recent and finished examples:

- Campus Restaurant with Auditorium for the Trumpf company in Ditzingen (Germany) by the Barkow Leibinger Architekten studio and finished in 2.008.

-Pompidou Media Centre in Metz (France) by the architect Shigeru Ban and finished in 2.010.

-Pavilion for the Federal Horticultural Show in Koblenz (Germany) by many authors and finished in 2.011

We can see that the technology for designing and building is already set. The mentioned examples show structures that mostly bear light weights, sush as roofs. Creating structures for bigger loads, such as floors, is the next challenge for this technology in timber structures.

5.2.-The generic design

The following paragraphs will explain the design process in a clear way. The starting point is the search for an optimal construction system.

A system which will allow for an up to date and manifold service in the same way newly built buildings do. A constructions system that can harbor a wide-range of uses during the life span of each space, from the ground floor all the way to the roof. An optimal system that can house all the needed facilities. A system that can guarantee a bioclimatic behaviour.

There is no intention in this first approach to come about new spatial solutions for architecture. It is rather a research for an constructive development. And so, the spatial solutions and partitions mentioned are of common and conventional character. Thus, we want to achieve a system that can serve a normal space.

Neither is the object of the present approach to design new facilities or service installations. On the contrary, we would like to house those systems in a proper way, in the correct place. We also intend for them to be totally accessible for repairing and follow ups.

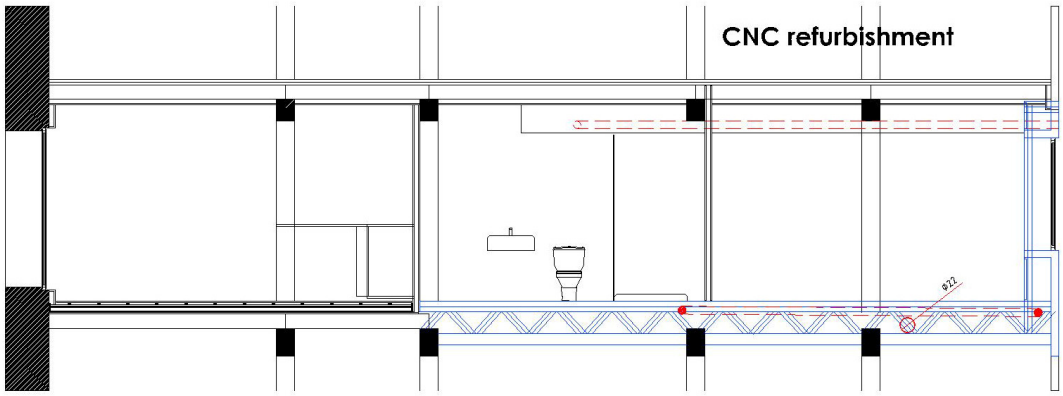


Figure 15: *Cross section of an apartment refurbished with CNC.*

Nowadays, the facilities take up more and more space and usually run along the ceiling. Air-conditioning and sanitation ducts are usually the ones with bigger dimensions. In consequence, they ask for a wide floor section. In many buildings the distance from the ceiling to the top of the finished floor can take over 60 cm. This is also observed in residential buildings. So, we will proceed to assume this distance (60 centimetres) for our building system. Moreover, the fact that the service ducts run independent of the structure or partition walls, allows for interior partitions to be flexible.

The construction system should be based in bioclimatic principles. It should keep energy in, lower the energy demand and profit from the solar energy in order to attain healthier interior environments. Therefore, and in order to achieve a higher heat isolation, a double skin facade is proposed. The two planes would be separated by 90 cm or more.

If we study the scheme, free of any structural support, we believe a double-support truss can be easily adapted by placing it in the interstitial space between the facade planes.

Ultimately, we will obtain 3 types of spaces. The primary one is the lived space and the secondary one “serves” the other one. This second level space can be optionally used for

storage and every day purposes. It will depend on the ruling use of the building, as well as on the width of the mentioned space. Finally, we must mention the third type of space which is located horizontally between two primary spaces. Its purpose is to exclusively house facilities and structure.

In order to develop this system, we should not despise the use of recyclable materials such as plywood, WPC, composite panels and the like. The choice will depend on how adequate it is for each project. At the same time, it is indispensable to create the building system using state of the art CNC cutting machinery. This allows:
- for adaptability in non –orthogonal plots; the machine is able to cut in a wide range of angles.
- we do not need to follow a certain module system; it is easy to coordinate with other dimensions. The cutting is realised with the needed accuracy depending on the context. It is a customised design.
- Project execution guarantee. What is projected, is drafted and built in site exactly.

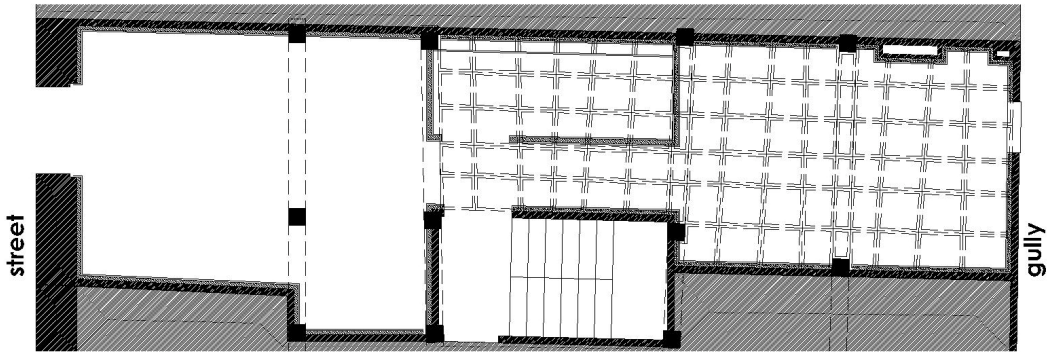


Figure 16: *Scheme of the reinforcement made by using CNC TECHNOLOGY. A none orthogonal grid is made.*

It appears that all buildings, just as other equipment, will be in the need of a continued maintenance and follow up by law. This also applies for the building services and facilities. The building, as it seems, will be required to guarantee the adequate service regarding the structure and the facilities. Our system should be adaptable to such a reality.

5.3.-Maintenance and flexibility
The system's structure, partitions and facilities are entirely flexible. The joints must be adjusted and released with a simple turn of a key. This would permit that the user, together with technical advice and the help of an architect, could move any element of the building. The facilities run through the horizontal structure. As an example, it is proved that in a 60 cm floor width, a drainage duct of 110mm diameter, can evacuate and reach the vertical duct with a 12% slope.

So, we can say that the only fixed element that should be reflected in each floor is a vertical thruway for facilities. The less 'elbows' a duct has, the larger efficiency of the service can be. This applies for most of the installations. The user in each floor is free to design an adapted layout, based on personal needs and taste. The same building can house different layouts without compromising the floors below or on top. In addition, they can also be changed through time.

5.4.-Project process and CAD-CAM coordination

The process starts with the project. Both project and building have to be coordinated. As mentioned before, a plug-in will be installed in the CAD program that the designer uses. So with this plug-in the designer can draw with accuracy the building. The designer starts the project using the data base solutions. One might think this way of working prevents the designers from being creative. Far from that, the system offers multiple choices to the designer. Making a parallelism, it can't be said that the laws and norms of concrete are a restriction for the designer, but instead offer multiple solutions.

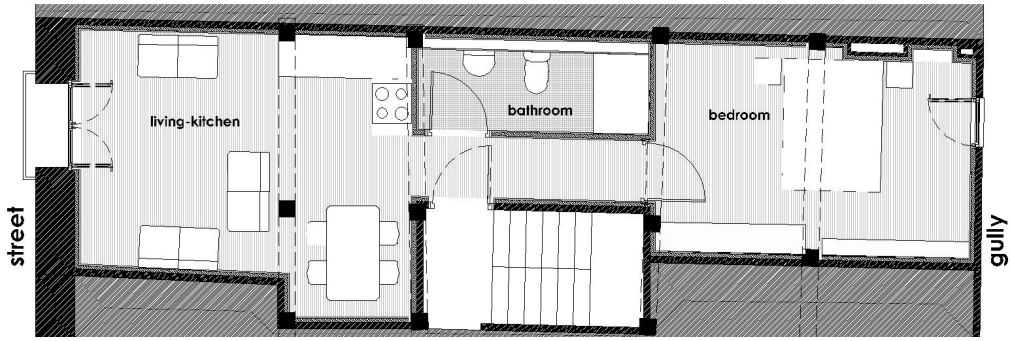


Figure 17: *Project for the apartment.*

With some general measurements as a starting point, preliminary and execution projects are developed. The project must seek the most precise dimensioning, but it is also convenient to take into account some tolerance variance. The designer has a complete control over what it is designed. Once the project is modelled in 3D, the designer could know if the solution proposed for each project fulfils the structural and insulation requirements and regulations.

5.5.-The process for building with CNC.

Once we receive the building permit, we will proceed to check the current state of the dwellings on top and below of ours. We will certify the state –existing cracks and other deficiencies- by writing a report. We should check if the partition walls on the top house and in ours concur. It is probable that they are in contact and so loads might be transmitted. In such case we will build discharge reinforcements to direct the loads towards the rafters. This must be done before starting to tear down the existing partitions walls. The reinforcement elements will be part of the new structure system. In order to install correctly these pieces, we will tear down the ceiling. By doing so, we will also manage to do a more concise diagnose of the state the top rafters and beams are in. A bigger quantity of reinforcement might be needed then.

Before starting to demolish the walls, we must locate a flexible element around the wall so it can cushion the strike of the toppling material. In this way we will prevent the floor from cracking and of rubbish falling down to the apartment below. It is recommended that a prop or post will be placed to avoid movements created by demolishment vibrations.

Once the partitions are put down, we can take apart the floor boards, and proceed to check on the rafters and beams below them. By experience, it is usually enough to do so in the floor of bathrooms and kitchen. In the rest of the bays, it is enough to look around the pillar bases. This process for demolishment can easily extend throughout two weeks. It is common to bring down the rubbish by hand through narrow stairways. This complicates and adds extra tiredness to the job.

At this stage of the process, the space is better read without the partition walls and with the structure unveiled. We can now take accurate measurements, either with measuring tape or digital tools. As for the next step, we must draft a proper and exact floor-plan, reflecting on it the possible collapses in the party walls and the planimetry of the floor as well as the ceiling.

Once we have produced the accurate 3D model, we shall redraw the project thinking on the manufacturing stage. The CNC machinery will produce accurate reproductions of the pieces on the 3D model.

A worthy advantage is obtained with this method, we can supply the building site with the needed pieces without having to store them in a warehouse. It is a direct and fast relationship between the workshop and the site.

5.6.-Maintennance of the building CNC.
All the project will be saved completely, element to element as it was built. Using the CNC technology permits that years later after the refurbishment was made, we can make the same piece as original. Even more, we can provide new pieces for new situations, and those new pieces could be attached or jointed perfectly.

The apartment that has been refurbished with this construction system will easily adapt to a new user. Apartments change from hand to hand. If we want to have this adaptability, there must be a maintenance, a parallel service has to be provided. This way, there will be a permanent link between the contractor and the user. This is not new, not even in construction world. The ideal situation would be that the building user could install or un-install the partition walls or structure elements wherever he or she is interested. The client or the space user could request this parallel service to provide change of structure from place to place. If he would need a piece, he could buy or rent from the maintenance service. Of course, a technician should allow all these changes.

The system is both flexible in structure, in partition and in installations. The joists of the structure and partition could be opened or closed with a simple wrench. So the user, with the help or guidance of a architect (or similar), could move the partition, the installation or even the structure. All this is supported by a flexible installation, partition and structure scheme. Almost everything is movable, the only element that should be kept in place or fixed on every floor, it´s an installation shunt (even this could me movable but not recommended).

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