

# Refurbishing homes for elderly using BIM and CNC technology

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**Purpose** This article was developed in the context of research on a construction system based on CAD-CAM-BIM and CNC (Computer Numerically Controlled) technology and it is focused on the implementation of sustainable refurbishments in historic districts. During field work in historic districts, it was established that more than 25% of the population in these areas is older than 60, and most of them have lived in the same apartment or house their whole life. The problem is that these old timberframed buildings require better equipment to fit elderly peoples' characteristics. For instance, a better distribution of space in the home would be beneficial to the elderly. To ensure better living conditions for the aging society, comfortable and big bathrooms, corridors, and doors are necessary, instead of the narrow and cramped current spaces. Likewise, more space for the installation of technological equipment is needed to support people who are disabled. Automated homes for the elderly require machinery that take up a significant amount of space. Moreover the installation of new equipment and redistribution of space has to be done rapidly so that the process creates minimum disturbance. The construction system that is being developed gives priority to the preservation of the current timber-framed structure and masonry walls, instead of dismantling the inner structure. This way, the refurbishment works are less traumatizing and the elderly and their elderly neighbors can continue to live in their homes. **Method** The construction system is designed for different building contexts to demonstrate its universal applicability. Before being applied in a real situation, the first step was to ensure the refurbishment system's suitability using virtual tools. For this purpose, a BIM-building simulator was used. The preliminary works focused on two different building typologies. The first typology is an apartment building (located in Bilbao) with a common staircase where properties are divided horizontally. The second typology is a terraced house located in London. In both cases, the refurbishment system was compared to traditional refurbishment processes. The parameters of comparison have been refurbishment costs, timing, and quantity of used energy. In both cases the project was personalized for a disabled aged person. **Results & Discussion** A proper refurbishment process grounded on CAD-CAM-BIM and CNC-technology needs to be based on detailed and exact measurements. Moreover, it is advisable to collect data more than once during the refurbishment process because the timber-framed building could move some millimeters. To avoid problems due to measurement errors, the CNC-fabricated pieces should offer measurement tolerances in order to facilitate the assembly and staging process. These first steps of the project – the defining of the refurbishment system – take a long time, since all the joints must be designed in 3D. This delay in the design process will be reduced when a detailed BIM-library is set up. However, the duration of the building site process is clearly shortened and that is why how disturbance is minimized. The construction system enables a flexibility of the inner distribution and the BIMsoftware helps with the tracking or monitoring of changes in the future. If the health condition of the elderly person requires more care or supply, modifications in the home can be fixed easily.

**Keywords:** *refurbishment, CAD-BIM-CNC technology*

## INTRODUCTION

Many buildings formed by load-bearing walls and inner wooden joists have become useless for some inhabitants and particularly for the aged people. The increasing aged society needs to refurbish or renovate homes, especially in the buildings with timber joists. During the field work made in the historic districts, it has been certified that more than 25 % of the population in this areas is older than 60 years<sup>1</sup>. Those buildings need a customized refurbishment owing to the countless variety of geometries<sup>2</sup>. Using BIM (Building Information Modelling) and CNC (Computer Numerical Control) technologies could be useful to improve the nowadays refurbishment process situation.

Due to last advances in Software eta CNC fabrication, it is possible nowadays to fabricate building elements with complex geometry<sup>3</sup>. This availability to produce elements with complex geometry can be useful in the field of old building refurbishment. Similarly, last advances in accurate measurement and 3D data collection can be profitable<sup>4,5,6</sup> in order to get a more accurate data collection.

The background research's overall main purpose is the implementation of automation and "robotization" in the refurbishment processes of buildings. The research contemplates a definition of a "Refurbishment System" that could be used in the future refurbishment of buildings. This paper is a reflection about the comparison between the ongoing research and the traditional refurbishment processes. Particu-

larly it focuses on the competitiveness compared to traditional ways of refurbishment.

In order to limit the research field, this paper will focus in a specific type of buildings, erected from 1830 to 1900. There are many variations in the technology used to build them. But basically those buildings were formed by load-bearing walls and inner wooden joists. If we analyze the building form or building typology, we'll find two building categories. Firstly, we can see the typical block of apartments or flats that were mostly built in the main cities in continental Europe. Secondly, there are the so called Terraced Houses, where independent houses are organized in a row. This typology was preferably built in the cities of Anglo-Saxon countries.

The approach to refurbish is different in each typology. In the block, the minimum habitation unit is the flat whereas, in the Terraced House, the home unit includes several floors, from the basement to the roof. The problems and the solutions are different.

In both cases, many buildings have become out of phase and they need a refurbishment. Sometimes, the lack of a proper maintenance provoked several pathologies in several building elements. Some other times, the inner distribution became inefficient for the inhabitant. In these cases a readjustment is needed to adequate to the new situation. This paper emphasises the refurbishment works for the proper fitting of minimum home units for the aged people.

#### RESEARCH METHOD

As it has been said before, the building context is different from one country to another. And the research itself has to be developed in different ways.

The proportion of buildings made using the load-bearing walls and inner wooden joists is low in Bilbao. This is mainly because the biggest urban explosion was made during 1960 decade. During this period, reinforced concrete technique was the most extended technique. Although there is quite an important research dealing with the pathologies with this kind of buildings, grounded on the nearby city of Donostia<sup>7</sup>, literature about refurbishment of old timber buildings is not particularly big in the Basque Country. In order to find facts, samples of refurbishment have been monitored in the old quarter of Bilbao. Altogether, ten apartments have been monitored. All of them were located in different blocks and their owners were private investors. In four cases, the apartment was the main home of the owner. Eight of them were close to 70 square metres while two of them were around 120 square metres. One of these 120 sq m apartments was divided in two apartments.

The monitoring started in each case with the first contact with the client and finished when the refurbishment

works were over. The parameters of the monitoring are as follows:

- 1.- Possibility to obtain a proper home for an aged person.
- 2.- Period length of the project and the works in the building site.
- 3.- Collateral damages caused in the neighbourhood.
- 4.- Size or amount of work in each case.

The data collected in those monitoring have been compared with a different building context, that is, the Terraced Houses in the UK.

The proportion of buildings made using the load-bearing walls and inner wooden joists is bigger in the United Kingdom than in the rest of Europe. During the Victorian period, and particularly in the 1.890 decade, more than 150.000 terraced houses were built in the UK<sup>8</sup>. Most of them are still up nowadays, there are close to five million homes<sup>9</sup> just in England. Facts and data about refurbishment of this kind of buildings are already collected. Literature about this topic is wide, and it has been used for the comparisons.

In all cases, the possibilities and needs to implement a refurbishment using BIM and CNC technologies have been analyzed.

Towards a definition of the works that have been held during each refurbishment, a list of "common duties" was drafted. This list shows the size of the works that have been completed. The list is as follows:

- 1.- Demolition of the internal partition and dismantling of all Mechanical, Electrical and Plumbing (MEP) services.
- 2.- Repairation of timber joist, wherever it was needed.
- 3.- Placement of a properly levelled floor, meaning that it will correct the common differential settlement of the structure.
- 4.- Installation of new MEP and erection of new distribution, according to the inhabitant's needs and respecting local laws.
- 5.-An improvement of insulation of the entire perimeter closings that is floors, external walls and ceilings.
- 6.- Finishing.

#### DATA INTERPRETATION

Which are the reasons that have pushed to think that a refurbishment based on BIM and CNC technology is needed? The main reason is an overall inefficient performing of the whole refurbishment work. In the monitored cases in Bilbao, there facts can be joined up in two main groups:

On the one hand, there is a general lack of skills to achieve a task properly. This lack has been detected among all the partakers of the refurbishment, which includes the contractor and all workers.

On the other hand, the architect loses the control over the work being developed, unless he or she is in the building site for the whole day. The architect can't guarantee with 100% certainty that the projected building requirements have been properly delivered.

All this derives in many problems. Some of the works had to be repeated. The planned timing suffered several delays. In the analyzed samples, just two processes were considered to finish in the scheduled period. A 70 sq m apartment should be properly finished in 3 months. But some of them were finished after 12 months since the first demolition started.

A lack of skill of the contractor (frequently with a tricky way to think) can be a problem in the accuracy of the project. They tend to drop prices easily. But they normally ask for more money in order to finish despite a contract is signed between all the parts involved in the work.

All ten apartments had an increase in the budget. Just two of them had increased less than ten percent. In two of the cases, the budget has increased in between 10 and 15 percent. In the rest of the cases, the budget has increased somewhere around 20 percent.

The budget of these refurbishment cases, varied from 450 Euros per sq m to 650. The variation depends on the type of installation and the quality of the finishing.

It is quite difficult or it could take a big amount of time to make an accurate comparison between the refurbishing costs in Basque Country and in the UK. The published research by BCIS<sup>10</sup>, show that refurbishing costs are quite similar. Although there are some disparities in some of the budget units, the overall cost of refurbishing can differ around 5-10%.

### **Structural damage**

A reinforcement of the structure was needed in all the cases. Most of the times, joist were reinforced with steel beams. The area affected with rotten joist never reached the 20 percent of the total area of the apartment.

Probably, a bigger problem is that the structure is not rigid enough, which means that it has differential settlements. In the worst of the cases, there were 30 cm of level difference between one point of the floor and the other.

This differential settlement will be increased unless there is a stiffening of the whole apartment floor.

It has to be said that this kind of buildings have an irregular geometry and it is quite difficult to introduce prefab elements into them. Unless the measurement is really accurate, materials are manipulated in the building site.



*Fig.1. Typical steel reinforcement of the timber floor joists. Image by Kepa Iturralde.*

### **Accessibility**

Every living unit should be accessible by anyone without any help. But sometimes it is quite difficult to reach that objective. In three of the analyzed cases, there was a lift installed in the apartment block. In another four cases, it could be quite simple to install a lift, because there was enough space around the staircase. In the rest of the three cases, installing a lift would mean losing inner space in the apartments. There is quite a different situation in the Terraced Houses. The home unit here starts in the front door. The owner of the Terraced House has the opportunity to install by himself a lift. But, probably it's an element too expensive to install and maintain for just one home unit.

### **Collateral effects of the refurbishment**

Refurbishing processes create a building situation that is mostly anything but optimal. The demolition process itself shows the partial poor condition of the building. The building moves sufficiently enough to create disturbance. In all of the monitored cases, there have been justified complaints from the neighbours. The reasons of these complaints have been:

1.-Due to the movements caused by the demolition of the inner partitions, some cracks appear in the upper floor apartment's walls. None of the cases have been dramatic or important, but the owner of the upper flat asked for a reparation in seven cases out of ten. These cracks appear even if some provisional reinforcement of the structure is placed. In one case, the movement was so strong, that a mirror in the upper floor fell from the wall. All this is quite normal considering that the structure elements are not rigid enough. The reinforcement should be placed before the main distribution is demolished. This way, the structure gets more rigid and the movements due to demolition could be minimized.

2.-The ceiling of the downstairs apartment collapsed partially in five cases. This occurred where the joists were in a bad condition and removing them was necessary. The plaster ceilings are usually attached to the timber joists. So whenever is necessary to remove the joist, part of the ceiling falls down.

3.-Neighbours complained about the generated noise in all cases. During refurbishment period, every kind of finishing is removed which works as an insulator. This temporary lack of insulation is really noticeable whenever a worker has to manipulate an element in the site.

4.-The staircase of the apartment block suffers an unpleasant treatment during the refurbishment works. Scratches, stains, and overall dirtiness were produced. In four cases out of ten, there were several repairs to be made in the staircase to return it to its previous situation.

5.-In all ten cases, new MEP services or equipment was installed. Some of the cases, the neighbours presented their complaints because somehow they feel affected. Particularly, the new ventilation outlet and tubes were a cause of a discussion.

If we compare this situation with the Terraced houses, the collateral effects can be minimized. There are less shared elements with neighbours. The properties are divided with the vertical "party walls" and there is no horizontal property border. So, it is quite clear that the less the apartments share, the less annoyance are felt.

#### **REFURBISHING WITH BIM AND CNC**

Using this refurbishing process should change with the use of the new technology. Probably, the nowadays schemes could be changed into a more automated process. It may be quite common thinking that the automation in the building site should increase costs and budget. This might not be totally true. First approaches show that, increase will be around 10-20%. This overrun of the budget could be reduced or limited if the link between the BIM software and the CNC fabricating process was somehow systematized.

#### **Defining an ideal situation for the elderly people**

When dealing with the refurbishment focused in aged people, some special goals have to be accomplished. It means that besides the general goals for refurbishment, which are: improvement of the insulation, reparation of the structural damages or energy saving measures. It has to be said that all the new equipment and distribution has to be installed in a rapid way and this process has to create minimum disturbance. The specific needs for the aged people in a refurbishment can be these:

1.-Everyone should reach every stage or floor with mechanical help. This means that a lift should operate in every apartment block.

2.-The new distribution of the apartment should be designed properly for the people who may have some difficulty. For instance, it's recommended that doors, bathrooms, bedrooms and kitchen should be designed for disabled people. The design of the apartment should facilitate a self-management

3.-If some extra equipment is installed, this should be integrated in the overall design concept and it should be friendly.

4.-The apartment should be easily restored into a new situation. All the distribution and the equipment should easily be moved or removed. People's life situation change and the apartment distribution should not be an impediment to adequate to that change.

Taking into account all the mentioned points, a research has been developed to find a more systematized refurbishment process. BIM and CNC technology can be a useful tool to improve every task during the process. Some very first design steps have been made.

#### **Measurement and tolerances**

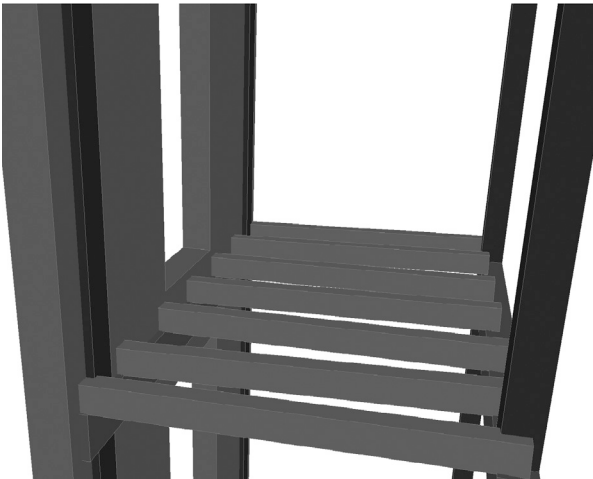
A proper refurbishment process grounded on BIM and CNC technology needs to be based in a detailed and exact measurement. Even more, it should be advisable to make more than one data collection during the refurbishment process because the timber-framed building could move some millimeters. To avoid related problems, the CNC fabricated pieces should offer measurement tolerances in order to facilitate the assembly and staging process.

The CNC fabricates the pieces with extreme accuracy. The measurement in the building site has to be really accurate in order avoid having problems when assembling the elements. Therefore, the measurement process is as important as working with BIM or fabricating the pieces with the CNC.

Measuring a hundred year old building formed by load-bearing walls and inner wooden joists can be a tough task if there a proper tool is lacking.

Once the data are collected, the designer or architect should have interpreted them properly, identifying and giving a property to each element.

It is not the purpose of this article, neither to the background research, to define new measurement processes. Instead, the last approaches<sup>4,8,10</sup> in this field will be taken into account. A test in real situation should be proved if those devices are profitable for the implementation of BIM and CNC technology. It has to be said that measuring and testing the movements that the different elements have suffered are really important to the whole process. All walls, beams and joists may be twisted due to tension and torsion forces, and they shouldn't be considered as simple linear elements. A no-destructive timber structure monitoring system could be ideal.



*Fig.2. Even though it seems orthogonal, there are many slight level irregularities that should be measured before the design starts. Image by Kepa iturralde.*

The previous research in this field has been focused mostly on masonry walls<sup>8</sup>. In order to make a bigger step in the development of the "Refurbishment System", the structure's differential settlements should be collected.

But besides measuring the geometrical characteristics of the structural elements, the 3D data collecting should consider achieving the material's resistance property. In the old buildings, material has suffered much pathology that can cause structural deficiencies. All these pathologies should be repaired and a level of the damage has to be measured in order to proceed properly.

In order to keep control over the works, several measurements should be done during the refurbishment process. The measurement could be classified in three groups:

- 1.-Measurement made before the demolition that should be used to draft the preliminary project. This measurement should be used to design, produce and assembly the structural reinforcement.
- 2.-Once the structure is reinforced, the distribution could be dismantled. A new measurement could provide a certainty to produce the enclosure elements.
- 3.-In the end and after the enclosure elements are assembled, a final measurement should be needed in order to fix the final finishing.

In order to achieve a rigid structure, tolerances between the junctions have to be minimized.

### **Drafting the project**

In these first steps of the definition of a refurbishment system, making the project takes long time, since all the joints must be designed in 3D. This delay in the design process will be reduced when the BIM library of details is set-up.

In a common refurbishment process, projects are usually really simple. It means that the budget, the

local planning standards and the client's requirements force an austere use of resources. One architect by him/herself can draft this kind of project in five working days.

Instead, drafting the project using BIM and designing all the building elements would take us around three weeks of work. The main reason behind this delay is that each element has to be placed and tailored for the specific geometry of the building. In order to avoid designing each of the elements every time, some patterns are needed. The ongoing research should resolve and facilitate the adjustment of the elements to the required geometry. Probably a new software solution will be needed.

Besides that, using BIM software can be a proper tool to prevent quarrelling or even claims with neighbours, once some ventilation pipes are installed. Using BIM facilitates the understanding of the project. If any neighbour considers that some change will affect his apartment, it can be discussed clearly before.

In a way to avoid damages in the staircase, the building elements can be designed in accordance to the staircase size. If there is any doubt if the stair is big enough, a demo can be made using BIM software.

### **Element production in CNC**

Once the project is drafted and the elements are defined, a CNC machine needs a model to mechanize. In other words, the CNC mechanizes an element out of a model that has been previously generated.

It has been estimated that near 1,400 different elements have had to be mechanized for the refurbishment of an apartment of 70 sq m. To generate a model for those 1,400 elements can be a tedious work. Each mechanization model should be automatically generated from the BIM model. Some of the software programs enable the link between the BIM model and the CNC machine, but as a rule, a specific CAM or plug-in will be necessary in order to link both the BIM model and the CNC machines. The work load will decrease considerably with the automation.

Besides, there are some facts that should be taken into account when designing a mechanized element. One fact is that the mechanizing or milling time should be as short as possible. Nowadays, some CNC machines operate with time and form simulator so we can predict how many time will be necessary to fabricate all the pieces used in the refurbishment process.

How to make a standardized junction among pieces is going to be another fact of discussion. One choice is to mechanize the elements for the use of traditional bolts. But nowadays there could be another

choice to that solution. Some CNC welding techniques have brought new expectance to the area. CNC machinery characteristics and the output mechanized element are totally linked. Before a design of a mechanized element is drafted, it should be necessary to know what kind of CNC machinery we are going to work with. The available CNC machinery should be defined, before any design has been made.

### Assembly

The main task when assembling is to fix every part to its correct and proper place. How can all these pieces be levelled in place following a systematized way? Somehow we need a ``sneaking`` or a checking device that can tell us if the element is correctly placed. This ``sneak`` could be based on the last technology using global positioning systems or another Metrologic device.

### Quantity of material used

A comparison has been made between traditional refurbishment process and the one which is proposed. It is difficult to quantify the material in a virtual case. The very first design approaches made by BIM show that the quantity of material used in the traditional way or by the new system can be similar. If the aim is to design a more sustainable building refurbishment process, it is quite important to economize the use of material. This concept is quite important if we want to achieve an environmentally friendly refurbishment process.

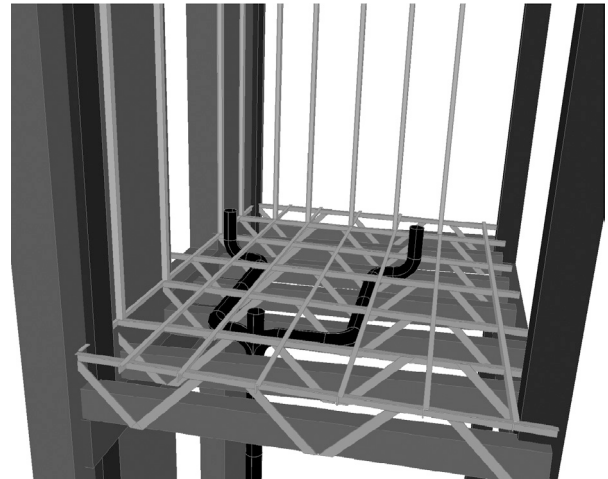
### Maintenance

BIM can be an efficient tool for the future maintenance of the apartment. A ``BIM as built`` concept should be defined. This BIM as built could serve for the future retrofitting of the apartment. This new retrofitting could be designed and drafted with the BIM software and the CNC could produce all the required elements as well.

In the very first designs, it has been important that most of the installation pipes should run between the joists and the new reinforcement guides. This way, the new retrofitting process could be more flexible

### Looking forward an efficient design

As it has been said before, the definition of the ``Refurbishment System`` is in the very first process. Many tests have to be made, particularly in real situation. There is still a long way to go. In a way, the recent approaches define somehow an appropriate direction that should be followed.



*Fig.3. As it is shown in the figure, a convergence of the structure reinforcement and levelling guides could maybe allow a more efficient performance in the building site. Image by Kepa iturralde.*

It seems that the key factors to achieve an efficient refurbishment of this kind of buildings are as follows:

- 1.-Formal and functional convergence: the structural reinforcement and the guides of the ceilings and floors.
- 2.-these guides should probably be made in steel L and U profiles with light sections that could work better than others. There must be a trial to work with some other materials, such as laminated wood and aluminium.
- 3.-In the analyzed samples, the refurbishment was limited to the apartment. The property system in Spain is oriented to an inhabitant owned apartment. This fact hinders the refurbishment of the whole building. This means that this kind of refurbishment is limited to the physical constrain of the upper stage's floor and the lower stages ceiling. Everything has to be made within that limit.
- 4.-The refurbishment work has to be independent to any other work that some other neighbour would do, meaning that the system used in the apartment shouldn't involve or implicate any other member of the apartment block.

### CONCLUSION

A common refurbishment process is based on low efficient systems. Time and money are often wasted. Therefore, new approaches are needed in order to improve the situation. Implementing BIM software and CNC technology in this kind of work can be a choice.

It seems quite clear that before introducing or implementing in a systematized way the BIM and CNC technology, some other steps have to be achieved. Instead, the whole process will still have a crafting character to it. Briefly, it can be said that in the measurement field, 3D data collection should be made in a simpler or more systematized way, and

this should be proved useful to the assembly process as well. In the software field, the different programs should be more interconnected or linked, both between them and with the rest of the process.

#### **ACKNOWLEDGEMENTS**

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