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List of Acronyms

AEC – ARCHITECTURE, ENGINEERING AND CONSTRUCTION
 BIM - BUILDING INFORMATION MODELLING
 CAD – COMPUTER-AIDED DESIGN
 CNC – COMPUTOR NUMERIC CONTROL
 DGMW - GERMAN SUSTAINABLE BUILDING COUNCIL
 EPBD-ENERGY PERFORMANCE OF BUILDINGS DIRECTIVE
 GIS - GEOGRAPHIC INFORMATION SYSTEM
 HVAC – HEATING, VENTILATING AND AIR CONDITIONING
 IFC – INDUSTRY FOUNDATION CLASSES
 PDF – PORTABLE DOCUMENT FORMAT
 QR CODE– QUICK RESPONSE CODE
 RFID – RADIO-FREQUENCY IDENTIFICATION
 ROI – RETURN OF INVESTMENT
 VOB- VERGABE UND VERTRAGSORDNUNG FÜR BAULEISTUNGEN

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1 EXECUTIVE SUMMARY

In order to meet the objectives of the Kyoto Protocol, we have to concentrate on improving the energy-inefficient building stock. Thus, renovation is envisaged as a key strategy to reduce the energy impact of the building sector.

In order to foster energy efficiency building renovation, an urgent need for a holistic and integral building energy efficient renovation approach is required, from the data acquisition to the implementation of the solutions, in order to reduce the renovation operations time.

BERTIM will develop a prefabricated solution which will provide the opportunity to renovate improving energy performance, air quality, aesthetics, comfort, and property value at the same time, while ensuring low intrusiveness during renovation works. The manufacturing of the solution will be included in a holistic methodology for the renovation project process, from data collecting to installation. The systemic methodology will be based in a digital data flow in BIM that will be implemented in a software named RenoBIM that will enable reduction of renovation operation time, customized mass production, and lower financial risk for investors.

Work Package 2 “Intelligent Modelling Based methodology for the holistic building renovation process with prefabricated modules” aims to define the requirement, specifications and methodology to develop the energy efficient prefabricated modules and the decision supporting tool (RenoBIM). This will lead to define the BERTIM prefabricated modules in WP3 and to develop the systemic renovation supporting tool (RenoBIM) in WP4. To obtain WP2 objectives, this deliverable aims to provide a general vision and description of the new holistic renovation process.

The first step (see Chapter 3) has been the analysis of European building stock, in order to identify the requirements for the process imposed by the building characteristics of the different countries represented in the project (Sweden, Germany, France and Spain). For each country an analysis of the building typologies, their constructive characteristics, energy efficiency standards and the type of ownership has been carried out. This analysis has been complemented with a study of the refurbishment market and finally conclusions for each country have been drawn identifying the key parameters for selecting the most proper target building typologies.

In the next chapter (Chapter 4), the current refurbishment practices and processes have been studied for Sweden, Germany and Spain in order to perform a gap analysis. The stakeholders have been defined, the different phases of the process addressed and the retrofitting solution and their industrialization level analysed. In section 4.4 an special analysis regarding the wood products in construction and refurbishment have been carried out in order to take into account the specificity of the timber in the holistic process.

The final chapter (Chapter 5) address the BERTIM holistic renovation process in all its phases: feasibility phase, building survey, retrofitting project design (with special emphasis in the energy efficient design of the modules), manufacturing and finally the transport and installation, including the building preparation, on-site logistic and support bodies. Finally, the Chapter 6 summarizes the general conclusions of the deliverable.



2 INTRODUCTION

Under BERTIM project: “Building Energy Renovation through Timber Prefabricated Modules”, Work Package 2 “Intelligent Modelling Based methodology for the holistic building renovation process with prefabricated modules” aims to define the requirement, specifications and methodology to develop the energy efficient prefabricated modules and the decision supporting tool (RenoBIM). This will lead to define the BERTIM prefabricated modules in WP3 and to develop the systemic renovation supporting tool (RenoBIM) in WP4.

This deliverable provides a general vision and description of the new holistic renovation process in order to obtain WP2 objectives.

It begins with a state of the art describing current renovation process: first, in Central Europe, then, the same in North Europe and finally, in South Europe.

In each part of Europe, existing buildings typologies are analyzed and classed by age, by uses and occupants, by geometry and flatness, and by material composition.

Then, an inventory of required data gathering methodologies is made: checklist, guidelines and equipment. After data gathering phase, a design phase includes current practices to define building refurbishment strategy, the target costs and planning.

In each phase, stakeholders, their roles and their needs are identified. Thereafter the experiences in manufacturing phase are Europe is listed with some examples of prefabricated kit intended to building renovation.

Finally, the practices in installation phase are described, including support devices, preparation of existing building, supply and transportation, and implementation of renovation solutions.

This state of the art allows defining BERTIM holistic renovation process, the second part of this deliverable. This work tries to avoid overlapping and to improve the efficiency of the process. The data flow from existing building data gathering to installation will be linear. The communication frameworks, areas of application and required information sharing among the involved stakeholders will be defined, for reducing operation time.

3 ANALYSIS OF THE EUROPEAN BUILDING STOCK FOR PREFABRICATED REFURBISHMENT

This chapters includes an analysis of the building stock in three different climatic zones in Europe. The objective is to provide inputs that will allow to identify wich buildigns are target buildigns for the implementation of BERTIM modules.

As timber manufacturers are in Sweden, Spain and France, the analysis in this three countries is carried out, as well as in Germany that is a target market also for the manufacturers.

3.1 Building characteristics in Sweden

3.1.1 Building typologies

To classify the buildings stock in the same way in all countries, three time period have been established:

- Until 1945 (old buildings)
- Between 1946 until 1990 (post war buildings)
- After 1991 (current and new buildings).

To get the whole picture it is also interesting to see what sort of buildings there were before 1930 eventhough there are quite few and most of the pnes that are still standing are already renovated.

The higher number of new constreuction was between the years 1950 and 1980. In this period a high number of multifamily houses were built.

Apartments built i Sweden between -1930 to 2011

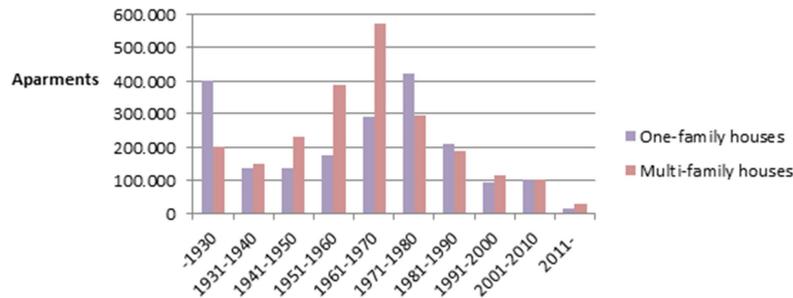


Figure 1 Apartments built in Sweden [Source SBC]

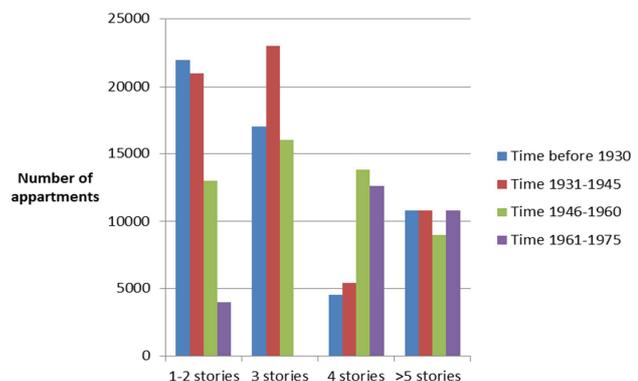
Three-storey houses are the most common type of house among multifamily houses in Sweden. Most of the three-storey houses are built after 1945.

Higher buildings, five floors and more and built before 1930 almost exclusively. This type are closed block buildings in urban areas. Recently, the higher houses are more built as freestanding houses.



Skanehatan 1917, Stockholm, Photo: Multifamily houses, outside city center

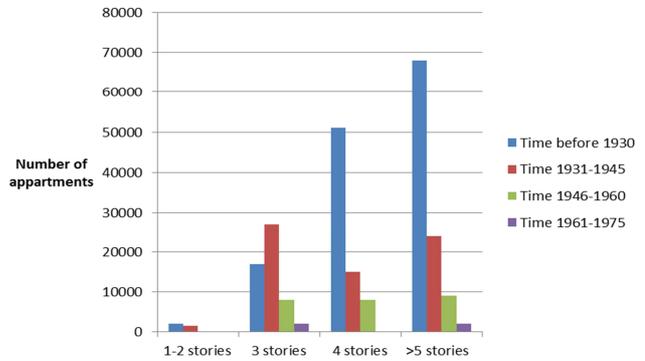
Multifamily-houses, outside city center



Stockholms stadsmuseum, Wikimedia



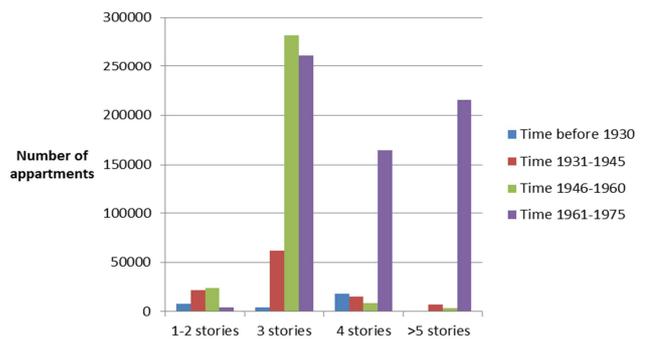
Multifamily-houses, city center



Gammel Strand København, Photo: Mahlum, Wikapedia Multifamily houses, city center



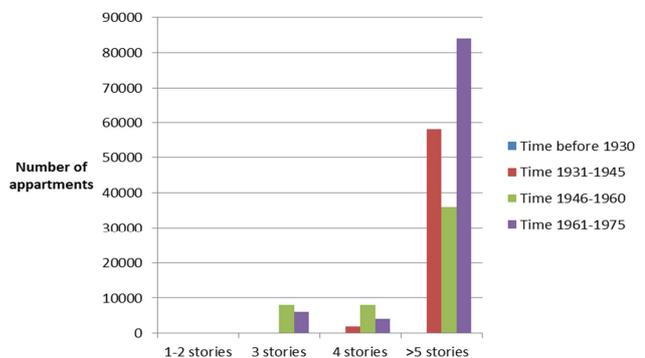
Multifamily-houses, "transverse bearing wall system"



Sätra, Stockholm, Photo: Holger Ellgaard, Wikapedia ("lamell-houses") Multifamily houses, "transverse bearing wall system"



Multifamily-houses, tower blocks



Slottshöjden hus, tower blocks Photo: Jesper Olsson, Wikimedia

Multi-family houses, tower blocks

3.1.2 Constructive characteristics

According to Statistics Sweden, SCB, there were 4,633,678 dwellings in the Sweden in 2013-12-31. These are divided into 1,999,964 apartments (43 %) in private one family house, 2,332,253 apartments (50 %) in apartment buildings, 222 334 apartments (5 %) in special resident units and 79,127 (2 percent) in the other house.

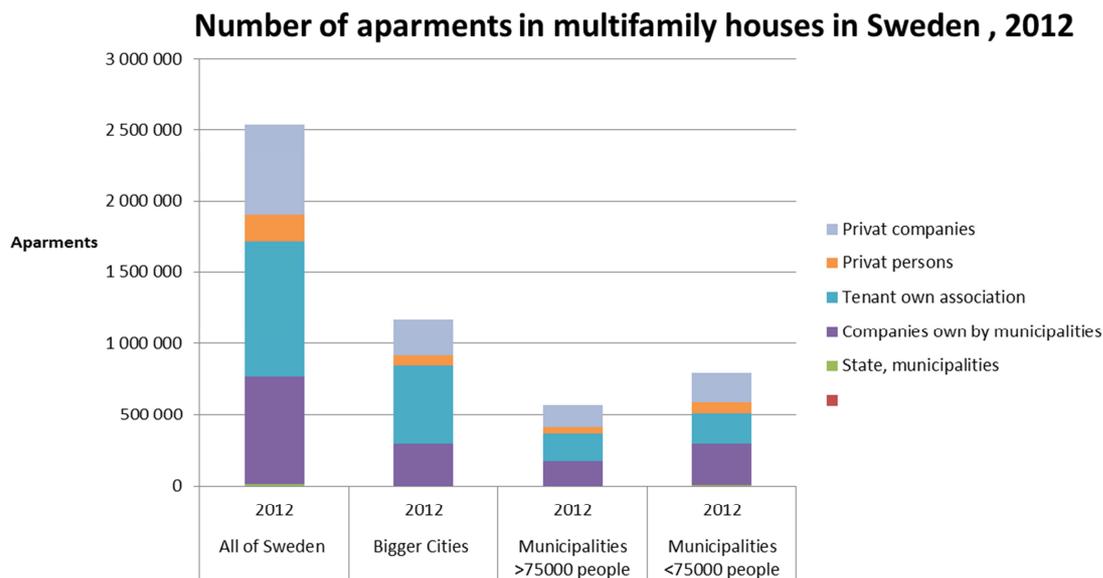


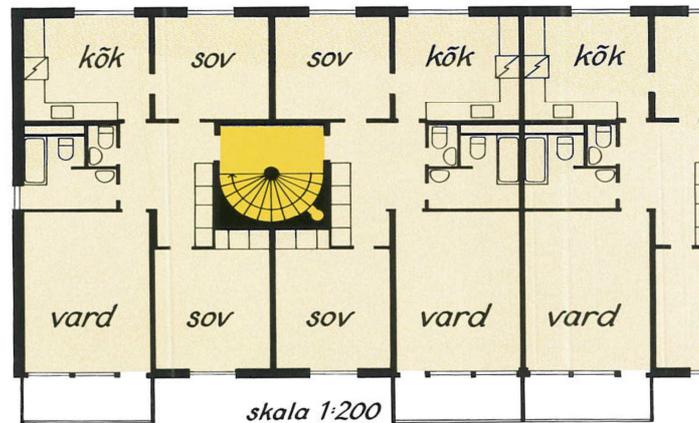
Figure 2 Number of apartments in multifamily houses in Sweden, 2012.

High-rise buildings in concrete and brick façade

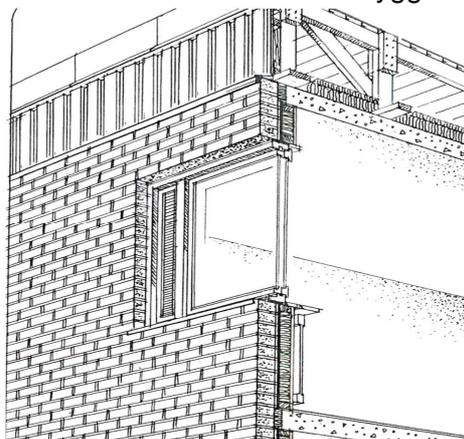
This type of building was built between 1940 and 1970. Already in the end of the 1950s the traditional elongated building got a new design. Saddleback roofs was replaced with flat roofs or butterfly roofs. The roof frame was made of rafter with posts with a center-distance of 1200 mm. The posts of the trusses rest on the concrete slab. The roof surface is made of tongue and groove wood and three layer of roof paper. The floors-slabs could in some cases be only 120 mm thick concrete and insulated with approximately 120 mm mineral-wool. This created a roof with low slope and dewatering inward. With the Nordic region's cold climate and temperature changes, this is not a good solution if it is not executed in a good way and also maintained in a good way. The bearing walls consisted of in situ cast transverse concrete walls and the facades was made of non-bearing light walls.

During the period 1960-1976 there was built more than 300 000 flats in Sweden of this type with 3-6 stories. The building was divided into different lengths, usually two or three stairwells with a similar design regardless of topography. The houses are often planned after a system called 3M-system, and a common width of rooms in the apartment was 39x3M = 3.90 meters.

The "infill" walls were often built up of isolated (100-150 mm) timber frame with plaster on the inside. The façade surface was often made with bricks or fiber cement boards.



Example of layout. Picture from the book "Så byggdes husen 1880-2000"



Example of the structural design. Picture from the book "Så byggdes husen 1880-2000"

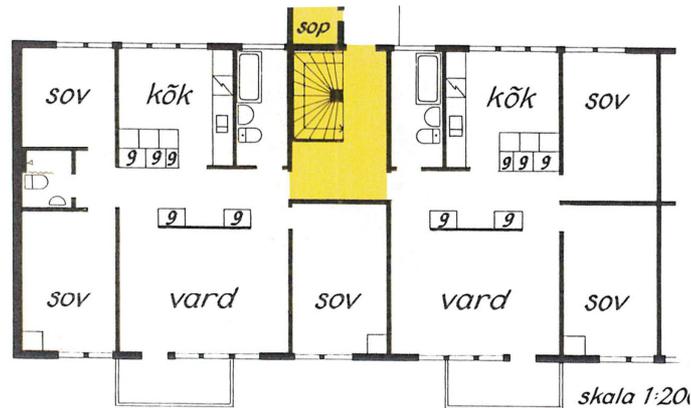
Figure 3 High-rise buildings in concrete and brick façade

High-rise buildings in concrete and wooden facade

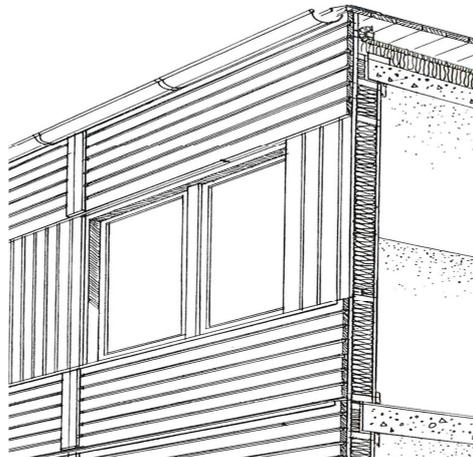
The houses of this type were built in the late 60th century. The houses are built with a conventional in-situ concrete structure with transverse load-bearing walls and a thickness of 160 mm. The floors were cast in place using room-sized shutter trestle which also had an influence on the layout and specified the width between bearing walls.

The roof frame was made of rafter with posts with a center-distance of 1200 mm. The posts of the trusses rest on the concrete slab. The roof surface is made of tongue and groove wood and three layer of roof paper. The floors-slabs was normally made of 160 mm thick concrete and insulated with approximately 150 mm mineral-wool.

The exterior walls were made of room-sized prefabricated (also built on site) elements of wood. The elements were performed by a wooden frame with 120 mm insulation covered with wood on the outside and gypsum boards on the inside.



Example of layout. Picture from the book "Så byggdes husen 1880-2000"



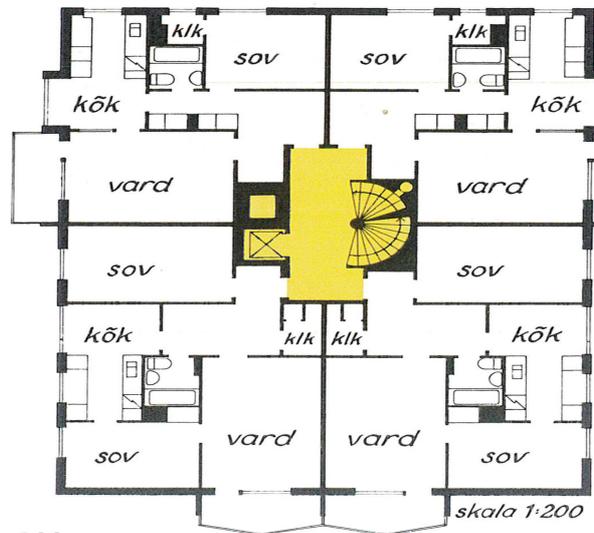
Example of the structural design. Picture from the book "Så byggdes husen 1880-2000"
Figure 4 High-rise buildings in concrete and wooden facade

Tower blocks 3-6 stories

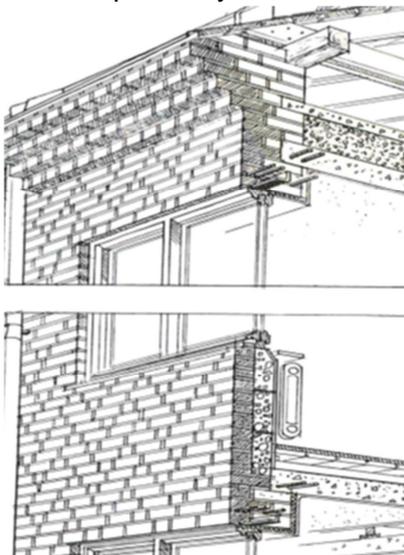
The houses of this type began in the late 1940s. Houses bearing structure was made lightweight concrete blocks and brick walls. The roof structure was as Swedish roof truss with rafters and tie beams allowing interior of the attic space. The floor was made of concrete with a thickness of 160 mm. The exterior walls was made of lightweight concrete with a thickness of 250-300 mm.

Tower blocks 8-9 stories

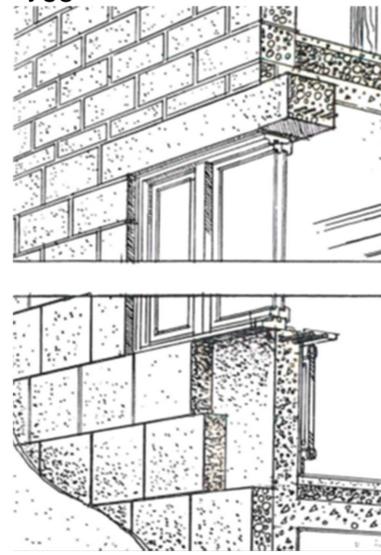
During the 1950-60's were tower blocks of 8-9 floors of the most commonly used building type for the growing suburbs of the larger cities. Many different construction techniques was tested during this time and there are therefore many individual solutions. The house was built almost entirely of cast in place concrete structures. Plaster on lightweight concrete was often used as façade surface. The roof structure was made of rafter with posts with a center-distance of 1200 mm. The posts of the trusses rest on the concrete slab.



Example of layout. Picture from the book "Så byggdes husen 1880-2000"



Example of the structural design. Walls made of bricks. Picture from the book "Så byggdes husen 1880-2000"



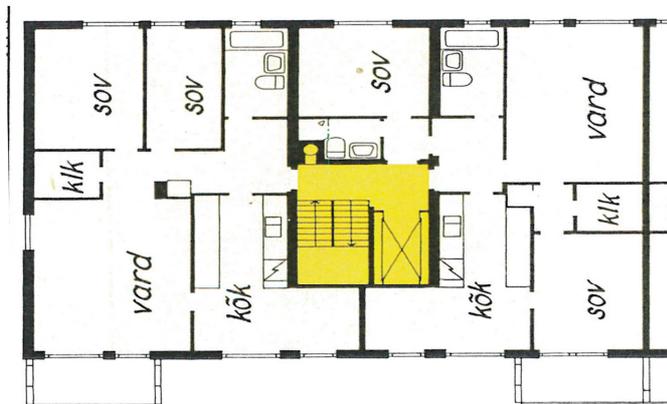
Example of the structural design. Wall made with lightweight concrete. Picture from the book "Så byggdes husen 1880-2000"

Figure 5 Tower blocks 8-9 stories

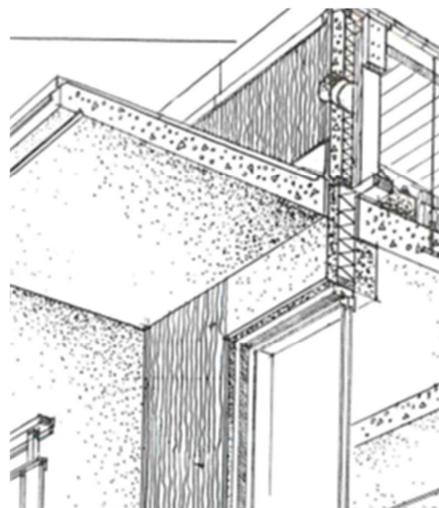
Buildings with precast concrete elements

During the 1950s, the technology of using prefabricated concrete elements was developed/introduced but the technology had no direct impact until late 1960s. Layout of the houses was divided so that each stairway serviced 2-3 apartments per floor. The houses were often built with load-bearing floor-slabs, apartment separating walls, columns, facades made of concrete elements and manufactured in a factory. The facade elements was made are of the sandwich type with two concrete slabs with insulation.

There were also semi-industrialized production methods where the walls panels were prefabricated in a temporary factory and the floor slabs are cast in situ.



Example of layout. Picture from the book "Så byggdes husen 1880-2000"



Example of the structural design. Picture from the book "Så byggdes husen 1880-2000"

Figure 6 Buildings with precast concrete elements

3.1.2.1 Building systems

Heating systems:

Multifamily buildings constructed between 1955 to 1970 have all central heating systems. In apartment buildings dominate the district heating, 64% of the buildings have district heating. During the last 10-15 years there has been an increased use of heat pumps even for multifamily-houses as the main heating source.

Ventilation systems:

In multi-family houses are mechanical ventilation frequently most common. In older apartment buildings is still natural ventilation used in many buildings. In multifamily houses -dwelling

buildings dominates mechanical waste air systems, F-systems, until 1986. After 1986 mechanical waste and fresh air systems, FT-systems, become more frequently used.

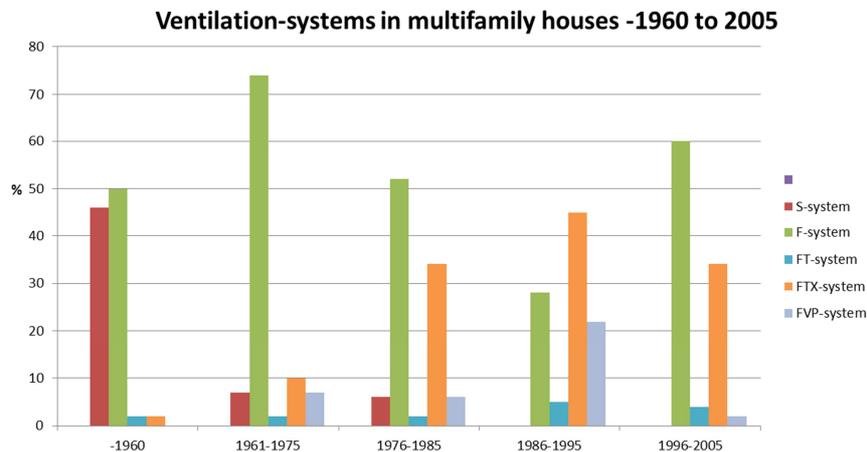


Figure 7. Ventilation systems in multifamily houses

Source: BETSI- project

- S-system: Natural ventilation
- F-system: Mechanical ventilation, outgoing air
- FT- system: Mechanical ventilation, outgoing and incoming air
- FTX-system: Mechanical ventilation heat recovery, air exchanger
- FVP-system: Mechanical ventilation heat recovery by heat pump

3.1.3 Energy efficiency standards

The average apartment in Sweden is built in 1959 and consists of basement and three floors above ground. The façade is in brick or plaster and has gable roof with concrete roof tiles. The heated area, A_{temp} , is 1426 m² and the exterior walls U-Value is 0.411 W / (m² K). The house has 14,6 apartments and the live an average of 1.7 people in each apartment /4/.

Figure 8 shows an average U-value of external walls of apartment buildings. Outer walls U value has improvements in apartment buildings up to the period 1986-1995. In the older buildings in order to achieve an equally low U-values as the buildings from 1995 it is needed additional insulation equivalent to 190 mm mineral wool on average.

The average U-value for windows from 1961 to 2005 have changes from 2,3 W/m²K to 1,9 W/m²K.

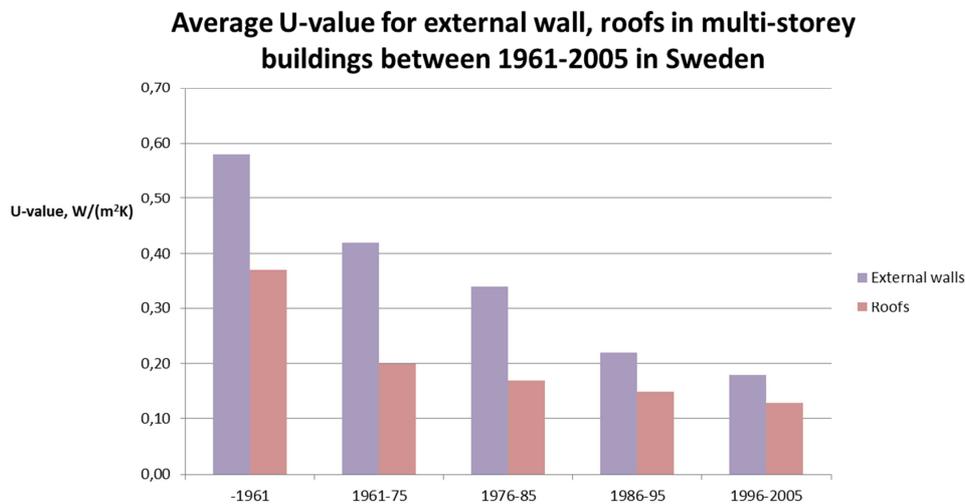


Figure 8 Average U-value, external walls and roofs between 1961-2005. [Source: Boverket BETSI-project]

3.1.4 Type of ownership/residents

Of the apartments in multifamily-houses, 40 % of the apartments is owned by tenants or own by house associations, 29% of the apartments is owned by cities and municipalities and 19% is owned by private companies.

3.1.5 Refurbishment market

Most interesting houses for refurbishment is probably houses from 1955-1970 because they are 40-50 years old and there are many of this type. These types of high-rise houses came from a special period of building development in Sweden known as the "Million Program" wherein the Swedish state decided to build 1 000 000 new dwellings in the 10 years between 1965 and 1974.

During million program there was built a total of around 920,000 apartments in multifamily houses, around 830,000 of these is current residential property according to Industry Facts 2008. Approximately 390,000 of these apartments are owned by municipal housing companies, while the remaining apartments are privately owned or owned by housing associations. Of the municipal housing company apartments from million program, around 20-30 percent have been renovated, which means that just over 300,000 flats of the municipal portfolio remains to be renovated. (Mattsson-Linnala, 2009).

In Sweden as in every European country, the status of the existing building stock is coming increasingly under scrutiny. There are two principal reasons for this, the first being the fact that a disproportionally large number of buildings were built in the post WW2 period, with as much as half of the building stock for housing and somewhat less of other buildings built between 1950 and 1980 in most central and North European countries /1,2,3/. These buildings are now 30-60 years old and many parts of the buildings need to be replaced or refurbished, especially the building envelopes and the building services systems such as HVAC, water and sewage, whereas the building structures are generally sound /4/.



Possibilities to refurbishment

In the BETSI project “Swedish National Board of Housing, Building and Planning” asked some antiquarians to study the material that had been reported from a number of buildings within BETSI to assess the opportunities for adding insulation and change the façades. The conclusion is that such action is in many cases difficult to implement without spoiling the building's heritage values. It was possible in 41 % of the studied buildings and “maybe” in additional 28% of the buildings.

3.1.6 Conclusion

The most suitable target houses for BERTIM project in Sweden could be the houses built in the period from 1955 to 1970. The most common characteristics in this type of buildings will be the following:

- Average U-value of external walls range from 0.4 to 0.6 W/m²K in this period while the new buildings have U-values less than 0.2 W/m²K.
- Buildings with mechanical ventilation included only outgoing air.
- Central heating systems, and no cooling

3.2 Building characteristics in Germany

3.2.1 Building typologies

In Germany, age classes play an important role when determining the value, specifications and standards embodied in buildings. Following building age classes are distinguished (Loga, 2012) as shown in Table 1.

Table 1. Building age classes in Germany

Class	Time phase	Main characteristic
A	before 1859	studwork houses
B	1860 - 1918	Wilhelminian style buildings
C	1919 - 1948	Industrialisation of building component production
D	1949 - 1957	Low quality post war buildings
E	1958 - 1968	Large scale developments
F	1969 - 1978	Industrialised construction
G	1979 - 1983	Heat Insulation Ordinance No. 1
H	1984 - 1994	Heat Insulation Ordinance No. 2
I	1995 - 2001	Heat Insulation Ordinance No. 3
J	2002 - 2009	EnEV 2002
K	2010 - 2015	EnEV 2009
L	2016 -	EnEV 2015

In particular, Loga (2015) showed that residential buildings belonging to the age classes D (up to 300 kWh/m², a primary energy consumption) and F (about 250 kWh/m², a primary energy consumption) that have not yet been renovated are of low quality concerning their energy performance, due to the low quality of building materials (in case of class D) and the experimental and industrialised building methods used at that time (in case of class F). Even after refurbishment, buildings of these age classes remain usually slightly below the performance optimum of similarly renovated buildings of other age classes (see Figure 9). Loga (2015) also showed that statistically with the size of buildings, and a rising amount of dwelling units contained in them, due to a better volume to surface ratio and a higher efficiency of centralised energy supply systems, energy consumption decreases in general.

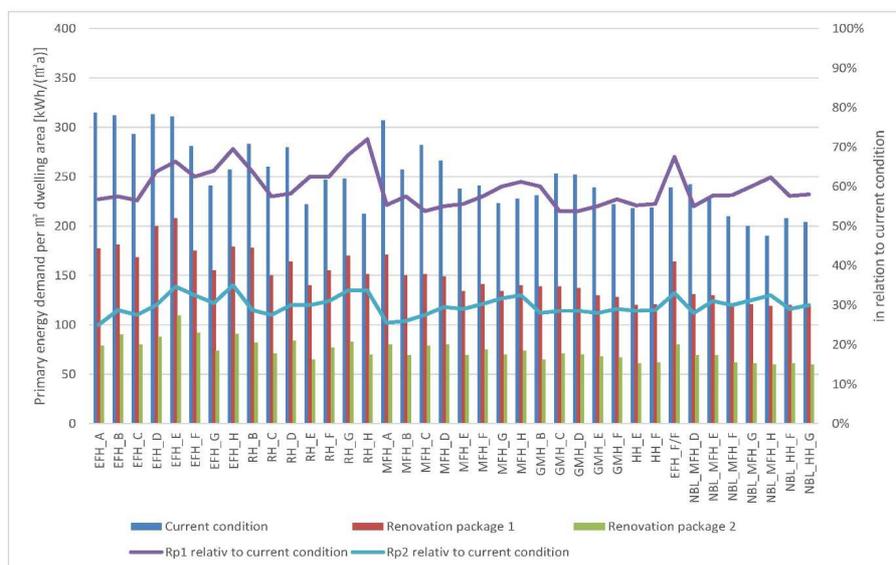


Figure 9 Primary energy consumption of building size types in different age classes (adopted from Loga, 2015)

Hoier & Ehorn (2013) represent the existing residential building stock by so-called “average typologies”. According to their statistical calculations the average single family house contains 1.24 dwelling units (this equals to 135m² dwelling area) and single family houses account for 83% of all existing buildings. The average multi-family house contains 6.83 dwelling units (this equals to 457m² dwelling area) and multi-family houses account for 17% of all buildings). In contrast, Loga (2015) identifies five building size typologies:

1. Single-family houses (1-2 dwelling units)
2. Terraced houses (1-2 dwelling units)
3. Multi-family houses (3-12 dwelling units)
4. Large multi-family houses (12-64 dwelling units)
5. High-rise buildings (over 64 dwelling units)

Loga sets these five building size typologies in relation to the previously defined age classes and thus systematically identifies a multitude of building typology categories as shown in Table 2.. These categories were then specified in more detail regarding performance indicators as frequency of occurrence and energy efficiency (e.g., primary energy consumption).

Table 2. Building typology categories in Germany (adopted from Loga, 2012; Loga, 2015; Episcopo, 2015)

Age Class				Single Family Houses	Terraced Houses	Multi-family Buildings	Large Multi-family Buildings	High-rise Buildings
				Basis-Type				
A	...	1859		X		X		
B		1860...1918		X	X	X	X	
C		1919...1948		X	X	X	X	
D		1949...1957		X	X	X	X	
E		1958...1968		X	X	X	X	X
F		1969...1978		X	X	X	X	X
G		1979...1983		X	X	X		
H		1984...1994		X	X	X		
I		1995...2001		X	X	X		
J		2002...2009		X	X	X		
K		2010...2015		X	X	X		
L		2016...		X	X	X		
Special Cases	F/F	1969...1978	Prefab	X				
	FEG_D	1946...1960	FEG ¹			X		
	FEG_E	1961...1969				X		
	FEG_F	1970...1980					X	X
	FEG_G	1981...1985					X	X
	FEG_H	1986...1990					X	

On this categorisation the overall amount of residential buildings in certain building typology categories and the resulting dwelling areas were determined as shown in Table 3.

¹Industrialised Housing Construction in *Former Eastern Germany (FEG)*

Table 3. Occurrence amount of residential buildings in certain building typology categories (adopted from Loga, 2015)

Analysis of building and dwelling count done in 2011 Cut-off date: 09.05.2011		Age Classes										Sum	%
		Until 1860	1861-1918	1919-1948	1949-1957	1958-1968	1969-1978	1979-1983	1984-1994	1995-2001	2002-2009		
		A	B	C	D	E	F	G	H	I	J		
German residential buildings stock until 2009	Single Family Houses	X	X	X	X	X	X	X	X	X	X		
	Number of res. buildings in 1,000	330	966	1,131	859	1,509	1,507	704	1,160	1,035	775	9,976	55%
	Number of dwelling units in 1,000	399	1,213	1,389	1,060	1,948	1,915	881	1,397	1,204	858	12,263	31%
	Dwelling area in million m ²	46	135	150	116	218	233	110	178	158	119	1,463	41%
	Terraced Houses		X	X	X	X	X	X	X	X	X		
	Number of res. buildings in 1,000	148	492	710	447	633	611	335	652	619	384	5,030	28%
	Number of dwelling units in 1,000	181	617	840	546	749	685	374	722	674	409	5,796	15%
	Dwelling area in million m ²	19	62	82	52	76	79	45	85	80	52	633	18%
	Multi-Family Buildings	X	X	X	X	X	X	X	X	X	X		
	Number of res. buildings in 1,000	54	442	388	356	586	412	146	309	244	85	3,023	17%
	Number of dwelling units in 1,000	214	2,177	1,911	2,003	3,348	2,313	852	1,826	1,390	461	16,495	42%
	Dwelling area in million m ²	16	163	129	125	225	169	64	133	104	39	1,168	33%
	Large Multi-Family Buildings		X	X	X	X	X	X	X				
	Number of res. buildings in 1,000	0.6	28.7	7.4	17.3	34.0	50.1	15.0	28.7	20.9	7.6	210	1%
	Number of dwelling units in 1,000	11	526	126	308	818	1,366	356	605	408	151	4,467	12%
Dwelling area in million m ²	0.7	35.8	7.9	17.0	47.1	86.7	21.9	34.8	25.5	10.4	288	8%	
Number of residential buildings in 1,000	533	1,929	2,236	1,679	2,762	2,580	1,200	2,150	1,919	1,251	18,239		
%	3%	11%	12%	9%	15%	14%	7%	12%	11%	7%			
Number of dwelling units in 1,000	806	4,533	4,265	3,915	6,863	6,279	2,463	4,550	3,675	1,880	39,228		
%	2%	12%	11%	10%	17%	16%	6%	12%	9%	5%			
Dwelling area in million m ²	82	396	370	309	567	569	240	431	368	220	3,552		
%	2%	11%	10%	9%	16%	16%	7%	12%	10%	6%			

Large quantities of residential multi-family buildings/dwelling units are allocated within the categories terraced houses and multifamily house. In particular, this makes these categories in

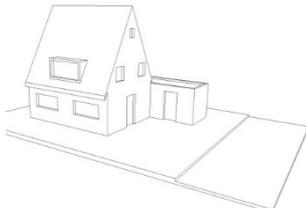
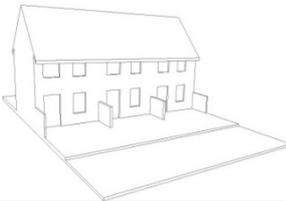
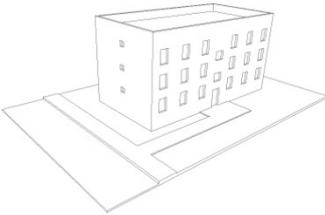
the age classes between 1861 and 2001 interesting as targets for mass manufacturing based refurbishment. Further details regarding the energy performance of buildings in certain building typology categories as well as the categorisation methods used in other EU countries are available through the TABULA project website (**TABULA, 2015**).

3.2.2 Constructive characteristics

Residential buildings can be specified in terms of the following constructive characteristics:

According to Graubner (**2014**) and DGMW (**2011**), 73% of the building stock in Germany is based on masonry structures (usually masonry walls combined with steel-reinforced concrete floors), 8% on steel-reinforced concrete (usually, steel-reinforced concrete walls combined with steel-reinforced concrete floors), 16% on wooden construction and 3% on construction with other materials. The predominance of masonry-based structures in multi-story, multi-family residential building construction can be observed throughout all age classes (from class B to class L). Although prefabricated concrete based buildings experienced some popularity in the age classes E and F (in particular, for large multi-family buildings, high-rise buildings and super-large housing estates as previously outlined), masonry-based structures dominate in all age classes. Also today masonry based construction is highly popular among the end-users (renters/dwellers) due to the ease and comfort they create (e.g. in summer, they keep buildings cool without ventilation). However, concrete based buildings has increasingly become an option for investors and contractors in the fast-growing urban areas due to “the cheap availability of concrete”, “advances in concrete engineering (reinforcement techniques, novel additives for super fast hardening, etc.)”, “the availability of advanced, labor saving tools”, “machinery allowing the fast and productive casting”, and “slip forming of concrete structures on site”.

Table 4. Predominant geometric building typologies

Category	Concept	Example
Single-family house Examples by Iturralde, Linner, br2/ TUM		
Terraced house Examples by Iturralde, Linner, br2/ TUM		
Horizontally oriented building block Examples by Iturralde, Linner, br2/ TUM		

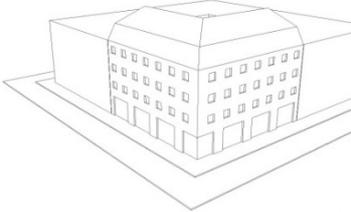
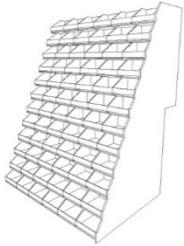
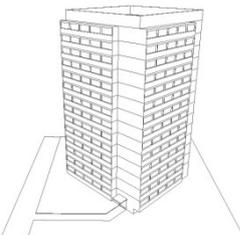
Category	Concept	Example
<p>City building block Examples by Iturralde, Linner, br2/ TUM</p>		
<p>Buildings with terraces Examples by Iturralde, Linner, br2/ TUM</p>		
<p>High rise building Examples by Iturralde, Linner, br2/ TUM</p>		

Table 5. Predominant geometric building typologies

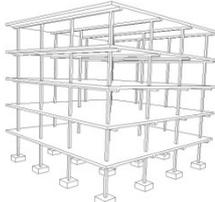
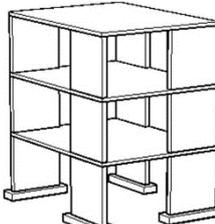
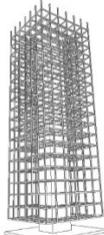
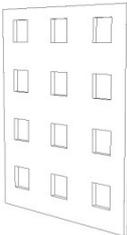
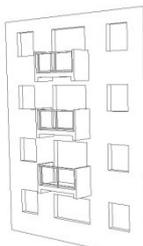
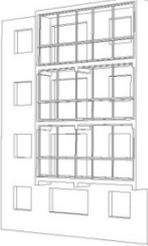
Category	Concept	Main building material
<p>Skeleton-based construction</p> <p>Examples by Iturralde, br2/ TUM</p>		Concrete
<p>Shear wall construction</p> <p>Examples by Iturralde, br2/ TUM</p>		Masonry or concrete
<p>Central core construction (usually high rise buildings)</p> <p>Examples by Iturralde, br2/ TUM</p>		Steel/ concrete

Table 6. Predominant geometric building typologies

Category	Concept	Main building material
<p>Perforated facade</p> <p>Examples by Iturralde, Linner, br2/ TUM</p>		
<p>Faced with balconies</p> <p>Examples by Iturralde, Linner, br2/ TUM</p>		

Category	Concept	Main building material
Facade with loggias Examples by Iturralde, Linner, br2/ TUM		
Façade with access balconies Examples by Iturralde, Linner, br2/ TUM		
Facade with movable/foldable panels Examples by Iturralde, Linner, br2/ TUM		

In Germany, the prefabrication of wooden panels is predominantly practiced in the construction of new single-family houses, semi-detached houses and terraced houses by specialised prefabrication companies. Prefabricated houses have a share of 15-20 percent (depending on the region) in the German housing market. The majority of prefabricated buildings constitute wooden panelised buildings. Key players in the market are Weber House, Kampa House, Bien-Zenker, Huf Haus and Baufritz. Sales volume of each company is in the range of 300-1000 houses per year.

3.2.3 Energy efficiency standards:

In Germany, building standards are used for both classifying newly constructed and renovated buildings. The majority of renovation activities currently focuses on achieving energy standards between KfW 55 and KfW 115. Up to date, only a minority of renovation activities targets at “Passive House” or even “Active House” standards. However, with strengthened standards applicable for newly constructed buildings, the expectations for energy saving achieved through renovation rise. It can be expected that after the year 2020 standards



such as “*Active House*”, “*Efficiency Building Plus*”, “*Zero Energy Buildings*” and “*Passive House*” will be applied, which has to be achieved through renovation as well.

As a combination of information from **Hegger et al.(2013)** and **KfW (2015)** the efficiency standards relevant in Germany and their specifications are outlined in Table 7.

Table 7. Comparison of energy efficiency related building standards in Germany

Efficiency Standard	Primary energy requirements (kWh/m ² a)	Scope	Loan/Subsidiaries		Technical requirements
			new building	refurbishment	
Active House	< 0	Heating, cooling, auxiliary energy, drinking water, lighting, production of the building (grey energy), maintenance and repair, cleaning, disassembly.	Subsidy by Federal Ministry of Transport and Digital Infrastructure: up to 70.000 € for planning; Insulation and regenerative/innovative energy generation technology is subsidised with 300€/m ²		as below + building can actively generate energy
Efficiency Building Plus	< 0	Heating, cooling, auxiliary energy, drinking water, lighting, household appliances	Subsidy by Federal Ministry of Transport and Digital Infrastructure: up to 70.000 € for planning; Insulation and regenerative/innovative energy generation technology is subsidised with 300€/m ² ; additionally KfW support possible		as below + building can actively generate energy
Zero Energy Building	about 0	Heating, cooling, auxiliary energy, drinking water	Subsidy by Federal Ministry of Transport and Digital Infrastructure: up to 70.000 € for planning; Insulation and regenerative/innovative energy generation technology is subsidised with 300€/m ² ; additionally KfW support possible		as below + in this case no heating system would be required
Passive House	< 25	Heating, cooling, auxiliary energy, drinking water, lighting, household appliances	Subsidy by Federal Ministry of Transport and Digital Infrastructure: up to 70.000 € for planning; Insulation and regenerative /innovative energy generation technology is subsidised with 300€/m ² ; additionally KfW support possible		Basic: (1) building should be air tight; (2) consequent use of regenerative energy; (3) air conditioning with regenerative heat recovery; (4) wood pellets heating, biomass heating or heat pump; (5) solar plant for heating drinking water; (6) exterior wall insulation; (7) roof insulation; (8) windows with triple glazing and highly insulated frame
Efficiency Building KfW 40	30	Heating, cooling, auxiliary energy, drinking water	max. 50.000 € per accommodation unit/acquittance subsidy: 10%	same as KfW 55	Basic: (1) building should be air tight; (2) consequent use of re-generative energy; (3) air conditioning with regenerative heat recovery; (4) wood pellets heating, biomass heating or heat pump; (5) solar plant for heating drinking water; (6) exterior wall insulation; (7) roof insulation; (8) windows with triple glazing and highly insulated frame



Efficiency Standard	Primary energy requirements (kWh/m ² a)	Scope	Loan/Subsidiaries		Technical requirements
			new building	refurbishment	
Efficiency Building KfW 55	40		max. 50.000 € per accommodation unit/acquittance subsidy: 5%	max. 75.000 € per accommodation unit/acquittance subsidy: 12,5% + capital investment grant: 17,5% of the energy related capital investment (max. 13.125 € per accommodation unit)	Basic: (1) air conditioning with regenerative heat recovery; (2) wood pellets heating, biomass heating or heat pump; (3) solar plant for heating drinking water; (4) exterior wall insulation; (5) roof insulation; (6) windows with triple glazing and highly insulated frame. Recommended: (1) floor and wall heating, (2) very thick insulation; triple glazing(insulation also of doors; (3) sun oriented orientation of the building
Efficiency Building KfW 70	50		max. 50.000 € per accommodation unit/acquittance subsidy: -	max. 75.000 € per accommodation unit/acquittance subsidy: 10,0% + capital investment grant: 15% of the energy related capital investment (max. 11.250 € per accommodation unit)	Basic: (1) air conditioning with regenerative heat recovery; (2) heating with a gas condensation boiler; (3) solar plant for heating of drinking water and heating support; (4) exterior wall insulation; (5) roof insulation; (6) windows with double glazing. Recommended: if heated with wood pallets regenerative heat recovery for the aeration system might not be needed.
Efficiency Building KfW 85	60		none	max. 75.000 € per accommodation unit/acquittance subsidy: 7,5% + capital investment grant: 12,5% of the energy related capital investment (max. 9.375 € per accommodation unit)	Basic: (1) air conditioning with regenerative heat recovery (recommended); (2) heating with a gas condensation boiler; (3) solar plant for heating of drinking water and heating support; (4) exterior wall insulation; (5) roof insulation; (6) windows with double glazing. Recommended: if heated with wood pallets regenerative heat recovery for the aeration system might not be needed; (1) if existing walls are thick enough new insulation layers might not be required.
Efficiency Building KfW 100	70		none	max. 75.000 € per accommodation unit/acquittance subsidy: 5% + capital investment grant: 12,5% of the energy related capital investment (max. 7.500 € per accommodation unit)	Basic: (1) heating with oil or gas condensation and solar plant for heating of drinking water (2) exterior wall insulation; (3) roof insulation; (4) windows with double glazing. Recommended: if heated with wood pallets regenerative heat recovery for the aeration system might not be needed; (1) if existing walls are thick enough new insulation layers



Efficiency Standard	Primary energy requirements (kWh/m ² a)	Scope	Loan/Subsidiaries		Technical requirements
			new building	refurbishment	
					might not be required.
Efficiency Building KfW 115	80		none	max. 75.000 € per accommodation unit/ acquittance subsidy: 5% + capital investment grant: 12,5% of the energy related capital investment (max. 7.500 € per accommodation unit)	Basic: (1) heating with an oil or gas condensation and solar plant for heating of drinking water (2) exterior wall insulation; (3) roof insulation; (4) windows with double glazing

Hegger et al. (2013) outline that standards can be expected to go beyond the sole view on the building's operational performance and consider more and more buildings complete life cycles (e.g., grey energy embedded in the components) as well as additional life areas (e.g., food, mobility, etc.) in the future. In this context, the German seal of quality issued by the DGNB(2015) to individual buildings upon request was introduced in 2008. It allows a holistic assessment and certification of a building's sustainability by 50 performance indicators (indicator categories: ecologic quality, economic quality, socio-cultural and functional quality, technical quality, process quality, quality of implementation related to location of the building).

3.2.4 Type of ownership/residents

The home ownership rate in Germany is about 53% (Eurostat/LBS Research), which is relatively low compared to Spain (83%), Sweden (71%), and France (62%). Moreover, the people living in social housing units with low rents account for about 18% in Scandinavian countries, 15% in France, and currently only 7% (Eurostat/LBS Research) of the population in Germany. In many German cities and metropolitan regions, the home ownership rate is below 53% (in average 20-30%), whereas in rural areas it is usually above 50%. Moreover, a study done by the Bayern LB (2009) showed that the ratio of owner-occupied residential multi-family buildings in Germany is highly dependent on the age class and increases steadily since 1918: B: 10%, C: 5%, D: 13 %, E: 15 %, F: 18 %, G: 25 %, H: 20%, I: 25 %, and J: 35%. From this data, it can be concluded that the potential target group of buildings (larger housing estates where mass-manufacturing techniques can be applied) for this project will have a relatively low ratio of owner-occupied dwelling units.

In this context, it has to be considered that laws and regulations tend to become more and more favourable for renters in order to protect them from severe financial burdens due to renovation as well as a disturbance to their living environment. In any case of a refurbishment of the building in which they live, the renters have the right to terminate the renting contract prior to the time the refurbishment starts. This might lead to considerable losses on the owner/investor side. Furthermore, the increase of monthly rents as well as the amount of the



cost of the refurbishment that can be passed on to the renters is limited by the federal law. Furthermore, it is common owners have to lower the renting fee during refurbishment (due to disturbances of the functionality of the building caused by the refurbishment activities) or the renter is transferred to a hotel paid by the owner during the period where heavy refurbishment work has to be performed. Thus from an economic and legal perspective, a fast, free of disturbance and well-scheduled refurbishment process is a must in order to minimise losses and claims by the renters against the owner/owners.

In terms of ownership structure, a multi-family residential building can be owned by

1. One entity (in most cases a private or governmental housing company) or
2. Multiple entities (e.g. the owners of the individual dwelling units within the building).

In case multiple entities own the individual dwelling units of a residential building, the common areas of the building (basement, functional rooms, etc.) as well as the financial obligations (running cost of the building, etc.) are split proportionally and the part of the total building owned by an individual is notarially certified. With the purchase of a dwelling unit, owners automatically belong to the so-called “home owner community” of the building (**WEG, 2002**). In that context, each owner transfers a certain amount to a joint account (usually as monthly fee per owned m²) to build up a common budget (called also “reserve fund”). The accumulated budget is used to repair, maintain or renovate the jointly owned building. The members of the homeowner community can (through a majority vote) jointly take decisions regarding refurbishment activities. The amount needed for a particular refurbishment project that exceeds the money available through the reserve fund can be provided by the individual home-owners (in proportion to their ownership) or alternatively the home owner community can jointly take out a loan.

3.2.5 Refurbishment market

Refurbishment measures related to energy efficiency are related to not only the refurbishment of a single building but the refurbishment of whole settlements, quarters, large housing estates, villages or cities (**Habermann-Nieße, 2014; Wick, 2014**). The size of settlements can be utilised and the installation of, for example, centralised energy systems that supply the whole settlement with energy based on renewable-energy sources (e.g., wood pellets, methane, etc.) can guarantee high-energy efficiency or even complete autarky as in case with the German “bio-energy villages” (<http://www.bioenergie-doerfer.de/>) in rural areas. Also in cities, large settlements or complete urban quarters (in some cases even belonging to a single private or governmental housing company) are increasingly the subject of large-scale refurbishment (see for example “Märkisches Viertel” in Berlin; **Berlin, 2014**).

A large quantity of large housing estates with usually more than 2.500 dwelling units (in some cases even beyond 15.000 dwelling units as in case of “Märkisches Viertel” in Berlin, “Neuperlach” in Munich, or the large housing estates in Erfurt) were built between 1950 and 1980. Today these large housing estates provide 4 million dwelling units for more than 8 million people and account for 20% percent of the German residential renting market (**WI21, 2015**). Such large housing estates have to be improved not only in terms of energy performance but also regarding floor plans, design, public areas, linking to public transport and road infrastructure, and the urban open space around the buildings. The study “*Perspectives*

for large housing estates” (KG ev., 2015) estimates that about €90 billion investment would be needed in the next decades to update large housing estates and stresses that, in particular, industrialised methods of refurbishment and prefabrication can be considered practical due to the so called “serialised character” of most of those estates. Many of those large housing estates are based on horizontally and/or vertically repetitive structures built from concrete or concrete based prefabricated panels.



Munich-Neuperlach



Munich-Olympia Zentrum

Figure 10 Representative examples large housing estates in Germany. [Examples: Linner, br2/ TUM]

The study “Energy performance focused refurbishment of large housing estates” (BBSR, 2015) examined eight pilot refurbishment projects targeting large housing estates (the estates examined had each between 700 and 15.000 dwelling units and were distributed all over Germany) and showed that usually about a quarter of the cost of refurbishment of such large housing estates is spent on energy performance related measures where the energy-efficiency standards aimed at are usually KfW 85 or KfW 100. Furthermore, it was shown that in many cases due to the public relevance of such projects (in this case, refurbishment impacts whole cities or urban quarters and their profile) the owners/investors profit besides KfW funding from further local state or city funds.

3.2.5.1 Location of potential refurbishment areas/buildings (city vs. rural side)

According to Statista (2015) the ratio of people living in cities in Germany will increase from 75.6 % in 2015 to 78.3% in 2030. A more detailed overview is given by the *Federal Institute for Research on Buildings, Urban Affairs and Spatial Development* showing that currently 28.7% of the population lives in large cities (cities beyond 100.000 inhabitants), 39.5 in urbanised areas around those large cities (density above 150 inhabitants/km²), 17.1 % in rural areas around those large cities (density above 100 inhabitants/km²), and 14.6 % in sparsely populated rural areas (BBSR, 2012).

In the next decades, the expected decrease of the population in Germany will lead to an increase of the amount of vacant dwelling units. Already today the vacancy rate (percentage of non-occupied buildings in relation to the total building stock) in industrially weak areas equals to 13-15% (e.g. in Saxony and Saxony-Anhalt it equals to about 15%; the German average equals to 8.6% according to DESTATIS, 2010). In terms of refurbishment strategies, it has to be considered that even in larger cities in structurally weak regions, a shrinkage of the building stock will be necessary. Refurbishment in those regions must ensure that the existing building

stock can be made attractive enough to allow it to compete for the remaining inhabitants and/or to attract new inhabitants and thus to stay economically viable. At the same time, rents in those areas have to remain affordable in order to be socially sustainable which prevents overly costly refurbishment.

A completely different situation can be observed in a few growing metropolitan regions in Germany (high rent regions as Munich, Hamburg, Frankfurt, and Stuttgart) where the demand for dwellings is and will during the next decades remain higher than the supply with dwellings. On the one hand, refurbishment activities must ensure that additional living space can be created in those regions. Furthermore, it is due to the acceptance of high rents and higher margins that can be achieved, more attractive for investors to invest in renovation and building upgrades in urban areas. According to the *Institut der Deutschen Wirtschaft Köln (2015)* the migration of people from urban regions and cities to these metropolitan regions will be increased further by the rapidly ageing society in Germany because elderly people value the excellent supply with goods, public transport, and health care services in those regions.

3.2.6 Conclusion

It can be concluded that the age class plays an important role when the future target groups for Germany should be determined. Hoier & Ehorn (2013) showed that for various scenarios, a simplified assumption can be made regarding the relation of age classes and individual 10-year time periods between 2010 and 2015. Table 8 shows that (considering the fact that BERTIM results can be fully exploited not before 2020) the age classes F to I and thus residential buildings built between 1969 and 2001 shall be considered as relevant for the German case.

Table 8. Expected numbers of residential multi-family buildings that will be renovated within certain age classes in specific 10-year time periods between 2010 and 2020 (adopted from Hoier & Ehorn, 2013)

	period of time	2010-2020	2021-2030	2031-2040	2041-2050	2010-2050	sum
	Period in years	11	10	10	10	41	
Class	B (1961-1918)	4.104	2.037	1.722	1.287	2.332	95.597
	C (1919-1948)	1.086	5.182	4.446	2.831	3.330	136.540
	D (1949-1957)	0	0	0	18.546	4.523	185.462
	E (1958-1968)	30.328	0	0	0	8.137	333.603
	F (1969-1978)	5.094	21.634	0	0	6.643	272.375
	G (1979-1983)	0	9.393	14.074	0	5.724	234.671
	H (1984-1994)	0	0	22.114	12.605	8.468	347.193
	I (1995-2001)	0	0	0	22.201	5.415	222.013
	J (2002-2009)	0	0	0	0	0	0
	sum	40.612	38.246	42.356	57.470	44.572	1.827.453



Furthermore, it can be concluded that

- The majority of the multi-family houses in need of refurbishment will be terraced houses (1-2 dwelling units), multi-family houses (3-12 dwelling units), and large multi-family houses (12-64 dwelling units).
- The average multi-family house has about 7 dwelling units.
- Over 73% of multi-family buildings are masonry construction.
- Of particular relevance in Germany are large housing estates with more than 2,500 dwelling units, which account for 20 percent of the rental housing market.
- Large housing estates are predestined for industrialised refurbishment due to their “serialised character”.
- Only less than 30% of multi-family residential dwelling units are owner-occupied.
- The majority of residential building refurbishment projects targets at between KfW 100 to KfW 55 standards (higher standard is considered as economically not feasible).
- In high rent regions such as Munich, Hamburg, and Frankfurt refurbishment should be combined with creating new living space and barrier-free buildings and dwellings.
- German Government funding agencies recommend (and fund these activities) to combine energy related refurbishment with refurbishment activities that create barrier free buildings.
- A majority of buildings is based on shear walls and perforated facades.

3.3 Building characteristics in France

3.3.1 Building typologies

For the central Europe architectural classification, 5 time periods were found from 1850 to 1974.

Period 1: 1850 to 1914:

This period is characterized by increase of rural migration for working in town. This situation leads to a lack of housing in urban neighbourhoods. Awareness about the unhealthy living conditions of the workers (industrial revolution period) lead State to make laws for healthy housing. Also, they allow building or expanding taller buildings up to 20m.

In 1894 appear the first private organizations that manage low-cost and social housing. Most of walls are made by local stones masonry. Since 1895, buildings were made by manufactured materials: concrete, cement, steel, brick and tiles.



Figure 11 Haussmannien: ca 1860. Faubourien: ca 1888 Post-Haussmannien: ca 1901

Period 2: 1918 to 1939

During this period (between 2 wars), facades are linear and buildings constitute block of houses detached from the existing city. The most used design system is concrete columns and beams, filled by masonry walls.



Figure 12. Low cost housing 1925, 1934 and 1934

Period 3: 1944 to 1953

This period is characterized by generalization of concrete structure (column and beam) and filled by masonry and improvement of manufacturing phase: prefabricated elements: bays, slabs, timber floor board, metal formwork.



Figure 13. Rationalism: ca 1953 and Modern Classicism: ca 1953

Period 4: 1954 to 1966

During this period, Industrialization of construction runs with high speed in order to solve housing lack crisis. Large constructions are built in suburban areas. Most of buildings are made of concrete: slab and wall system overtakes column and beam system. Slab and wall system allows using sliding formwork and tunnel.



Figure 14. Social housing: 1959-1960

Period 5: 1967 to 1974

Consequences of the last urban planning (with large buildings and social housings) were disapproved because of social relations, lack of equipment and uniformity of design. Then, innovative construction came out with diversification of design and function. Concrete is still the major of material used for building and building was industrialized. Large and tall buildings are forbidden in little and medium city areas. Buildings design presents new elements: cavity, loggias and balconies.



Figure 15. Tower: 1971 and Tall building 1969

3.3.2 Constructive characteristics

3.3.2.1 Building envelop

Façade types

Six façade types are defined from RECOLCI French national project and TABULA European project.

- Façades F0 are flat and do not include any balcony. Possible variants are presence of horizontal bands marking the boundary between stages, or presence of small flaps or chassis.

- Façades F1 are flat and have windows with flowing supports and have no balcony. Possible variants are presence of guardrails for windows/doors, presence of horizontal bands marking boundary between stages, presence of bands framing the bays.



Figure 16. Type F0 and F1 facades.

- Façade F2 types are flat and have windows, doors and balconies. Possible variants are extension of balconies for two or three doors or, F1 with balconies.



Figure 17. Type F2 facades.

- Façade F3 are similar to F2. Number of doors is more important than with F2 type.



Figure 18. Type F3 facades.

- Façade F4 types are characterised by horizontal projection of intermediate floors and grooving (vertical projection). Possible variants are: horizontal projection only or vertical projection only, or thickness of projections.



Figure 19. Type F4 facades.

- The façade F5 types balconies are of loggias characteristics. Possible variants are presence of guardrails.



Figure 20. Type F5 facades.

Facades may also be represented by combination of two or three different types.

Roofing types:

French building are covered by sloping roof or flat roofs. There are three main types of pitched roofs:

- One slope
- Two symmetrical or asymmetrical slopes
- More slopes

And also three types of flat roof:

- With balustrade (acroterium)
- With balustrade and no overhang
- No balustrade and no overhang

3.3.2.2 Building systems

Among the various types of heating the French park, the collective central heating is largely predominant, with over 70% of homes affected (more than 3.1 million), individual central heating represents 1 / 5 th house (900 000 residences). As for electric heating, it represents only 7% of homes (about 300 000 homes). The distribution of types of heating is given in following table.

Table 9. Main residences in apartment buildings 1949-1974 by type of heating and number of floors.

Units : thousands of homes (source: project RECOLCI).

		Number of floors				
Heating	Fuel	<4	4 to 8	≤8	>8	Total
Individual central	Oil	18	3	20	3	23
	Gas	367	420	786	53	839
	LPG	18	2	20	0	20
	other	12	4	17	1	18
	Total	415	429	834	56	900
Collective central	Oil	215	528	743	180	923
	Gas	309	977	1286	409	1695
	LPG	8	7	15	1	16
	heating	25	206	231	175	406
	Other	23	52	74	43	117
	Total	579	1771	2350	808	3157
Electrical		176	117	293	6	298
Another type		59	44	102	5	107
No heating		0	2	2	0	3
Total		1228	2362	3590	875	4465

3.3.3 Energy efficiency standards

The actual thermal regulation RT2012 sets rigorous performance expectations, requiring that residential and non-residential buildings use a maximum of 40-65kWh/m²/pa depending on locality and altitude of the building.

France is divided into eight climate zones: H1a, H1b, H1c, H2a, H2b, H2c, H3 and H2d.

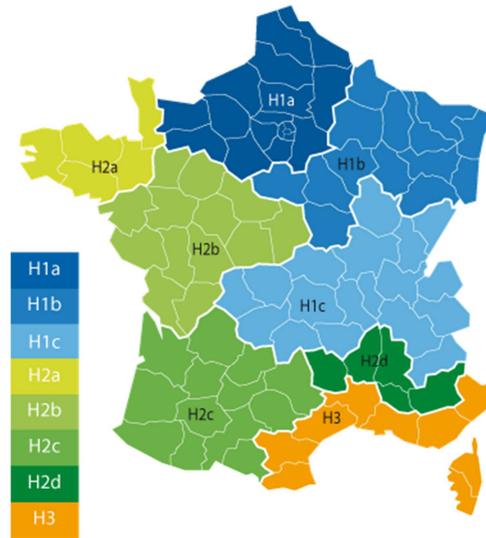


Figure 21. Metropolitan France climate zone

Thermal performance of the envelop

Typology	Uvalue (W/m ² K)	Glazing	Ventilation
F0-F1-F2	1,8 to 3,5	Simple	By sealing default or by air inlet/openning on envelop
F3-F4	2.1 to 2.9	Simple	
F5	2 to 2.9	Simple	

3.3.4 Type of ownership/residents

There are four types of ownership:

- individuals, including family members,
- public housing agencies, which include the offices, companies and the OPAC (public organism of construction)
- administrations, comprising state and local governments,

The following table shows the distribution of types of ownership. Individuals and organizations HLM (Low-rent housing) share most of the park: more than half of the homes for the former and over 40% for the latter. In addition, all owners own 80% of homes in building exceeding 8 floors.

Table 10. Main residences in apartment buildings 1949-1974 depending on the owner and the number of floors. Units: thousands of homes.

Owers	<4	4 to 8	≤8	>8	Total
Private	755	1192	1947	358	2305
Low rent house compagnies	384	1045	1429	435	1864
Other compagnies	49	93	143	62	205
Administrations	39	30	69	15	84
Associations	2	1	3	5	8
Total	1228	2362	3590	875	4465

Of the 2.3 million primary residences owned by individuals, 84% are in group of buildings (32% in buildings with less than 3floors and 52% in building with 4 to 8floors).

Of the 1.8 million primary residences owned by HLM, 77% are in group of buildings (21% in buildings with less than 3floors and 56% in building with 4 to 8floors).

3.3.5 Refurbishment market

After the end of Second World War, nearly 9 million homes that were built in France between 1949 and 1974, with production growing almost steady over this period. The year 1973 was a greatest year, with 556 000 housing units.

Since the first regulation on 1974, building envelop are insulated and energy consumptions of new residential buildings are more and more optimised. That is the reason why we choose to focus on the period between 1949 and 1974 for BERTIM solutions in France.

3.3.6 Conclusions

The focus of BERTIM should be buildngs built between 1949 and 1974.



Buildings F0-F1-F2
1949-1974
2,47millions (9,9%)



Buildings F3-F4
1949-1981
1,89 millions (7,6%)



Collective buildings F3-F4-F5 : 1949-1967
154000 (<1%)



Collective building F5
1968-1974
244000 (1%)



The most representative wall of these typologies of building

Façade type	U[W/m ² K]
Brick masonry	1,80 to 3,5
Cinderblock wall (20mm) + air (50mm) + internal brick masonry (50mm)	1,45
Concrete wall (200mm)	1, 24
Concrete blocks	1,52

Concerning roofing, representative performances are :

	U[W/m ² K]
Heavy roofs	
No isolated	0,68
Isolated	0,34
Light roofs	
Ventilated	1,94
Isolated	0,49
Pitched roof and not isolated	1,7

3.4 Building characteristics in Spain

3.4.1 Building typology

Three time period have been established for building analysis

- Until 1945 (old buildings)
- Between 1946 until 1990 (post war buildings)
- After 1991 (current and new buildings).

In the case of Spain, the Bertim project has to be focused on the building period 1946-1990 due to several reasons. Buildings previous to 1945 are considered old buildings and they could require deeper interventions than energy rehabilitation. Moreover, a significant quantity of buildings has high probability of demolition in a near future. Another fact is that they are usually involved in strategic city action plans or they constitute the cultural heritage of the city, unlike the rest of the building stock.

Buildings constructed after 1991 have minimum comfort conditions as a consequence of the existing standards in that period. Thus, energy efficient rehabilitation would not achieve so high impact in terms of energy performance improvement. Furthermore, it might become complicate to convince dwellers for an energy efficient rehabilitation when no noticeable upgrade can be obtained.

In contrast, during 1945-1991, the industrial revolution led to a huge immigration into the cities as a result of the need for laborers, and added to the high fertility rates of the period, there was a massive construction. The need for a dwelling resulted in a rapid buildings construction which was not demanding and, therefore, with low quality. Nowadays, buildings constructed between 1945-1991 are obsolete in terms of energy efficiency and living conditions. Additionally, according to Boverket (2005), the majority of the buildings in Spain, Italy, Greece and France are constructed between 1945 and 1980 (see Figure 22).

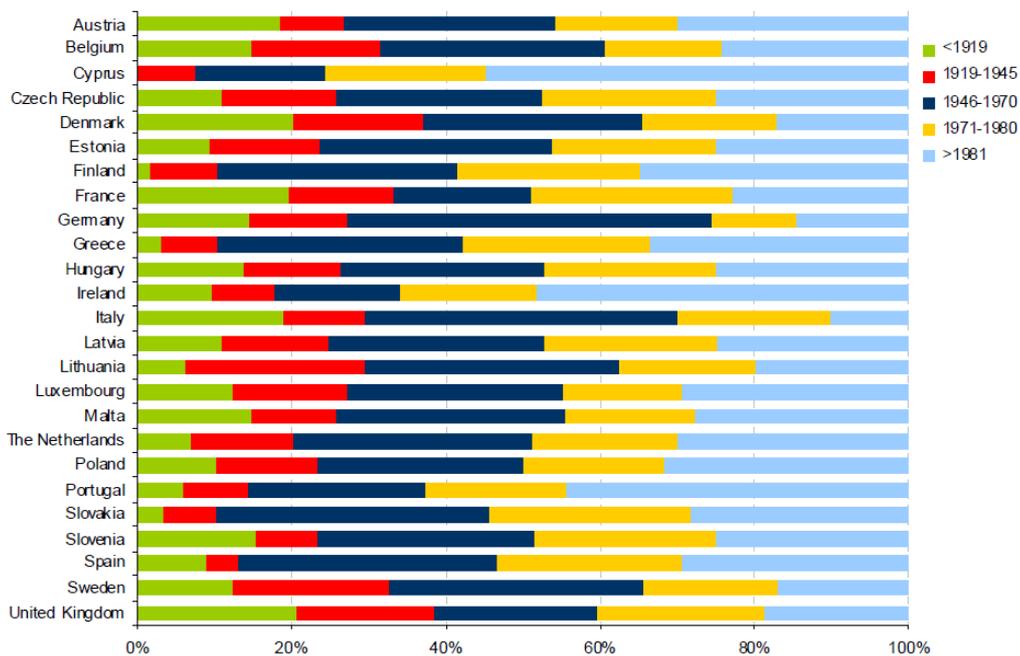


Figure 22. Age distribution of the housing stock (Boverket, 2005)

Spain had a massive construction activity between the 50s and the 80s, time of boom due to industrial development period, as said before They are all pre-normative constructions. As a consequence, all the Spanish building stock erected during this period is of poor quality and highly inefficient in terms of energy performance.

According to SECH-SPAHOUSEC (2011), 60% of the buildings were erected between 1941-1980 and 49% of the buildings erected before 1979 are multifamily blocks of houses. With regard to unifamiliar houses, a vast majority was erected in the last 30 years. The existence of standards in this period led to more strict building requirements with better determined constructive solutions and installations than multifamily buildings. Consequently, **the most representative building typology in South Europe will be characterized by the multifamily blocks constructed between 1945-1980.**

3.4.2 Building size typologies

TABULA project provide the definition of the main building typologies in Spain depending on the year of construction.

In general, according to the results of the SECH SPAHOUSEC (IDEA, 2011) project, the Spanish building stock is mainly composed of block of flats (70%) which are usually located in high density urban areas.

The height of this flat blocks is very variable, but the geometry hasn't change along the years.

	Big multifamily house	Small multifamily house (4storeys)	terrace house
- 1960	 <p>1960 typical Multifamily house > 4 storeis, compact ➡</p>	 <p>1960 typical Multifamily house <= 4 storeis, compact ➡</p>	 <p>1960 typical terrace house, compact ➡</p>
1960 - 1979	 <p>1960-1979 typical Multifamily house > 4 storeis, compact ➡</p>	 <p>1960-1979 typical Multifamily house <= 4 storeis, compact ➡</p>	 <p>1960-1979 typical terrace house, compact ➡</p>
1979 -	 <p>1979 typical Multifamily house > 4 storeis, compact ➡</p>	 <p>1979 typical Multifamily house <= 4 storeis, compact ➡</p>	 <p>1979 typical terrace house, compact ➡</p>

Figure 23. Age distribution of the housing stock (Boverket, 2005).

3.4.3 Constructive characteristics

The constructive characteristics vary depending on the region and period of construction.

Considering building structure, There are two options of structure typology for buildings built before 1965: Timber and masonry structures or reinforced concrete structures with non load bearing facades of several types (brick, cavity, concrete block). In the case of the vast majority of residential buildings built after 1965, the structure typology is reinforced concrete. Stone or brick load bearing facades are more common in older buildings, built before 1945. Unfortunately, there is no available source of information regarding use percentages for each of these facade solutions.

For building envelop, the most representative façades have been established as:

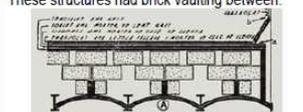
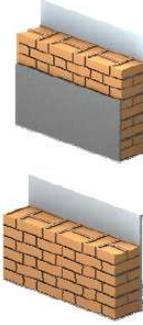
Façade type	U[W/m ² K]
Stone masonry	2,22
Brick factory	1,98
Cavity wall made of perforated or hollow bricks	1,75
Cavity wall made of perforated or hollow brick with thermal insulation in the cavity	1, 58
Concrete blocks	1,52
Precast concrete panels	0,43

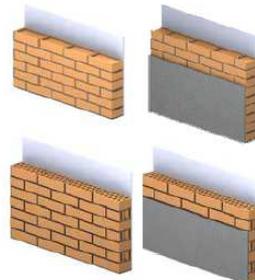
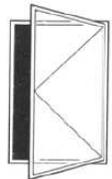
As in façades, different types of roofing are present in the Spanish buildings:

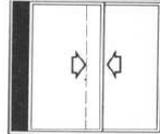
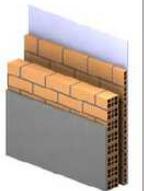
	U[W/m ² K]
Heavy roofs	
No isolated	0,68
Isolated	0,34
Ventilated with partition walls (only in the case of flat roof)	1,74
Light roofs	
Ventilated	1,94
Isolated	0,49
Pitched roof and not isolated	1,7

Between 1945 and 1980, the most common façade typology is brick factory or cavity wall made of perforated hollow bricks without insulation. The typical roof typology is pitched roof without insulation. And finally, windows are built of aluminium or timber frame, both with single glass

The TABULA project provides some example of the most typical building constructive characteristics depending on the year of construction.

YEA R	ROOFING		EXTERIOR WALLS		WINDOWS			
	Type	U W/m ² K	Type	U W/m ² K	Type	U _{glass} W/m ² K	U _{Frame} W/m ² K	g _±
1900	<p>In the early twentieth century the most common pitched roofs were a set of wooden trusses which supported one or more ceramic pieces layers, as support for the tiles. Often the attic space was closed with a straw ceiling covered with plaster to create a ventilated chamber.</p> 	4,17	<p>In the early twentieth century, especially in buildings of short height and in small towns, the load-bearing walls of stone are still been used, either limestone or granite.</p> 	2,63	<p>Wooden swing windows with monolithic glass.</p> 	5,7	2,2	0,80 - 0,85
	<p>In the early twentieth century, the most common solution of flat roofs were the ventilated flat roofs generated by brick partitions. This brick partitions had hollows to permit ventilation and they were leaned on metal or wood structures. These structures had brick vaulting between.</p> 	3,08	<p>Although in Europe framed structures have been introduced, in Spain, the load-bearing walls are still in use until the 1940s. The facade usually consisted in a single wall of brick of a foot or a foot and a half, either coated or uncoated. The slab was supported by the entire sheet thickness. Sometimes a thin brick wall was built as an interior skin.</p> 	2,63				

YEA R	ROOFING		EXTERIOR WALLS		WINDOWS			
	Type	U W/m ² K	Type	U W/m ² K	Type	U _{glass} W/m ² K	U _{Frame} W/m ² K	g _±
1940	<p>After the reinforced concrete framed structures proliferation, the brick partitions of the ventilated flat or pitched roofs now lean on unidirectional slabs. These slabs had mostly plaster joint infill blocks as a lightening between joists.</p> 	1,67	<p>From 1940 framed structures are begun to be used, usually of reinforced concrete, with lights of 3-4 meters. From the sixties these structures were the most common. The facade is released from its structural function, so in most cases the thickness of the facade was reduced to half a foot of solid or perforated bricks. The slabs were supported by big beams in which the factory fully rested. There was no movement joints between structural components and facades which has caused numerous cracks and fissures in the brick walls.</p> 	3,03	<p>Folding steel window with monolithic glass.</p> 	5,7	5,7	0,80 - 0,85
	<p>In the forties, the advent of lightweight concrete, allowed the introduction of an insulating body which replaced in many cases the air chambers in flat roofs. The roof becomes a single sheet multi-layer: slab, concrete slope, waterproofing and protection.</p> 	1,37						

YEAR	ROOFING		EXTERIOR WALLS		WINDOWS			
	Type	U W/m ² K	Type	U W/m ² K	Type	U glass W/m ² K	U Frame W/m ² K	g _L
1960	<p>In the sixties, coinciding with the development of waterproofing, flat roof extends to populations with a tradition of pitched roof. The ceramic joist infill blocks take greater prominence to the time the concrete ones start to enter in the market.</p> 	1,92	<p>In the sixties the framed structures grow in height and raise the lights to 4-5 m. A hollow brick inner sheet is added to the existing brick wall, leaving a cavity in the middle. With the entry into force of the Standard NBE-CT-79 thermal insulating are into the air chambers.</p> 	1,43	<p>Aluminum sliding window with monolith glass.</p> 	5,7	5,7	0,80 - 0,85
	<p>Ventilated roofs are still used frequently. NBE-CT-79 Standard entry into force in 1979 and insulation begins to be putted in the air chambers of the ventilated roofs and under the pavement of non-ventilated roofs.</p> 		<p>The cheapest alternative to perforated brick was used in the outer sheet: a half foot hole brick wall covered and painted. In many buildings, combining both options.</p> 					
1980		2,33		1,33				

3.4.3.1 Building systems

Multifamily blocks constructed between 1940 and 1965 do not have gas heating system. Sometimes, we can find electric radiators, installed recently. In the case of buildings constructed between 1965 and 1980, **electric radiators or gas heating system** are installed recently. The gas heating systems are usually common heating systems for each building block. The most recent buildings have gas systems with individual boilers in each dwelling.

Buildings located in the Center and South of Spain have individual cooling systems.

Many houses located in the Mediterranean area don't have any kind of heating systems.

There isn't any mechanical ventilation systems installed in any building typology.

3.4.4 Energy efficiency standards

The EPBD was transposed in Spain by means of three royal decrees:

One of it was the "Technical Code of Buildings (CTE). It was approved in May of 2006 and it is divided in six "basic documents": Structural security (DB-SE); Security in case of fire (DB-SI); Security of use and accessibility (DB-SUI); Salubriousness (DB-HS); Protection against noise (DB-HR); and Energy saving (DB-HE) (CTE, 2006). Two of these documents were used as important data sources in this master thesis:

The Energy savings DB-HE document establishes the required procedures and regulations for energy savings in the building sector. It sets, for instance, the required U-values and the hot water demand for the design of the installation for the different climatic zones in the Country.

3.4.5 Type of ownership/residents

According to the Central European Bank the 83% of the Spanish residents live in a house of their own ownership. This number is much higher than the average of the 60% for the whole Europe.



Moreover the 33% of the population has a mortgage to pay their houses, also far beyond from the European average.

This ratio is similar for social houses, where the most of them are also built to be sold, not for renting purposes.

3.4.6 Refurbishment market

In order to fulfill the European requirements for the reduction of the greenhouse gases emissions, all the European countries should promote the energy efficient retrofitting in their building park.

In Spain, a study carried out by CONAMA establishes that the total number of buildings to be renovated for the years 2020, 2030 and 2050 starting from the year 2012 should be :

2020	2030	2050
2.200.000	5.700.000	10.000.000

The target buildings for retrofitting are usually located in the city centre or in the surrounding areas of the cities. It is not usual to find it in the rural areas.

3.4.7 Conclusion

Main characteristics of most representative building typology in Spain for the Bertim project, Multifamily blocks/Apartment blocks constructed between 1941-1980.

The insulation levels are very low and the energy performance of the building envelope is very poor in this kind of buildings.

The heating systems are electric radiators or could be central or individual gas heating systems.

4 ANALYSIS OF THE CURRENT REFURBISHMENT PROCESSES IN EUROPE

4.1 ANALYSIS OF THE CURRENT REFURBISHMENT PROCESSES IN SWEDEN

4.1.1 Stakeholder's definition

In Sweden, the stakeholders within the renovation process can be divided in two main groups:

- Users:
 - Property owner (property manager): Responsible for the building and play an important role coming to investment decisions.
 - Tenants: End users that have an influence on energy used in the building but also have an influence on maintenance costs
- Providers:



- Design team (architects, engineers, consultants, technology provider etc.): A group of people that participate in carrying out the design work. The consultants can be hired by the property owner or by the main contractor
- Contractor and subcontractors: Normally it is used one main contractor for the work who has all the responsible for the work. The main contractor normally use sub-contractors for all the work he can't do himself, mostly HVAC, electrical-work etc.

There are no standardized procedures for interaction between the different stakeholders as the communication depends on the project set up.

Nevertheless, the different responsibilities can be established according to different forms of contracts depending on how much the client wants to influence in the design. The choice of the contract form greatly affects the architect's work, both in terms of the ability to influence as well as the working method. The following contracts can be found:

Shared construction: With a shared construction contract, the customer procures the various parts (building, plumbing, electrical construction, etc.) each one individually. The master builder has direct contracts with both the planners and the individual entrepreneurs. The contractors are side-contractors relative to each other. The client is responsible for coordination and for the planning. This type of contract requires a large collection effort from the customer.

A variation of the *shared construction* is when all normal building-contractors works are gathered in one contract. Then the master builder is called general-contractor and this person is then responsible for certain general aids such as scaffolding, sheds and other workplace arrangements. The master builder (general-contractor) can also be responsible for coordination between the (sub) contractors.

General contract / implementation contract: A general contract allows the client to perform the entire design and procures the whole contract of a general-contractor, who will be the responsible for all subcontractors. The general-contractor is responsible for the coordination of (sub) contractors.

Coordinated general construction: The master builder procures entrepreneurs as with a *shared construction*, and then in the procurement of the building contract allows the construction contractor to take over the procurement for other contractors. Side contracts will thus be sub-contractors to the construction contractor.

Overall construction: An overall construction determines the clients contracts with only one contractor that designs and carries out the building in agreement with the functional requirements, or application of the specifications provided by the purchaser. The general contractor is responsible to ensure that the building is designed according to standards and according to the functional requirements as summarized in the specifications. A project manager is usually appointed as maintaining the client's action and follow up the project during the construction period.

The risk is that the client does not fully have control over the outcome and gets a building with high operating and maintenance costs because the bidders are usually looking for the cheapest solution to any functional requirements.

Total contracts can result in a restriction of competition as they're only larger companies with sufficient financial resources whom can cope with the planning that are able to participate and compete for the overall contract.

Controlled overall construction: For the client to have more control over the work the contractor carries out a controlled overall construction is applied. The client specifies one or more parts of the contract, for example; that a particular material or a given model of lifts or windows should be used but the contractor is responsible for delivering the total function.

Sub construction: Subcontracting is performed on demand by the main contractor. The ones whom are employed are then working for the main entrepreneur, not the client (often the developer) directly. Most often, the customer must approve the subcontractors.

Negotiation construction: In this construction type the master builder only turns to one contractor that already on the drawing board is engaged to assist with the production of technical and economic assessments. As the scope of the works take shape one sets the economy in agreement between the developer and contractor. Agreements may be concluded in the form of an overall construction.

Functional construction: The client formulates their goals in functional terms. Then the contractor tries to resolve its functional requirements with technology solutions, in this way very similar to the overall construction. The difference is in the basis character and that the contractor also can stand for operation and maintenance for a period of time after the end of the project.

In the following figure a scheme of the design and work process between different stakeholders is shown:

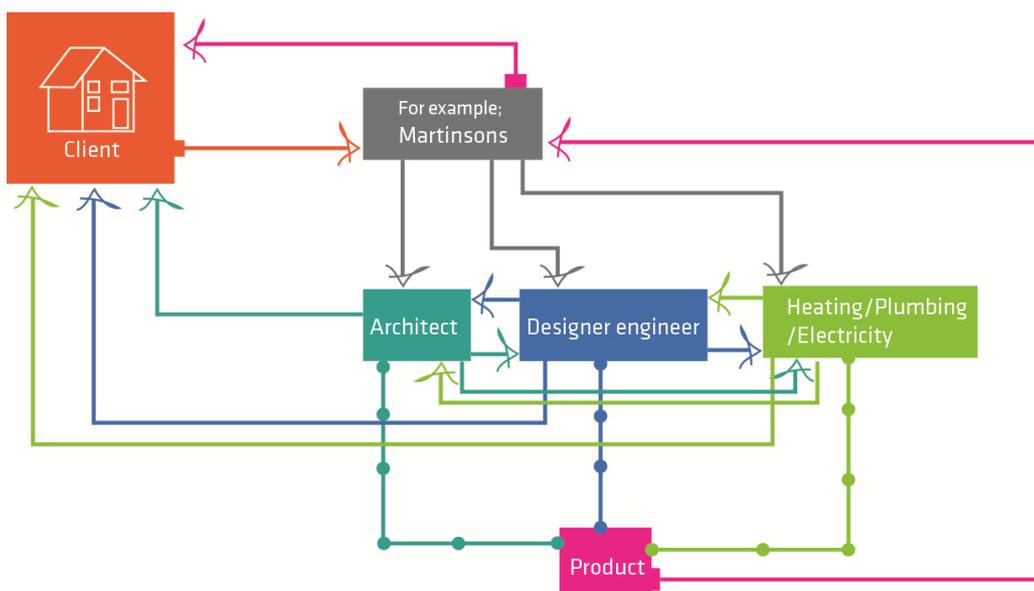


Figure 24: Scheme example on how the design process work today between different stakeholders.



The following table shows some of the information exchanges between designers, manufacturers and contractors:

Table 11. Some of the information between designers, manufacturer and contractor.

	Designer	Manufacturer	Contractor
Designer	Exchange of information between different designers.	Require: Drawings, technical information,	Require: Details as joints and order of assembly.
Manufacturer	Require: Coordinates, tolerances requirements		Require: Assembly operations and logistics information on site.
Contractor	Require: Product design and coordinates, tolerances requirements	Requires delivery and manufacturing information for planning of assembly operations	Exchange of information between main- and subcontractor

4.1.2 Current retrofitting design process:

The Swedish construction industry is well known for its conservatism. There are also a lack of competition and development in productivity within the sector which have been debated in Sweden /5/. In discussing the necessary change of the construction sector, comparisons with other industrial areas are often made, and especially the comparison with the automotive industry. Industrialisation means early involvement and taking control of the building process. One key point in industrialisation is the production of prefabricated components. Consequently, the assembly and completion work on site is minimized and comprises only a minor part of the work. In using an industrialised concept, it is important to be rigorous about keeping the product standardized, using a standardized building process and adopting a process oriented organization. This is especially difficult when you have to adopt everything to an old building and that's way most of the renovation work still is local business and construction-work on site.

The manufacturing process is part of the whole chain from “sales” to “finishing”. The manufacturing part of the total project is often relative small and the risk is also smaller comparing with work at site.



Figure 25: Example of total process including the manufacturing process

IT based systems are widely used and in some parts leading to fully integrated control of purchase, design, production and knowledge/experience feedback. Finally, it is worthwhile mentioning that the architectural design has to be adapted to the standardized building system. This does not mean applying a standardized architectural design.

4.1.2.1 Data gathering

The stakeholders that participate in the buildings rehabilitations need large information of the existing building and also about the regulations to be applied in the country where the building is located. They also need exhaustive technical information about the technologies to be applied in the building including execution specifications.

The tenants, designers and contractors require information from the construction site to complete their task. The data that should be gathered at least is the following:

- Accessibility to building-site.
- Analysis of construction in situ: drawings, plan for assembly, fixing, etc.
- Transport, logistics, temporary storing/covering.
- Type of scaffolding, crane
- Information needed for dismantling of structure of the existing envelope and assembly of new elements.
- Plan for quality control.(A checklist used through the project)
- Required building permits,

The information needed depends on the scale of the project. In most cases the first thing to settle is the level of detail to bring the project forward in accessible. It includes drawings of the structure intended of renovation as well as its surroundings. This is to make sure that the building can cope with a renovation, that the structure will hold or if it needs to be complemented in anyway. This also includes water, ventilation and to see if the renovation



creates any type of conflict with its surroundings that needs to be discussed in the decision making process.

The collection of data depends on the scope of the project but there is no clear guideline to know how essentially is to collect all the necessary information. The design team that holds the contract usually determines the necessary data for the project to be developed.

If the owner has significant data then this is given to the design team, depending on what kind of agreements that are signed.

In the municipalities there is usually at least a photocopy of current actions if not DWG drawings. This also includes the area's provisions on, for example, how many floors the building may consist of. Many municipalities are also working with GIS to store urban information that can be used as a basis in the renovation process. This is especially interesting for historical environments and buildings that have conservation value and are in the process of becoming culture marked.

When the project is running, all the information required for the process needs to be already in the project to avoid unnecessary and costly duplication of work / field work. Although it's common that information needs to be submitted as the project is running.

4.1.2.2 Design of retrofitting project

Although softwares such as BIM are making ground in Sweden, the main tool for renovation processes in the design phase is still mainly CAD. Some offices chose to work with both CAD and BIM depending on the size of the project.

Most companies work in data tools compatible with CAD, such as a DWX or DWG-file. The work is performed in a model-file drawn up by the architect and/or engineer, this file is the basis for the project and then the different consultants fill in on their fields. During the work various solutions is discussed to result in a product as good as possible under current conditions. Many companies have started to transit over to Revit, a BIM-like tool where multiple parties can work in the same model simultaneously. Everything is done in 3D so that, for example, problems with the joints or the construction can be solved more quickly.

In external communications the requested information are assigned. Is it to solve a problem or for example an addition or remodelling DWG-files are shared.

If the external communication is directly to customer, such as a private person, the file is locked so that it cannot be edited; precisely because if changes occur that are not approved technically and/or structurally the consequences can be devastating. And of course changes in the design can make the overall impression incoherent and the overall experience of the area or the building becomes negative. If a DWG-file is not requested the most commonly used format is PDF. The use of multiple softwares creates time consuming translation issues that easily could be fixed.

The documents to be produced during the construction process: The client reports their conditions, demands and wishes for the project.

- Program outline/inquiry. Featured work includes several options, and studies and analyses.



- Building program: the architect prepares a proposal to the client's desires, needs, budget, taking into account the site conditions, laws and regulations.
- Proposal document: basis for zoning, building permits etc.
- Calculation document: basis for calculating the cost of the project.
- System document: compiled investigative material that presents all the building's technical systems
- Tender request documentation: basis for tendering with all the associated documents. Ranking of conflicting information is seen by the general provisions.
- Construction document: document setting the project design, construction and quality that is the basis for the project execution, such as descriptions, drawings, regulations and lists.
- Follow-up: revisions, alteration-PM etc.
- Relation document/operation directions document showing a building's current appearance and design. The relation document should be followed-up by any change, e.g. remodelling.

Major refurbishment methods used in Sweden is often maintenance related. Such as repairing just the outer leaf, glassed balconies and/or getting the energy standards up (replacing windows, extra insulation.) Other refurbishment issues are often to bring up the standards for accessibility. Just as energy demands has this received higher requirements in recent years.

Currently the tools used for the refurbishment project of a building in Sweden are design tools such as Rhino3D, Sketch-up 3D and drawing design programmes such as AutoCAD, ArchiCAD, Revit etc. Programmes used to calculate the structure/construction are tools like Statcon etc.

4.1.3 Retrofitting solutions and industrialization level

There are few well-developed systems for facade renovations in Sweden. Mostly in site solutions are used for renovations. Manufacturer of plaster have their refurbishment (ROT) plaster system which is especially developed for objects one wishes to renovate the facade without first having to demolish the existing plaster.

Systems that can be prefabricated are used but are still not so common. The prefabricated level varies from fully prefabricated elements (as TES-elements) to partly prefabricated elements (just frame, thermal insulation and one sheet, with or without windows, no cladding).

In Sweden and for the few extension of buildings that have been made there are two different "systems" that are used

prefabricated bearing parts, usually post and beam system or surface elements. Prefabricated vertical installation or elevator shafts, prefabricated balconies, and prefabricated extension units are frequently used in combination with conventional construction techniques objects were it is possible (economically and structurally) it is often used as prefabricated box elements.

4.1.4 Installation phase

Assembly and fixation of elements or/and box-elements are the central aspects of the work on-site. Time and good praxis are central to achieve economic advantages and positive social impact.

In contrast to other industries, the construction sector has failed to adopt an industrialised viewpoint, and is still an industry dominated by guilds. Thus, in finalising a bathroom during on-site construction 5-7 different craftsmen are needed (concrete workers, plumbing, tiling, electricians, carpenters, painting and floor carpets). They need to enter at specific times, all being dependent on one and another. In an industrialised manufacturing system, the bathroom can be pre-fabricated by 1-2 workers under controlled environment in the factory.

4.2 ANALYSIS OF THE CURRENT REFURBISHMENT PROCESSES IN GERMANY

4.2.1 Stakeholder's definition

An overview of the general building refurbishment process in Germany is presented in Figure 26. The graphical representation shows the project phases and time lines the key stakeholders (the energy consultant, the project manager/developer on the owner/investor side, the architect, structural and HVAC engineers) follow. Each key stakeholder follows his own, standardized procedures. In the bottom line, a general overall workflow typical for (conventional construction) refurbishment of residential buildings in Germany is outlined.

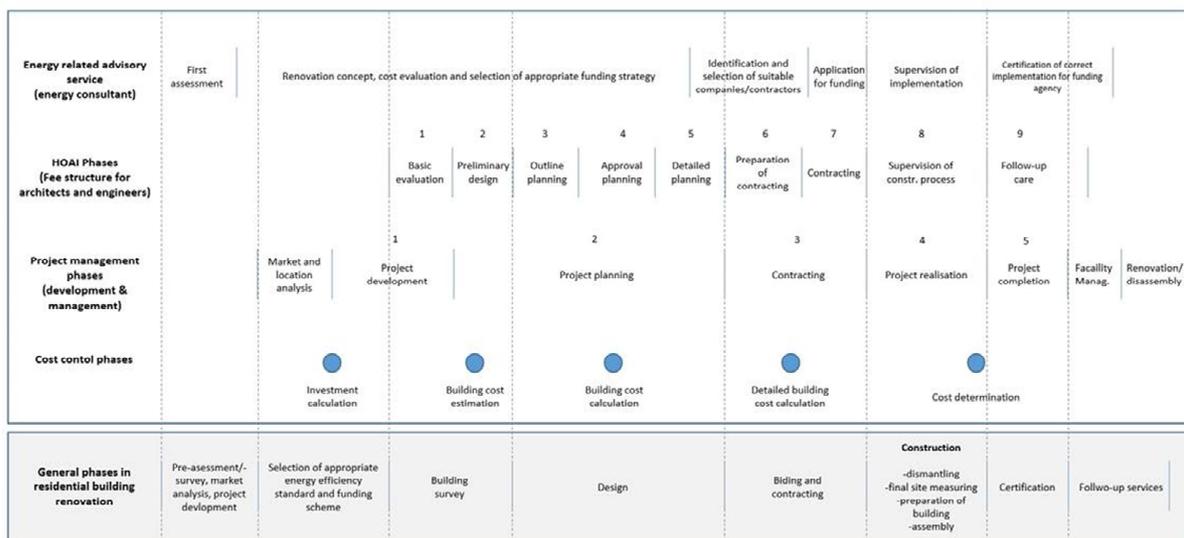


Figure 26: Outline of general/conventional building refurbishment process in Germany. Dr. Linner/ br2 TUM

Following the workflow for the implementation of refurbishment projects, four key stakeholder constellations are common:

1. Implementation with **individual** expert planners and **a multitude** of companies representing individual trades/professions

2. Implementation with **one** general planner and **a multitude** of companies representing individual trades/professions
3. Implementation with **one** general planner and **one** general contractor
4. Implementation with **one** prime contractor (conducting all planning and construction activities)
5. In case of refurbishment projects (for more details explanations, see: Augsburg case and Munich case in <http://www.e2rebuild.eu>) carried out by large housing associations in Germany, an architect along with project coordinators and controllers representing the client's side are usually responsible for tasks such as design, planning and building permission acquisition, and the coordination of the involved parties. Individual contractors (for example, builders, timber frame manufacturers, windows manufacturer, sealing work, drainage, metal worker, electrician, heat and sanitary, etc.) are contracted through a predefined, standard tendering process (Vergabeordnung für freiberufliche Leistungen, which means Procurement law for supplies and services of freelancers). Moreover, the construction planning and detailing phase and the phase of preparing the tender documents are coordinated by the architect and the client's representatives. Various management tasks such as site management, supervision of the HVAC and MEP (Mechanical, electrical, and plumbing) engineers, organizing meetings with dwellers, etc. are the responsibility of the architect. External experts who are responsible for health and safety coordination during the construction are coordinated by the master architect in consent with the client or in some cases even directly be the client if the client has the capabilities and resources to do so.

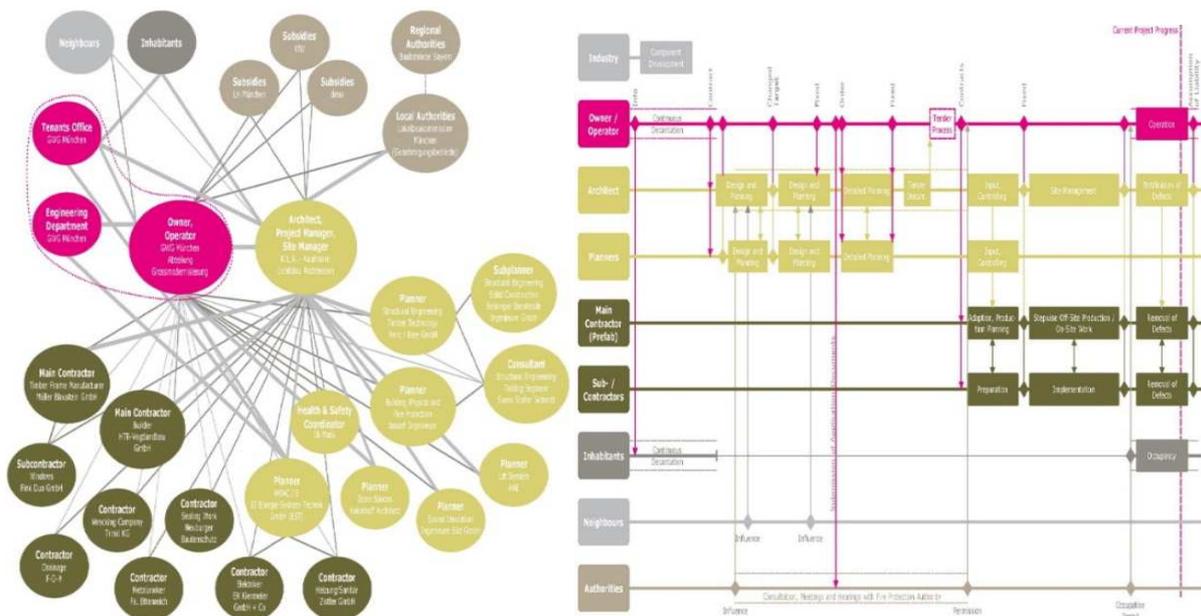


Figure 27: An example of collaboration model, Munich demonstration in E2ReBuild.

During the construction work and building renovation process, those are the competences and legal responsibilities of each agent:

- Architect. Design, arrangement of elements. Insurance is normally for 5 years.



- Engineer. Structural and material quality verification, among others. Insurance is normally for 5 years.

Those are the necessary permissions needed before the start of the works.

- Local permission for occupancy of the public space. Every municipality has its peculiarities. Normally the Road Traffic Authority is the agent in charge to give the permission (**BG-BAU, 2015**) and to check that the regulation (**StVO, 2013**) is fulfilled.
- Safety and health in the Construction place. The workplace must fulfil the specific regulation on this field, the ``Arbeitsschutzgesetz ``(**ArbSchG, 1996**).

The VOB / B is in German law a standard form clause work, which regulates the formalities in construction contracts. Accordant to the relations established before the initialisation of the works, the payments proceed accordingly. The payment from the client to the contractor and subcontractor are made once the Architect/Engineer supervises and accepts the works.

4.2.2 Desing of buiding retrofitting project

4.2.2.1 Data gathering

Defined as a pre-phase of the design phase, the data gathering phase is initiated with the identification, detailing and description of the refurbishment project requirements (quantitative/qualitative) suggested by owners, dwellers, and the building authority (e.g., recently the German building refurbishment funding agency KfW (<https://www.kfw.de>) started to funds on-site inspection and pre-assessment of buildings by a certified energy efficiency engineers). In Germany, the data-gathering phase significantly influences the building owner's decision making processes since the detailed knowledge about the initial condition, the outlines of improvement alternatives and detailed calculations about the achievable energy standards are a prerequisite for both subsidies and investment.

In the data gathering phase,

- maintenance status,
- documentation of user requirements,
- contracts that concern the building

are examined. Among others, a preliminary investigation is carried out to survey and investigate special issues and to prepare the necessary documentation material. Cost approximation might be based on previous experience of the designer and based on the available referencing databases². A common strategy is also that, e.g. a year before the planned refurbishment, building owners collect building data through the documentation of facility management and maintenance work. Good documentation means more cost in facility management, but can reduce the cost of data gathering before refurbishment.

² *BKI (Baukosteninformationszentrum Deutscher Architektenkammern): Since 1996, The Association of the German Architect (Die Architektenkammern aller Bundesländer) established a databased called BKI and provided the cost of the general construction. Since 2002, the BKI has also successfully specialized information for the energy-efficient planning and construction.*



The five main areas of as-is building condition parameters that need to be specified are:

- 1) **Geometric** information (as-built drawings and construction documents – layouts of all storeys basement and attic storeys, sections for all structurally independent building parts, sections of all staircases, elevation views of all facades, roof top views, historical drawings, sketches, photographs) [surveyors, civil engineers],
- 2) **Building structure/material** (provides a view to preservation worthiness and continued use of the structures concerned. Compliance with and/or implementability of construction law and other legal requirements) - wall, ceiling, floor structure, roof cross-sections, building envelope as the interface between building space and outdoor air [architects, Bauphysik Building Performance]
- 3) **Building services/technical equipment:** heating, ventilation, sanitary installation, electrical installation, building automation system, etc., [building services engineers]
- 4) **Exposure** (ground water, thermal loads in summer, noise, etc.): external influences
- 5) **Building/use history:** information from users, history data from facility management (FM), energy consumption data, technical status, building year, previous refurbishments/alternations, users, previous colour schemes.

For further inspection on the critical issues such as structure, energy quality, pollutants, and exposure to the environment, buildings are examined by using building diagnosis methods.

- 6) **Supporting structure** (this is conducted by using geometric, structural, historic stock-taking to measure load-bearing capacity, durability, suitability): wooden structure, brickwork, reinforced concrete, foundations, etc.
- 7) **Energy quality** (this is conducted by using geometric, structural, building services stock-taking)
- 8) **Pollutants** (possible hazards for users and the environment): Pollutant report: labour protection law, chemical substances laws, social code, accident prevention regulations
- 9) **Humidity and salt exposure**

A major sub-activity of the data gathering phase is the **stock-taking process** (information acquired through this activity is later on processed by planners and designers) which has two main procedures: overall recording of the as-is building condition and that of building condition using building diagnosis method. Stock taking in building refurbishment is an ongoing process throughout the design and construction phases. Of course, an initial stock-taking takes place in the beginning, but often after the design phase, after building preparation (disassembly of old facade parts, windows, etc.) or even during refurbishment/construction new materials and structures are discovered that have to be examined further. To do such examinations the owner, investor or architect usually involves specialised engineers such as structural engineers, specialist in the field of fire protection, energy engineers, HVAC engineers (in German: HLS engineer, Heizung, Lüftung, and Sanitär) which then provide their expertise.



To support decision-making processes for sustainable refurbishment and to bridge the gaps between the socio-cultural, environmental, and economic aspects of refurbishment, DGNB³ (German sustainable buildings Council, Deutsche Gesellschaft für Nachhaltiges Bauen) gets popularity for example, in case of large-scale refurbishment of office buildings

Basically there are three kinds of 3D building measuring techniques that are applied in building registration: Photogrammetry, Tacheometry and 3D Laser scanning.

- 1) **Photogrammetry**: Photogrammetry used in 3D building registration is defined as a technique of generating geometry or shape of objects by processing multiple images of those objects. Stereo vision deals with images acquired by a stereo camera setup, where the disparity between the stereo images allows depth estimation within a scene. 3-D information, hence, is retrieved which is essential in many machine vision applications such as building registration. When using disparity map (Sukumar et al. 2015) calculated from images using stereovision system, high quality geometric information of the targeted building can be obtained. There are dedicated software that can post-process images to create 3D information.
- 2) **Terrestrial Point Scanning, (TPS) using Total Station**: This is probably one of the most used tools in the construction field in Germany. It consists on a electronic theodolite that measures the distances and angles between the points. Nowadays, the Total Station do have a Global Positioning System and therefore it can collect, save and process the points' coordinates. Once the points are collected, the technician normally draws a CAD file with the gathered information.
- 3) **3D Laser scanning**: 3D Laser Scanning uses measuring technologies which are called LADAR (Laser Detection and Ranging), or LIDAR (Light Detection and Ranging), which project laser beams on the target object, and calculate the position of the object in 3D Cartesian coordinates, by analysing the direction and distance from the received laser beam. The Time-of-Flight (TOF) method is mainly used in construction, and performs scanning by rotating in certain degrees on a rotation axis. Also, by adjusting a reflection mirror inside the 3D laser scanner, it can obtain the scanning data of an object at a vertical location. The measured 3D data is supplemented with colour data, which represents the intensity of the received laser beam in 3D Cartesian coordinates (Lee and Yun, 2007; Ruiz-Correa et al., 2003).

³Building Council, is a non-profit and non-governmental organization whose mission is to develop and promote ways and solutions for sustainable design, construction and management of buildings. At the center of their work are the development and expansion of a certification system for sustainable buildings as well as the award of a certificate in the levels of quality gold, silver and bronze. The company was founded by 40 organizations from the construction and real estate industry in 2007. Against the background, planning, construction and operation of advancing sustainable buildings, representatives from the construction and property industry in June 2007 this club. The Association promotes the exchange of information, knowledge and experience on sustainable architecture and forms auditors from the DGNB certification system. In its constitution, the non-profit organization committed to serve the public and to support science and research in the field of sustainability. Together with its members, the company is developing the DGNB Certificate continually, which will be awarded as a quality mark for sustainable buildings

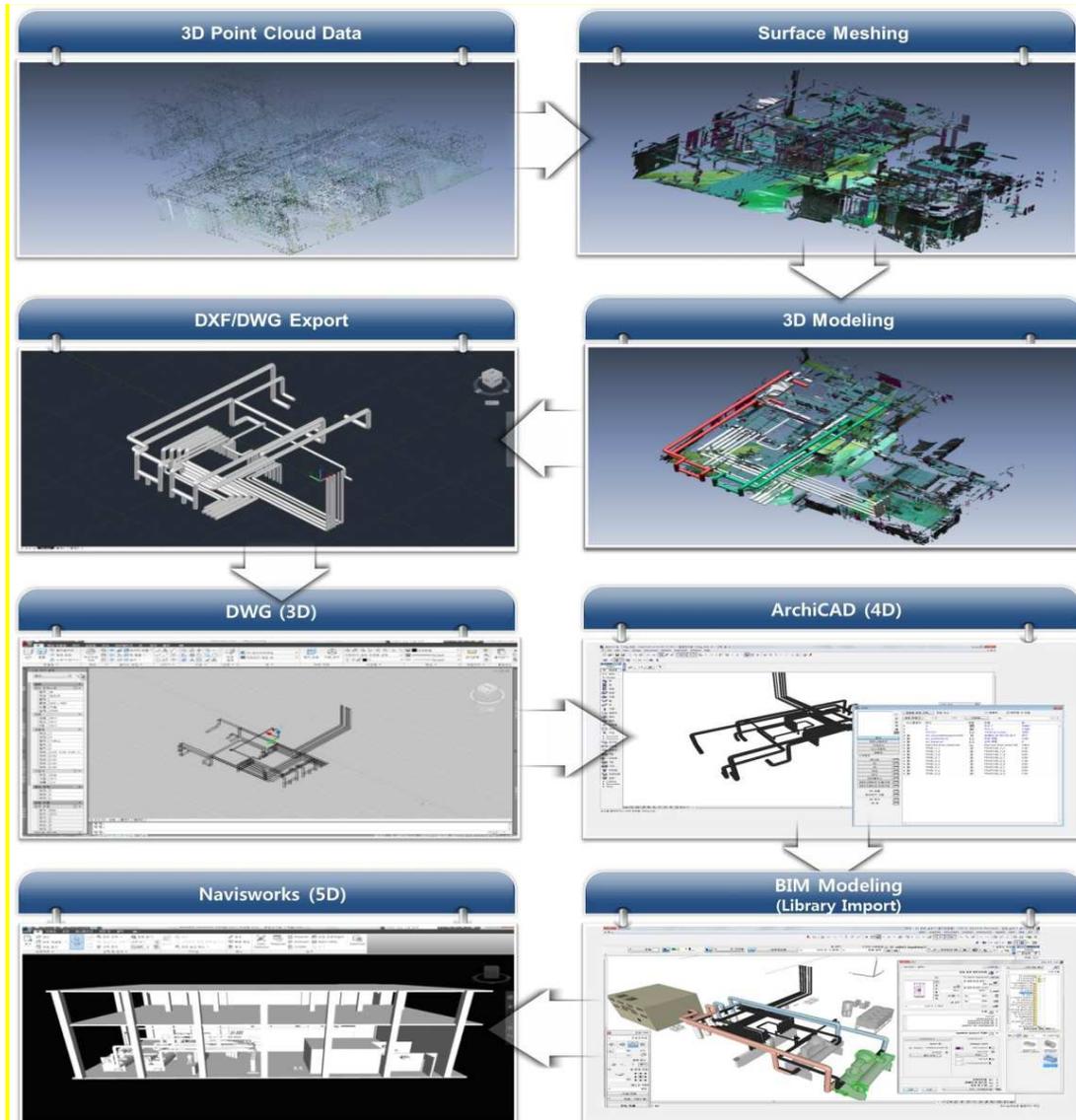


Figure 28 In-situ as-building model acquisition process using 3D Laser scanning data (Lee et al. 2013)

One of the most important tools of the energy engineer in the beginning of pre-assessment are thermographic inspection tools. Actually, in most cases these are the first inspection tools used. In Germany, also airborne imaging with infrared from drones and satellites is used to get very detailed thermographic images from buildings and whole city blocks (see: <http://www.igsse.tum.de/research/project/closed-projects/608-4d-city/team.html>). That is important since as we mention in the analysis, the refurbishment of large settlements from the 60s, 70s and 80s or whole city quarters is an increasing issue in Germany.

4.2.2.2 Design of retrofitting project

Based on the outcome of the assessment of the existing buildings and an analysis of case studies of similar, comparable buildings in order to approximate costs, architects can provide a



number of design alternatives to the customers in an early stage. In particular German investors tend to make informed decisions and to compare alternatives. The suggested alternatives are evaluated from an economic viewpoint, and regarding their impact on things such as revenue from a life-cycle perspective. Economic changes caused by the refurbishment of a building, need to be within specified and bearable levels, in particular for the dwellers (in particular significant changes of the rent). In this phase, in Germany, relatively new but now fully established and acknowledged profession of the energy engineer plays a key role. Promoted by government, legislation and funding programs, energy engineers offer a cheap initial assessment of the energy performance of a building and provide alternative proposals for energy-efficiency targeting refurbishment of a building. According to the promoted scheme, the energy engineer becomes the initiator and then the project developers (in many cases owners or clients), the architects and other engineers become active and implement these high-level suggestions.

When suggesting refurbishment alternatives, a grandfathering strategy (protection against retroactive changes in laws and regulations) is applied by identifying the legal, technical, functional, urban and architectural basis which potentially influences environmental impacts, resource savings and costs. For example, in case of a refurbishment that should generate floor extension, it becomes automatically mandatory to build an elevator shaft and to provide barrier-free access for the handicapped. If the existing stair shafts do not fit to solve this issue physically, exceptions are admitted in many cases and other, additional stipulations are negotiated.

The ownership structure (of a public or a private body, owned/partially owned by dwellers) of the building to be refurbished influences the decision making process during the design phase. In particular, public bodies (e.g. public bodies that own or supervise large housing stocks) have to follow the public regulations regarding the selection of the engineers and construction companies during the design process. Also private owners have to comply increasingly with public regulations in case the project is financed by the public subsidies.

The involvement of an architect or engineer in a certain project is in Germany by the fee schedule for architects and engineers (HOAI) divided into so called "work phases". The HOAI assigns the work phases to a certain proportion of the total fees and according to the complexity of the project to the individual architects and engineers and thus regulates their payments. The relevant HOAI phases are outlined in Figure 26. Preliminary design is the stage in which a design is developed. In Germany, the term refers predominantly to the third phase of the Fee Structure for Architects and Engineers (HOAI). In this stage, the extent/intensity of the refurbishment measurement is determined:

- Only refurbishment of façade necessary?
- Change of façade structure? Enlargement of window openings? (in particular buildings from the 1950 and 1960s have in general small windows- today customers demand large windows)
- Refurbishment of HVAC-system?
- Change of floor plans?
- Determine facade refurbishment strategy and new energy sources/HVAC-system
- Calculate/determine target cost (eventually even of alternative concepts)



- Consult building authority and ask if the planned measurements might be approved

The permit applications, also called input planning or permit application is part of a building design for construction of buildings. It is the fourth phase of the work phases according to HOAI and covers all works regarding the composition of a planning application with the aim of obtaining a building permit. For privately owned residential buildings (VOB/B), different rules for the call of bids apply than for state related/owned residential buildings (VOB/A). In case state related/owned residential buildings are concerned the bidding process is more complex and time consuming.

Furthermore, in the design phase it has to be decided if the work is split and assigned to individual trades or if a general constructor is approached. In case a general constructor is employed it is important to specify clearly the expected quality without getting too detailed. In case of façade refurbishment it has to be ensured that the company delivering the façade and the company delivering the scaffolding cooperate closely. It is a common practice that in case of façade refurbishment therefore the company providing the façade provides its own scaffolding or sub-contracts the scaffolding company.

The detailed design follows the preliminary design. As part of the detailed design, the previously conducted design planning and approval planning is taken further. In the phase of generating the detailed design, an intensive cooperation of experts of various professions such as engineers, and product manufacturers takes place in order to clarify details and ensure manufacturability (generation of plans and sections in 1:50, details of 1:20 to 1: 1). The goal of the phased detailed design is the provision of a comprehensive description of the building which allows its realisation. In that context, every single plan is assigned an individual plan number, which is, for example, supplemented by a numbering index such as "A". Since the implementation planning is a complex and interactive process which often involves continuous changes, subsequent versions of a plan are for example referred to by "B" or "C" indexes.

Information from stock-taking, building diagnosis and referred information such as building code and regulation is used during the design phase. In particular, socio-cultural/functional aspects must be considered including thermal comfort (in summer and winter), air quality (by using low emission products and materials, which is measured after the building completion), and noise and lighting (availability of natural light, visual contact with outdoor environment, distribution of light, etc.). To make the building accessible to and usable for as many people as possible, in particular, in an ageing society, the design must comply with the criterions for barrier-free building.

Regarding the used tools, in Germany, ArchiCAD (18% of the market), AutoCAD (16% of the market) and Vectorworks (10% of the market) are predominantly used (ArchiVision, 2015) but now BIM authoring tools such as ArchiCAD and Revit obtains more and more popularity. For process planning, AVA (Ausschreibung, Vergabe, Abrechnung) software is used in addition to these software. AVA software (for details see: <https://avanova.de/>) supports with generating the process of tendering, awarding and invoicing from data technology and can thus be seen as an electronic tool for the respective processing phases of the AVA-phases. With AVA programs power positions and leading records are created and organized as a tender structured. Dimensions (antecedents) can be determined from CAD data or taken from



CAD programs. Bills can be created manually or with position texts from databases. Position texts are managed in databases, and prefabricated third-party item texts can be integrated. By means of GAEB (for more details, see: <http://www.gaeb.de/en/>) data exchange, process between the planners and suppliers electronically (paperless) is mapped. A distinction is made between the formats GAEB90, GAEB2000 and GAEBXML. The latter is now widely used and found not only in AVA programs. However, the exchange is not always smoothly possible in spite of standardized XML schemas. Therefore, it is particularly recommended that the programs have a valid GAEB certificate. As part of the "Building Information Modelling" - BIM carried even further integration of CAD planning and AVA process.

A novel tool to support decision-making for sustainable refurbishment in Germany is provided by the DGNB (the German certification for sustainable buildings, Deutsche Gesellschaft für Nachhaltiges Bauen) specifications. The DGNB specification aims at the assessment of sustainable buildings at national, European, and international levels and key values are shown below. In case of large project for DGNB standards should be applied, a certified engineer has to be employed throughout all phases consulting the owner/investor/architect, resulting in significant cost for certification process.

Table 12. Key values addressed by the DGNB specification [SuPerBuildings, 2010]

Economic	Environmental	Social	Architectural
Value management -Planning/preparation -Management Whole life costs Asset Value -Building adaptability Ease of maintenance	Primary energy consumption (operational) Materials Construction phase Land use and ecology Water Management and risk LCA indicators -Global warming potential -Ozone depletion potential -Acidification potential -Eutrophication potential -Photochemical. oz. creation potential	Comfort and Health Building safety assessment User well being Accessibility -Physical impaired people -Green and open spaces -Public services/amenities Access to transport	Building aesthetics and context

4.2.3 Retrofitting solutions and industrialization level

Over the past decade, German companies have developed a variety of facade refurbishment solutions based on prefabrication. The developed solutions range from very high degrees of prefabrication (fully prefabricated large panels) over medium degrees of prefabrication (partly prefabricated elements) to low degrees of prefabrication (system kits). A high degree of prefabrication considerably reduces the amount of trades/professions that have to be coordinated on the construction site.



In complex refurbishment projects in conventional construction in Germany, due to the craftsmen-based tradition, up to hundred or more trades have to be coordinated and even if a contractor takes over responsibility he will at the end build on individual craftsmen and small local companies as subcontractors. The resulting multiple interfaces and interdependencies along with the fact that each company or trade uses its own set of software as well as the lack of knowledge about integration through BIM by smaller companies makes refurbishment a complex and error-prone process.

On the other hand, prefabrication in a structured environment allows controlling trades as well as material flows, logistics and handling systematically. German companies which prefabricate elements for new construction as well as for refurbishment usually employ all craftsmen from the multitude of trades that are necessary to build those elements. Thus in the factory, those companies create a "closed systems" that allows then for considerable degrees of standardized interfaces and processes (**Bock & Linner, 2015a**).

However, the conventional construction industry (large contractors as well as smaller firms) are usually reluctant to involving companies providing elements with a high degree of prefabrication since this would be risky for their own businesses, which is strongly related to on-site construction. Thus prefabrication industry and conventional construction industry are usually two separated industries that do not cooperate. In reality, a combination of prefabrication and conventional construction which would be required for successful deep refurbishment, does not take place commonly and the examples mentioned in the context of fully and partly prefabricated elements were predominantly developed and deployed as part of funded research projects. In reality, among the developed facade refurbishment solutions, system kits are highly popular in the German building industry since these kits can be used in and fitted into the existing trade structure and organisation of work.

Fully prefabricated panels

Fully prefabricated large panels provide advantages and disadvantages to the refurbishment of facades. On the one hand, they allow to achieve a very high prefabrication degree (ratio of work shifted into an off-site facility can be up to 80% in some cases). Furthermore, large panels that are made of a wooden frame or steel frame can be used as component carriers by themselves in a continuous workflow along a production line or at least in a flow-line-like manner. On the other hand, these large panels also create challenges during refurbishment process. The CAD representations of the building must be highly accurate and the manufacturing of these elements must ensure minimal tolerances since they must fit exactly to the existing facades (including window opening and openings for guiding HVAC systems).

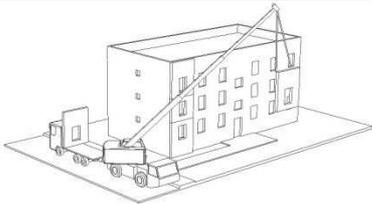
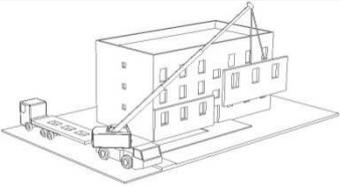
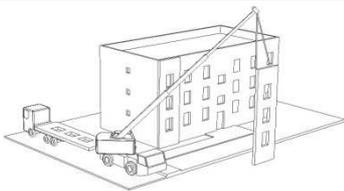
To achieve a seamless work and information flow, it is required that

- An excellent information flow needs to be created between the entities measuring the building (pre-measuring and measuring after disassembly of the old facade and during the preparation of the building for assembly of new elements) and entities designing the panels.
- Excellent quality, in particular, regarding the panels' dimensions and tolerances needs to be ensured (e.g. through laser scanning the panels during and/or after

manufacturing) and this information is feedback both to the entities designing the panels and measuring/preparing the panels.

- Since it is costly and not practical to store large elements for a long time off-site or on-site, it is required that off-site manufacturing and on-site installation are synchronised in a just-in-time just-in-sequence manner. This in turn might require the flow of materials to be continuously tracked (both off-site and on-site and during logistics) forexample, on the basis of RFID-tags, visual recognition systems, QR-codes or other means of component tracking.
- Cycle times of off-site activities and on-site activities need to be synchronized
- Workers on the site must receive detailed instructions, special training and if necessary specialised tools that allow them to handle and assemble large panels safely without scaffolding to facades.
- Component design and fast connectors need to be implemented through the manufacturing phase in order to simplify following activities on the construction site :
 - micro logistics/handling
 - positioning
 - alignment
 - fixation

Table 13. Installation processes of fully prefabricated facade elememets

		
<i>Medium sized horizontal</i>	<i>Large sized horizontal</i>	<i>Large sized vertical</i>
<i>Examples: Iturralde, br2/ TUM</i>	<i>Examples: Iturralde, br2/ TUM</i>	<i>Examples: Iturralde, br2/ TUM</i>

Partly prefabricated elements:

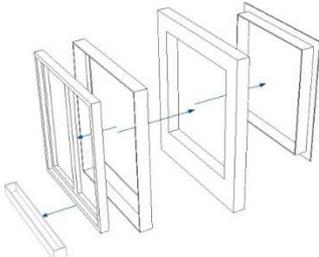
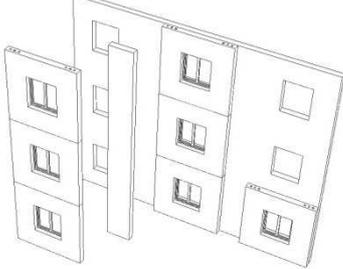
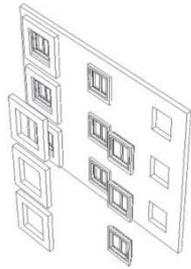
Partly prefabricated elements are less demanding regarding quality/precision requirements, organization of manufacturing procedures and the handling of the components on the construction site. The ratio of prefabrication degrees are usually between 40-60%. Deviations from planned dimensions can be corrected on the construction site since the prefabricated elements are combined on-site with other, smaller parts and components that can be cut to fit. The partly prefabricated elements enable to structure on-site work to a higher degree in comparison with that of conventional construction. The manufacturing process is also simplified, and higher degrees of automation might be achieved since fewer parts have to be assembled, and fewer final assembly operations are required off-site. Furthermore, since the elements are smaller and lighter, logistics and handing on the construction site is simplified.

To achieve a seamless work and information flow, it is required as follows:

- A sufficient information flow needs to be created between the entities measuring the building and entities designing the panels.

- Good quality in particular regarding the panels' dimensions and tolerances must be ensured.
- Just in time and just in sequence work organisation must not be as consequently implemented as with large panels and more process flexibility can be allowed.
- Cycle times of off-site activities should be balanced but do not have to be 100% synchronized.
- Buffer storages for manufactured components and panels off-site or on-site could be practical.
- Detailed instructions, training and specialised tools required can be less complex than that for the large panels.
- Manufacturing could be highly automated since finishing work is done on-site
- On-site installation equipment can be lighter and less complex than that for large panels

Table 14. Examples of partly prefabricated elements

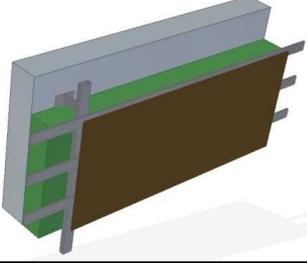
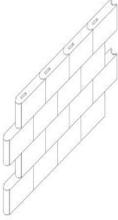
		
<p><i>Window-based insulation elements with technology intake box</i></p>	<p><i>Prefabricated window-including panels</i></p>	<p><i>System kit with window based insulation elements and insulation panel kit with avenues/templates for duct guidance</i></p>
<p><i>Examples: Fraunhofer IBP WDVS-Fenster-Modul Redrawn: Iturralde, br2/ TUM</i></p>	<p><i>Examples_ Swiss Consortium (Kobler et al., 2011) Redrawn: Iturralde, br2/ TUM</i></p>	<p><i>Examples: "Retrokit" Fraunhofer-Institut für Solare Energiesysteme ISE Redrawn: Iturralde, br2/ TUM</i></p>

System Kits:

System kits consist of pre-configured parts and components that are connected to the building and to each other through standardized screws, bolts or other types of connectors. The degree of prefabrication is relatively low. The parts and components can be supplied from manufacturers in a form of off-the-shelf parts or bespoke products (using CNC machines for cutting, bending, milling, etc.) by using automated equipment, which is capable of high-volume manufacturing. System kits are quite popular in the German construction industry since they can be used by craftsmen to make their trade-individual work more productive in the construction site. The individual parts of the kit are pre-cut and therefore only minimal rework is required on the construction site. In contrast to large prefabricated panels, those kits allow to

adjust to certain deviations/errors and thus achieve relatively high constructability in the construction.

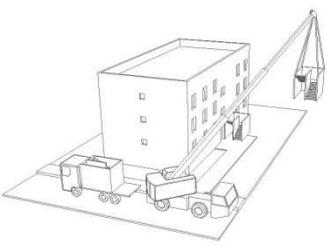
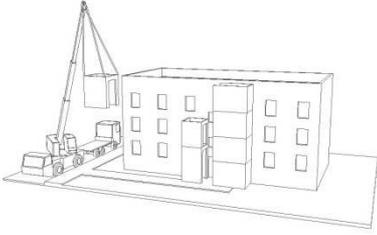
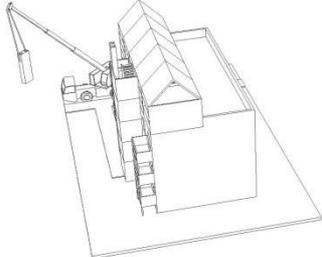
Table 15. Examples of system kits

	
<p><i>Post-beam-kits</i></p>	<p><i>Insulation panel kits with integrated aeration ducts</i></p>
<p><i>Examples: Iturralde, br2/ TUM</i></p>	<p><i>Examples: Fraunhofer FAW (FreshAirWall, 2015) Redrawn: Iturralde, br2/ TUM</i></p>

Prefabricated Building Extensions:

In Germany, prefabricated building extensions are in contrast to completely prefabricated facade refurbishment solutions that are commonly used. Prefabricated vertical installation or elevator shafts, prefabricated balconies, and prefabricated extension units are frequently used in combination with conventional construction techniques. The use of such elements conflicts less with the businesses of the core construction trades. In many cases, the companies supplying these extensions (e.g. staircase, elevator or balcony manufacturers) do anyhow to be involved as individual trades or sub-contractors.

Table 16. Examples of vertical installation of prefabricated components

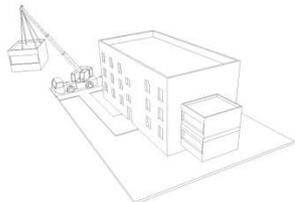
		
<p><i>Prefabricated towers with stairs</i></p>	<p><i>Prefabricated towers for elevators</i></p>	<p><i>Prefabricated installation shafts</i></p>
<p><i>Examples: Iturralde, br2/ TUM</i></p>	<p><i>Examples: Iturralde, br2/ TUM</i></p>	<p><i>Examples: Iturralde, br2/ TUM</i></p>

Prefabricated balconies:

Table 17. Examples of installation of prefabricated balconies


<p><i>Prefabricated balcony kits</i> <i>Examples: Iturralde, br2/ TUM</i></p>

Table 18. Examples of installation of vertical extension

		
<p><i>Prefabricated functional side extensions</i> <i>Examples: Iturralde, br2/ TUM</i></p>	<p><i>Prefabricated vertical extensions</i> <i>Examples: Iturralde, br2/ TUM</i></p>	<p><i>Prefabricated roofs</i> <i>Examples: Iturralde, br2/ TUM</i></p>

4.2.3.1 Impact of modularity on plug-and-play capability and prefabrication process

Modular facade systems can be made of sub-modules: individual basic elements (e.g., windows, opaque elements, etc.), energy generation elements (e.g., elements with solar thermal, photo voltaic or wind energy or heat generation), and supply services (e.g., supply utilities). They can be freely combined and exchanged over time in a plug-and-play-like manner. So far, these systems were predominantly developed for the new construction or refurbishment of office buildings.

An advantage of the modularity of such facades is a plug-and-play capability that can realize a fast and simple installation on the site. By replacing individual basic or functional elements, it is possible to maintain/upgrade aspects such as use and performance of the building over time. Furthermore, modularity, in that context, can be used to create an OEM-like (original Equipment Manufacturer like) integration structure (Bock & Linner, 2015) which is supportive to automation and mass manufacturing since **a)** it allows individual Tier-n manufacturers to supply specialised components in a mass production like manner and **b)** reduces complexity in final assembly. Furthermore, prefabricated facade panels can be finished more or less completely in the factory (high degree of prefabrication) or delivered to the site as a system kit (low degree of prefabrication) and thus gives some flexibility in designing and customising the overall construction process for a certain building.



- Multifunctional energy efficient facade system (MeeFs):
A lattice formed frame made from fibre reinforced polymers can be filled up with functional and technological modules. During the use phase, individual modules can be replaced to upgrade or maintain the performance of the façade. The lattice frame can be parametrically customised to meet the prepositions of a certain existing façade to which it can be connected by joining system.
- Multifunctional plug and play facade (mppf):
A lightweight steel based frame forms the basis and can be filled with either window or opaque elements. Functional elements such as solar thermal elements, photovoltaic, LED or sun shading elements can be plugged onto this frame in order to form a rear ventilated double layer façade. HVAC and other supply elements are integrated in so called parapet elements that are fixed to the floor slabs. The frames are fixed between these parapet elements and connected to them. In short, mppf has several advantages by providing several modular dimensions:
 1. The frames between the parapets are customisable/exchangeable elements
 2. The window and opaque elements filled into the frame are customisable/exchangeable elements
 3. The functional elements that form the front layer of the facade by being placed on top of the frame are customisable/exchangeable elements

4.2.4 Installation phase

Refurbishment involves partial dismantlement of the existing building and therefore schematic demolition or disassembly planning has to be conducted. Demolition/disassembly planning includes issue such as technical work, safety insurance, demolition planning, selective demolition method, waste management, etc.

- **Examine/coordinate technical work safety:** safety and health coordinator's involvement from planning stage (Construction Site Ordinance)
- **Demolition planning:** logistics concept, analysis of susceptibility to vibration, consideration of nuisance to the environment, handling of construction trashes/hazardous material, time scheduling, demolition methods
- **Selective demolition** (demolition method which ensures the continued trouble free use of the building space): preparation of a demolition concept and gathering of the necessary user information
- **Waste separation** and disposal possibilities: controlled and monitored waste separation

We will refer to the installation process as the period that comprises from the arrival of either raw material or prefabricated component to the site till the finalization of the works on the building. Normally, in the context of manual renewal processes, there is a considerable amount of manipulation processes of elements necessitated. On the contrary, by prefabrication, the installation is minimized to the placement and fixation of the component in its (final) place. Therefore, the temporary support structures, tools and devices differ in manual and fully prefabricated processes.

Installation types and main current practises



In the installation phase, there are four main steps:

- Installation of the necessary **Support devices** for carrying out the works.
- **Preparation** of the existing building before the fixation of the element.
- Transportation, Arrival and Temporary storage of the component.
- **Uploading, Placement and Fixation** or adding of the new elements or components onto the existing building.

Those first four phases can be considered purely as installation phases, which in principle, are conducted while the support device is on site. After the fixation of the component and the finalization of the works, **maintenance, monitoring and surveillance** might be needed. Every work implemented needs to be periodically maintained. This is specially the case for the energy harvesting devices integrated into the building.

We can identify three main types of current practises:

1. **Manual** procedures, those are based on manipulation of material on site.
2. **Semi-prefabricated** element installation. Here, the elements are brought to the site already pre-cut and machined, but the pieces are brought together on site.
3. **Fully-Prefabricated** component installation.

In on-site installation, in Germany, key issues are:

- Safety and support bodies are in reality the key issues in façade refurbishment
- In case the panels are too large and have to be assembled without scaffolding, severe challenges might arise
- With a ladder, workers are not allowed to go higher than 6 meters
- Special equipment to lift people higher than 6 meters is expensive
- At the end of the realization phase, a thorough approval has to be done
- Guarantee by firms, architects etc. in case of refurbishment projects is usually set per contract to 5 years
- After complex refurbishment project, architects and key companies usually get follow-up contracts for regular checking of the building and see if the quality is as promised

Depending on the size of the component that is fixed to the existing building, the support bodies, lifting devices and temporary structure will differ. Two main purposes of these accessory devices can be identified.

- Provide accessibility and security to the worker that performs the task of the installation process. Unless the renovation process considers the demolition of the existing building envelope, the installer will work from the exterior of the building.
- Facilitate the process of reception, upload, placement and fixation of the new façade. Here also security measures needs to be taken into account.

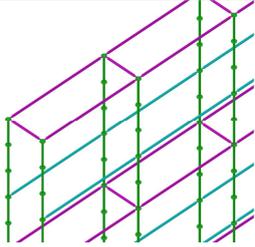
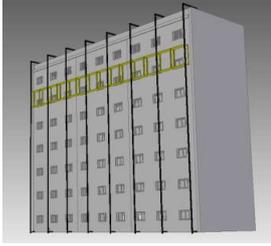
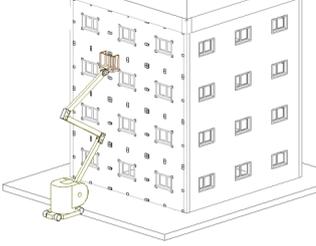
Among the support devices that are predominantly used in the German market, the most common devices are listed in the following:

- Fixed scaffolding. Probably the most extended support temporary structure.
- Mast climbing. It is based on a platform that is elevated along one or two masts. The masts are normally triangulated or spatial structures that host a rail or a rack. On this

rack, a pinion and its motor move the platform upwards and downwards. The mast normally is anchored to the existing façade. This is a limitation for placing.

- Aerial work platform. We can find two main types: Scissor crane and Cherry pickers. Normally those elements are used for supporting workers (Annex 50)
- Suspended scaffolding. Where the platform hangs from the tip of the building.
- Tower crane. This is purely used for placement of elements.
- Mobile crane is a crane attached to a truck
- Hoists, lifts and elevators. Normally, those are placed on vertical position, but they can be also be used on roofs.

Table 19. Some examples of the support devices

		
Tower crane	Tubular structure of a fixed scaffolding	Hoist, lift, elevator
Examples: E2rebuild Augsburg	Examples: Iturralde, br2 TUM	Examples: E2ReBuild, Roosendal
		
Hanging scaffolding system with guides	Aerial work platform	Mobile crane
Examples: Iturralde, br2 TUM	Examples: Iturralde, br2 TUM	Examples: Iturralde, br2 TUM,

The regulation for installing support temporary structures in Germany is specified by several norms (**BG BAU, 2015**). The use of Mobile Cranes and Aerial Work Platform must be approved by local administration, especially if a public road is blocked.

Usually in the context of the existing building envelope of the building to be renovated, some of the existing elements need to be removed. The main reasons can be specified as follows:

- **Damaged elements:** Due to the loss on the primary physical condition of the building elements, those need to be removed in order not to cause a major problem. In this case, some need to be replaced (e.g. structural elements, handrails) but some other can be remained.



- **Obsolete elements:** This is the case when the element itself doesn't fulfil the existing performance standards. This can be the case of windows with insufficient thermal insulation or the case of HVAC that needs to be upgraded in order to work according to new regulation.

Non-suitable elements: The new project requirements might force to remove some elements. For instance, the installation of a new elevator and staircase can be the cause for removing the existing staircase. Besides the case of some EIFTS insulating systems, the external cladding of the existing building needs to be removed in order to get a major adherence.

4.2.5 Specificity in timber

Organisation, machines, and information flows of wood based off-site manufacturing in Germany

In Germany, the prefabrication of wooden panels is predominantly practiced in the construction of new single-family houses, semi-detached houses and terraced houses by specialised prefabrication companies. Prefabricated houses have a share of 15-20 percent (depending on the region) in the German housing market. The majority of prefabricated buildings constitute wooden panelised buildings. Key players in the market are Weber House, Kampa House, Bien-Zenker, Huf Haus and Baufritz. Sales volume of each company is in the range of 300-1000 houses per year. The production volume largely depends on the degree of automation. Whereas the smaller companies build on workshop-like factory organisation, the larger companies such as Weber House use flow-line-like and production-line-based factory layouts. Similarly, throughput times vary considerably from a few weeks in the case of the smaller companies to a few hours in the case of the larger and more automated manufacturers.

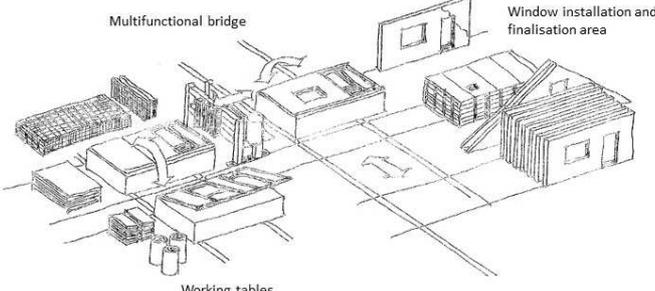
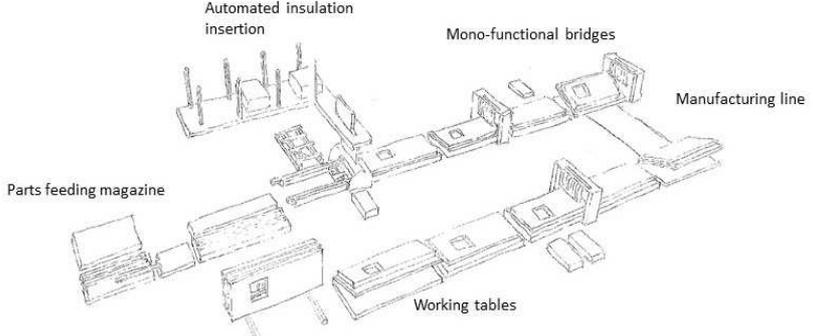
For example, in the prefabrication of panelised wooden buildings by Weber House, the wooden frames are first produced on the framing station, filled with insulation and then sealed on a multifunctional bridge station continuously. After these process, they are transferred to a moving final assembly line (assembly of windows, façade finishing, doors, electrical wiring, etc.) where they are finished in a hanging, upright position. If the production volume becomes larger, the relatively slow final assembly process (compared to pre-processing and framing, etc.) can be distributed on two parallel running lines.

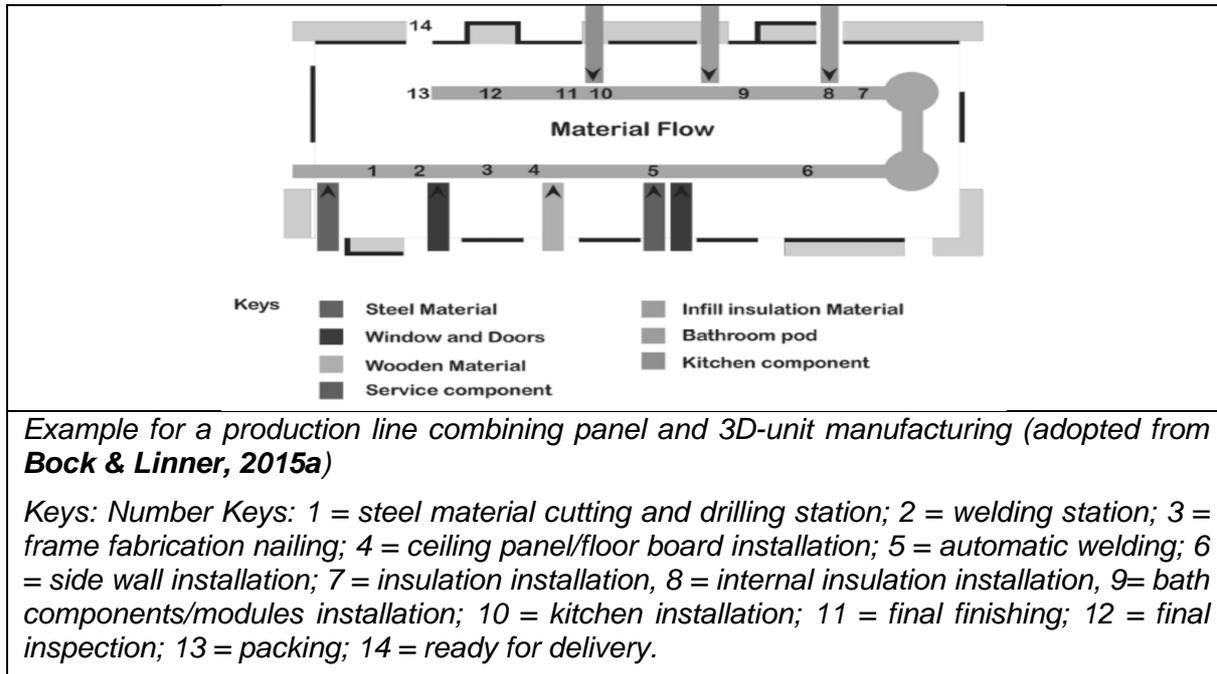
Most manufacturers of wooden panels in Germany are built on machine companies such as Hundegger in parts production (cutting and preparation of the studs, etc.) and Weinmann in assembly (framing, processing, and finishing of the panels, etc.). Weinmann, for example, provides workstations and machines (e.g. multifunctional bridges, laying tables, transfer systems, and butterfly tables) that can be used either as standalone solutions in a more workshop-like layout or as interconnected production lines. Modularity allows that individual workstations can be upgraded in a step by step approach from a low degree of automation (e.g. simple laying table) to a high degree of automation (e.g. a lying table with transfer system and a mechanism to automatically place the pre-cut insulation stripes). Similarly, framing stations are shipped with both lower degrees and higher degrees of automation.

Manufacturing layouts for wood panel/3D unit manufacturing:

Manufacturing layout variants for wooden panels in Germany range from workshop like organisation in smaller firms and flow-line-like organisation in medium-sized firms to production-line-based organisation in larger firms with high-volume production. Some large firms such as Weber House add to the end of the actual frame manufacturing line another final assembly line along which the panels are then moved, for example, in upright position for the assembly of finishing material. The material is supplied just in time just in sequence or over buffers to the location at the line where they are installed, however, in principle, the product (wall) comes to the worker and material to be assembled (mass production principle of Henry Ford). In contrast, smaller firms conduct final assembly with the product resting in a dedicated area (workstation or area in the workshop), and the materials are delivered from (central) supply shops. In some firms, mobile tool and workbenches (organising tools and materials) are used which individual trades/crafts men move to the location at the panel to assist in the assembly process. On the very top end, final assembly lines for panels are connected to manufacturing cells or lines for the assembly and finishing of 3-dimensional units. However, such systems can currently only be found in the Japanese prefabrication industry.

Table 20. Wood panels prefabrication


<p><i>Example for a wood panel prefabrication layout combining elements of workshop-like and flow-line-like manufacturing (adopted from WEINMANN Holzbausystemtechnik GmbH)</i></p>

<p><i>Example for a wood panel prefabrication layout with production line based organisation (adopted from Randek)</i></p>



Wood machining is quite automated and the use of different end-effectors in CNC machines is widespread in industrialized countries. Traditionally in manual wooden component manufacturing, each tool requires a specific machine. There is a workstation for sawing, another station for shaping, etc. Today, all these workstations have been linked and automated. Even though it could be difficult to saw, cut, plane, shape, mill, and drill in just one work station, nowadays, industrial robots can utilize different end-effectors that facilitate all facets of woodworking.

1. Automated cutting and shaping: Once either solid wood or engineered wood is produced, the first step to manufacture a component is to cut each element to an approximate size and shape. This step must occur before machining the element. The accuracy of the approximation depends on the element type. For a structural element, 5 centimetres can be left before final machining. For furniture elements, this allowable variation may be less than 5 millimetres before its introduction into a CNC machine. A circular saw is proper for linear cutting. This saw offers accuracy in linear shaping, and is rigid enough to maintain a straight cut. In manual cutting, circular saws were the cause of many injuries to carpenters' fingers. Band saws are flexible and better suited for cutting curved shapes. The band is continuous, normally turning in between two wheels and the element to be cut is placed between these two wheels. The band is normally less than 5 centimetres wide. Working with a manual band saw can be quite dangerous. If the curve of the incision is too small, the band could break apart or even burst.
2. Automated timber element machining: The main purpose of wood machining is to create a special shape for an adequate posterior assembly. When joining two wooden elements without any other special accessory, a void or channel is created in one of the elements and a slot in the other one. The milling cutter is designed with a special shape. Tongue and groove, finger joint, and dovetailing, are some of the most used wood joinery systems.



Sometimes, glue, adhesives, or nails are needed in order to make the joint permanent. Lately, special steel connectors are replacing permanent wood joinery systems. New furniture or even structural elements are a clear example for applying this concept.

3. Automated finishing: After the machining of the wooden element, normally the finishing of the wooden element is done before the assembly process. Wood must be protected against humidity, solar rays, fungus, and other threats (when wood is covered, this may not be needed). First, in order to open the pores and smooth the surface of the wood, sanding is required. This process can be done by robotic end-effectors. After this, the wood is impregnated with different chemical products. Painting and Varnishing must be done in special workstations, often closed cabins are used. To move from one workstation to another accurately, without inducing any scratches, robotic handling devices facilitate the transportation. In order to reduce time and space for wood machining, multi purpose CNC machines, by which an element can be cut, milled, drilled, and sanded, are used.
4. Tilting station: Wall and gable elements are transported from tables to the tilting station. The lateral procedure of the tilting table is carried out on the chosen track where the wall or gable element are subsequently positioned into the appropriate magazines.
5. Magazine for wall and gable elements: All walls and gable elements are temporarily or permanently stored in magazines whilst the walls are being processed. The plastering work or the painting of elements, as well as the assembly of doors, windows, and shutters are completed here. The walls or gable elements can then be directly loaded onto either a freight vehicle or dispersing wagon.
6. Nailing unit for the production of board batch elements: The individual boards are loaded onto the nailing unit using a conveyor belt or cross conveyor. This can be done manually or automated. A lifting apparatus sets up the boards that are then pressed together during the nailing process. During the automated nailing process, a nailing image is rendered containing defined protected areas that simultaneously control the nail entry and depth. The length and width of the board batches are variable. Key work stations/machines:

Machine and workstation solutions are available for all phases of manufacturing as the production of wooden parts (studs, beams, boards, sheets, etc.), the assembly of these parts into frames and their processing and final assembly, the assembly of frames and panels into 3D units and their final assembly, and last but not least logistics, transfer and storage solutions. Most equipment can be purchased by smaller firms as standalone equipment or combined by larger firms to production lines. Furthermore, most equipment or workstations are available as basic versions with low degrees of automation and as premium version with high degrees of automation. More and more researches are done regarding modularity and standardisation allowing that equipment can be upgraded gradually from low degrees of automation to high degrees of automation, and that stand-alone equipment can be extended towards full production lines.



4.3 ANALYSIS OF THE CURRENT REFURBISHMENT PROCESSES IN SPAIN

4.3.1 Stakeholder's definition

In Spain AEC sector is highly fragmented and the renovation projects are developed from design to implementation in a linear way. There is a lack of interaction between the stakeholders involved and the information flow is linear. In the renovation processes the stakeholders could be classified in the following groups:

- The design team (architects, engineers...)
- The main contractor and subcontractors
- The owner.

The law established clearly the responsibilities of each group, but currently, no protocols and standardized procedures exist for the interaction among different stakeholders and the manufacturers. It is not clear the role of each one in the data management and information flow. The communication flow depends in each case on the “modus operandi” from each different professional. Therefore, data acquisition and gathering usually will depend on the scope of the renovation process and the usual practices of the stakeholders.

The architect defines the building to be constructed or rehabilitated. He assumes the whole design of the building. In the case of large scale buildings with some technical difficulties or sophistications, the architect subcontracts different aspects of the design of the building (structure design and calculations, installations design and calculations). In the case of big architectural offices or big design companies, architects and engineers work together on the building project and do not need to subcontract anything. When not conventional technological solutions are included, the industrial providers of these solutions provide important technical documentation about these solutions. In this case the role of the technology providers is important in the design and installation phase of the products.

Usually the information is centralized by a technician with an architect profile within the design team who uses CAD for geometric information and different formats for semantic information. The different technicians work separately based on that CAD model of the building and the output is introduced in the model. The updating of this model is very time consuming due to this working method. The accuracy and consistency through all the process is difficult to obtain and requires high levels of coordination, discipline and compromise from the technicians.

Regarding the external communications, the design team usually is reluctant to share the information in editable formats with the customer/owner and the main contractor. Usually they use pdf formats or even printed copies to avoid not authorized use or modifications of the project information.

The authorities are the responsible for providing some necessary input to the renovation process, especially regarding urban and regional laws. In the last years, some municipalities and regional authorities have put a lot of effort in making some information accessible to the citizens. At national level there are institutions such as cadastre or the National Geographic Institute (IGN), which are responsible for collecting some of the geometric and semantic data



that could be used for the renovation process. These data include geometric and semantic information at building level (year of construction, height and number of floors) and its surroundings (public spaces, green areas, roads and transport networks, rivers or stream) with different levels of accuracy and detail. The great advantage of this information is that the geometric information is linked to semantic information and that usually interoperable formats are used. That means that the information can be exploited automatically or semi-automatically.

In the manufacturing phase, the involved stakeholders differ a lot depending on the product and the materials used. Due that the materials and the processes involved in the production of the different systems are so different the stakeholders vary for each product. But they always maintain the same scheme:

- Providers of raw material: these are the companies in charge of supplying the material which composes the product in a raw format and all the additional materials needed to transform the main material into the desire product.
- Providers of transport of the raw materials to the manufacturer company and the companies in charge (this role can be assumed by the main company) of deliver the finalized material to the clients of the manufacturer companies.
- Subcontractors that participate in the manufacturing of the component.
- Certification (quality-requirements) organizations that verifies that the requirements of the owner of the end product are accomplished by the clients/suppliers.

The current communication among the different stakeholders in the manufacturing phase is through graphic and text documentation. The main instruments for the information flow are the tables of requirements defined by the owner of the system that need to be accomplished by the clients/suppliers of the products than compose the façade system. Moreover in some specific moments of the supply chain different verifications (by tests, by factory production control, etc.) are made in order the check that the requirements established are accomplished.

4.3.2 Current retrofitting design process:

4.3.2.1 Data gathering

The automatization of the data acquisition phase is not a common practice and usually the data are gathered manually by field work in a highly time demanding process with a high uncertainty level. In some specific cases, as buildings with high cultural value, scanning methodologies or photogrammetry is used but the translation of the outputs to standard formats as IFC is not usual.

The needed information could be classified in two classes: geometric information and semantic information. Within the geometry it has to be included the building but also their surroundings in enough level of detail to be the base for the project. Regarding the semantic information it depends on the scope of the renovation, but usually it includes all the attributes of the building that can influence the decision making process. Especially important are the characteristics necessary to assess the current state of the building and the constraints for the decision making. This information usually is both semantic and geometric.



Some municipalities use GIS to store urban information that can be used as input for renovation processes. This information can be especially detailed in historic environments and buildings as the municipalities have the command of keeping a catalogue about the listed buildings and their characteristics.

The main lacks of actual procedures of data gathering in Spain are mainly due to the inexistence of a strategic vision about the data management. Some of the consequences are the followings:

- The use of multiple data models and the lack of coordination lead to redundancy, inconsistency and problems with data integrity and make more difficult the collaboration between the stakeholders.
- The use of proprietary formats makes the interoperability more difficult.
- The lack of planning in the data gathering phase makes the post-processing time demanding and with high risk of inconsistency.

4.3.2.2 *Retrofitting project desing*

Nowadays the penetration of BIM in Spain can be considered low and the main tool for renovation processes in design phase still is CAD. But, recently (July 2015) the Spain's Ministry of Infrastructure (Ministerio de Fomento) has launched a national BIM strategy, which is expected to result in mandatory BIM requirements on public sector projects with a possible starting point of 2018. Therefore it is expected the speed up of the adoption of technologies under BIM paradigm that will affect the data gathering phase.

The design team usually establishes the data requirements that are necessary for the project. The owner provides the data or the design team obtain them depending on their agreement. When the project is done, all the information necessary for the process should be already in the project. Therefore once the owner gives the project to the main constructor it should not be necessary additional field work. Anyway, the lack of strategic data management makes very often necessary additional data acquisition in the construction phase.

Currently, the equipment/tools required for the design of the refurbishment project of a building in Spain are design tools (like Autocad, Allplan, etc), tools needed for the calculation of the structure (like Tricalc or Fagus), and tools and data base needed for the costs calculation (like Presto).

The use of the tools within the design teams that address renovation processes depend of the size and scope of the projects. For relatively simple buildings the geometric information can be obtained with simple measurement devices where the level of necessary skill is quite low. For more complicated building more sophisticated technologies may be necessary as 3D scanning or photogrammetry. In this case the necessary skill is higher for the data gathering and post-processing. Analogously, the semantic information can be obtained also with different degrees of sophistication. When the identification of the characteristic and the current state of the building is made by expert judgement the required tools usually are few but the necessary knowledge should be high to ensure accurate results. Some devices and tools are used to support this semantic data gathering as sensors, lux meters, thermography, etc.

4.3.3 **Retrofitting solutions and industrialization level**

We can distinguish between three common situations in façade refurbishment in Spain:

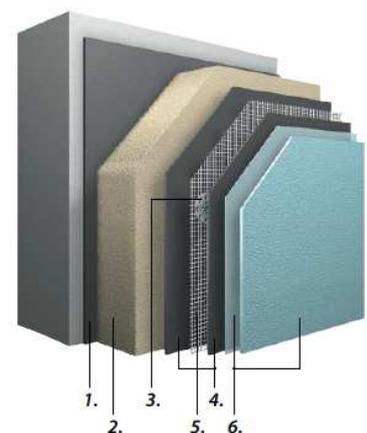
Older, listed buildings tend to have thick, stone or solid brick load bearing walls, which do not admit external insulation. Internal insulation is often used in these cases. Common exterior works include stone or brick cleaning, plaster and façade ornaments repair, and the latter use of “breathing” or stone protective layers. A high percentage of these buildings don’t get thermal insulation when refurbished. These can account up to 8% of façade refurbishment work.

- Solid façade buildings, account for a 10% of the stock. These are the most adequate cases for external insulation, since they are mostly buildings of no architectural interest, with huge energy consumption, and low income occupancy, which allows for public funding. In this case, the most used solutions are ETICS or a ventilated façade with metal substructure and aluminium, ceramic, treated wood or phenolic resin board finish. Other common solutions include the use of external sandwich cladding, composed by an insulation layer and an external, vapour resistant finish layer.
- Cavity wall buildings account for at least 70% of the stock. These are mostly post 60’s buildings with reinforced concrete structure and the façade is composed by an inner brick leaf, cavity and outer brick leaf with plaster, or ceramic cladding.
- Façade cracks, interior mould or detachment of parts of the facade are the most common causes of refurbishment regarding Energy Efficiency solutions, **the most used solutions are ETICS or a ventilated façade.**

4.3.3.1 ETICS system

The etics system (external thermal insulation composite system or also known as exterior insulation and finish system (EIFS)) is a system that combines different layers with different materials. A figure of the layers can be seen below. The typical layers that compose a system like this normally are the next ones:

- Adhesive
- Thermal insulation material
- Anchors (plastic or metal elements)
- Base coat
- Reinforcement, usually glass fibre mesh
- Finishing layer: finishing coat with a key coat (optional) and/or a decorative coat (optional)
- Accessories, e.g. fabricated corner beads, connection and edge profiles, expansion joint profiles, base profiles, etc.



All these elements follow different ways of production and normally they are manufactured by different companies with different characteristics and different methods of production. They are collected onsite by the company in charge of the manufacturer of the façade and they are put in the building layer by layer by specialized workers.

- ✓ **Adhesive:** the adhesive layer of an etics system can be composed of different materials: mineral mortars, organic mortars and polyurethane with controlled

expansion. The manufacturing of the adhesive layer of the system is done in different ways but its production is a high industrialization process. An image of a typical manufacturing process of a mortar can be seen in the next figure.

- ✓ **Thermal insulation material:** the insulation layer of the ETICS system can use different materials (expanded polystyrene, mineral wools, etc.) each of them with its own production process with a high level of industrialization.
- ✓ **Anchors (plastic or metal elements):** the anchors used in the etics system have different configurations. They can be made of plastic injection moulding, extruded metal, etc. but all of them with a high level of industrialization.
- ✓ **Base coat:** the base coat, used for support the reinforcement, can be made of a mortar. The production process of this material is also highly industrialized.
- ✓ **Reinforcement** is usually glass fibre mesh, also highly industrialized.
- ✓ **Finishing layer:** the final layer of the etics systems can be made of different materials most of them cement based or ceramic based (with and adhesive mortar to the previous layer).

So the manufacturing of each layer is highly industrialized but the whole product is installed one by one in the building, in a manual manner with very low industrialization level.

4.3.3.2 Ventilated facade system

Ventilated facades can be described as a skin fixed to a supporting wall by some framing system that generally integrates as well some type of insulation.

The system is composed by the following elements:

- **Insulation:** Usually mineral and glass wools, due to fire requirements.
- **Framing to support external skin:** Aluminium profiles are most common but also steel and wooden systems are used.
- **External cladding:** There is a high variety of finishing elements; ceramics, polymer, aluminium, concrete, wood.



These three layers are put together onsite, in the final building during the construction process. Until this moment they are produced by different clients and factories under the specifications of the façade company which is the one that has made the design and has verified the compatibility between materials and the good behaviour as a façade component. It is usual that the façade company has a stock of the different layers in order to increase the construction times and to have more controlled the whole process but it is also possible that the different suppliers send the material directly to the construction site.

- ✓ **Insulation:** The material used for insulation in these type of systems is similar to those used in the etics systems described above. Usually they are used mineral and glass wools, due to fire requirements. It has also a big presence in this market the polyurethane based materials despite its bad fire behaviour.

- ✓ **Framing to support external skin:** Aluminium profiles are most common but also steel and wooden systems are used. Some systems can have these elements made in wood but their presence in the market is lower than the other two systems.
- ✓ **External cladding:** The material used for the cladding element normally is the core material of specialization of the façade company. All the others materials are provided by subsidiary companies of the owner of the system.

There is a high variety of finishing elements; ceramics, polymer, aluminium, concrete, wood and all of them have different production processes. As an example, one of the most common systems for ventilated facades is the high-pressure compact laminate with a high industrialization level.

4.3.3.3 Internal insulation

Internal wall is a simple measure that consists of adding a thermal layer of material to the existing wall through the inside with a plaster finishing. This solution is usually adopted in the case of single dwellings of the building, as an individual particular intervention.

The system is composed by the following elements:

- ✓ **Surface coating (green):** The new plasterwork that covers the insulation layer. Just like a normal internal wall, it can be painted (green in this case) or papered.
- ✓ **Insulation (orange):** The layer that prevents warmth escaping through the outside walls of the house. In this case, rigid insulation boards have been used.
- ✓ **Internal wall (white):** The old internal plaster which is now covered by the new insulation board and plasterwork.



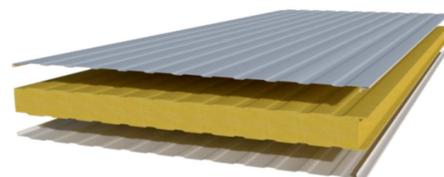
This can be done either with rigid insulation boards, or with a stud wall. The second one is thicker so it will reduce the size of the room more, but a stud wall is strong enough to hold heavy fittings such as kitchen units, radiators or wash basins.

If the façade is made of two layers with an empty air gap or cavity in between (cavity wall), this technology can be used by insufflating insulation from the inside or from the outside face. The main difference for certain height buildings is the access to the external face and the required means for those works.



4.3.3.4 Sandwich panels:

Sandwich panels for construction are a well-known technology consisting in two external steel layers and an internal light core with insulation. Self-supporting double skin metal faced insulating panels. It can be applied in roofs, external walls and the envelope of the building and for the following insulation materials; polyurethane, expanded polystyrene, extruded polystyrene foam, phenolic foam, cellular glass and mineral wool. The main considerations for these products and the expected application are:





- The structure or framing where the panel needs to be fastened. Generally a metallic substructure is not necessary for an over cladding application.
- Continuity of the insulation. The design and behaviour of the joint is critical for this point as well as the fastening solution.

The level of industrialization for manufacturing the components materials is very high and the manufacturing companies are working trying to improve these manufacturing processes. Nevertheless these two systems imply at this moment manual labours onsite and are these manual labours which make the systems to have problems due a big amount of time for installation and derived from this some quality problems in the final product.

The only way to change this lack of industrialization is changing the entire systems and their way to be installed in the final building. It is labour of the façade companies to propose new designs and systems, using market materials in a new configuration or asking for the developing of new materials, which can improve the industrialization process on the whole value chain trying to reduce the problems that appears during installation times.

4.4 WOOD PRODUCTS IN CONSTRUCTION AND REFURBISHMENT

The wooden house or wood-walled house is highly localized, and accounts for a small fraction of the European housing stock and for an even smaller fraction of the annual additions to that stock.

The sawnwood consumed in European housing enters into one-floor and two-floors family houses and in apartment blocks built of bricks, stone or concrete; it is consumed either in the house itself - as a building element (in the roof structure, joists and beams covering the basement and supporting the floors and ceiling, and various framework) or in joinery (flooring, doors, windows, stairs, cupboards, etc.) - or as part of the equipment used in the erection of the house (scaffolding, and molds for concrete constructions). Of the wood that becomes a permanent part of the house, that used for the building elements is required, generally speaking, in larger dimensions and with higher strength qualities than that used for joinery.

The fact is that, till now, the use of wood as a structural element had been declined most, and that this decline was closely bound up with changed methods of construction.

Now, the new Engineered wood products, and the need of a sustainable construction, give a hopeful future to wood construction.

There are limitations on the maximum cross-sectional size and lengths of sawn timber that can be used as a structural component due to the availability of log sizes and the presence of naturally occurring defects in the timber.

These defects can be cut out and the timber reconstituted using engineered wood techniques such as finger jointing (Figure 29) to create longer lengths of timber of an assured strength grade, or laminating to form a homogeneous timber section. Combinations of timber or laminated sections with different materials such as wood-based boards or metal elements are used to create 'engineered wood products' (EWPs) whose maximum size is limited only by manufacturing, handling and transportation constraints.

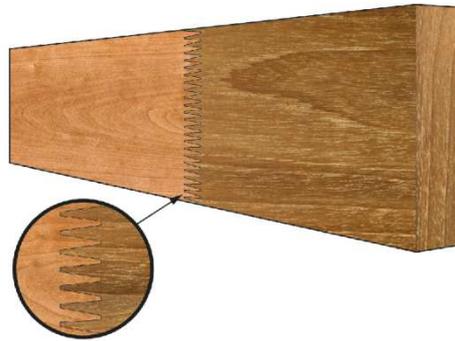


Figure 29. Finger jointing of timber

In addition to engineered wood products, there are reconstituted board products which comprise smaller wood-based strands and fibres re-formed into panel products. These have structural applications but are also used extensively in the furniture-making and packaging industries.

4.4.1 Engineered wood products

EWPs including glued laminated timber, finger joints, plywood, stressed skin panels, mechanically and adhesive bonded web beams and connected and nail plated trusses, have been in existence for at least 40 years.

Recently, there have been significant developments in the range of EWPs for structural applications with materials such as laminated veneer lumber (LVL), parallel strand lumber (PSL), laminated strand lumber (LSL), prefabricated I-beams, metal web joists and 'massive' or **cross-laminated timber** (CLT) becoming more widely available.

These EWPs are typically manufactured by adhesively laminating together smaller softwood sections or laminates (e.g. glulam and CLT) or veneers or strands of timber (e.g. LVL, LSL and PSL). The varying performance of EWPs is influenced by the size of wood component used in the product. At one end of the spectrum smaller sections of timber are laminated and finger jointed to form sections of glulam, whilst at the other end, reconstituted board products such as oriented strand boards (OSBs) and medium density fibre boards (MDFs) use small wood strands or fibres bonded together (Table 21).

Timber	<p>Sawn timber sections As cut from the tree</p>	<p>DECREASING SIZE OF ORIGINAL WOOD MATERIAL</p>
Engineered wood products (EWPs)	<p>Finger jointed lengths of timber Fabricated from smaller lengths of timber to form a longer element length</p> <p>Glulam and CLT Small sections typically 25-45mm thick glued together to form a bigger beam or slab section</p> <p>Veneers e.g. LVL or plywood Typically 2-4mm thick wood glued together to form sections – both boards and beams</p>	
Reconstituted board products	<p>Strands e.g. OSB wood slices Glued together to form sections – both boards and beams</p> <p>Wood fibres Bonded to form sections – more typically used for board products than beams e.g. particleboards and fibreboards</p>	

Table 21. Fibre size and beam types for timber products

4.4.1.1 Thin webbed joists (I joists)

I joists (Figure 30) are an EWP manufactured with flanges made from softwood or LVL with glued thin webs generally made from OSB, fibreboard or plywood. I joists can be used to resist either flexural or axial loads or a combination of both.



Figure 30. Use of I joists for a floor structure

4.4.1.2 Metal web or open web joist

Open web joists are shallow parallel-chord trusses manufactured using similar techniques to that used for trussed rafters comprising a member with flanges (or chords) usually made from softwood and with metal or timber strutting to form the webs (Figure 31).

The chords (and webs where timber webs are used) are generally planed softwood graded in accordance with BS EN 14081-1. The strength class of the timber is usually C27 in accordance with BS EN 338:2009 or TR26 (whose characteristic strength values are equal to that of C27 but whose characteristic stiffness values are taken from BS5268-2:2002). The depth of the chords is generally 47mm and their widths range from 72mm to 145mm. Metal webs are typically profiled, nominal 1mm galvanised light gauge steel with a zinc coating specification of Z275.

Open web joists are principally used as a roof or floor joist element. They are often preferred to I-joists as they allow a combined services and structural zone.

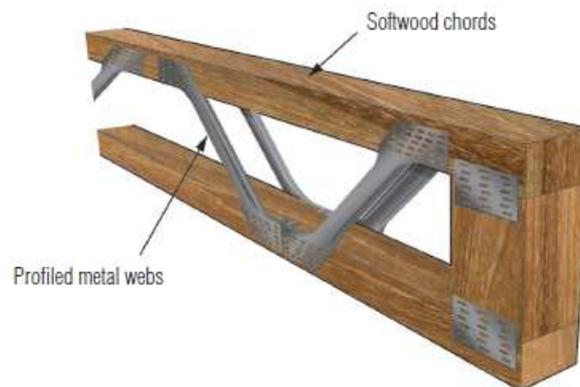


Figure 31. Open web joist

4.4.1.3 Plywood

Plywood is a flat panel made by bonding together, under pressure, a number of thin layers of veneers (or plies). Plywood was the first type of EWP to be widely available.

The structural properties and strength of plywood depend mainly on the number, thickness, species and orientation of the plies.

The structural grade plywoods that are commonly used in the UK construction industry are:

- American construction and industrial plywood
- Canadian softwood plywood
- Finnish birch-faced, birch and conifer plywoods. Birch plywood gives a good fair-faced finish and is readily persuaded into curved profiles
- Swedish softwood plywood

Plywoods are typically used for roof and floor decking applications and for wall sheathing boards.

Plywood for structural applications should be specified as “having exterior glue bond to BS EN 314-2 and veneers in compliance with BS EN 636:2003”. This replaces the previous definition for the plywood of WBP exterior grade where ‘WBP’ describes the properties of the adhesive and ‘exterior grade’ describes the durability of the outer veneers.

The characteristic strength and stiffness values for plywood for use in structural design are contained in BS EN 12369-2:2004.



Figure 32. Plywood

4.4.1.4 Laminated veneer lumber

Laminated veneer lumber (LVL) is a structural member manufactured by bonding together thin vertical softwood veneers with their grain parallel to the longitudinal axis of the section, under heat and pressure. In some cases cross grain veneers are incorporated to improve dimensional stability.

LVL is often used for high load applications to resist either flexural or axial loads or a combination of both. It can provide both panels and beam/column elements.

The requirements for LVL are contained in product standard BS EN 14374:2004.



Figure 33. LVL

4.4.1.5 Laminated strand lumber

Laminated strand lumber (LSL) is a structural member made by cutting long thin strands approximately 300mm long and 0.8mm - 1.3mm thick directly from de-barked logs. The strands are blended, coated with adhesive and oriented so that they are essentially parallel to the longitudinal axis of the section before being reformed by steam-injection pressing into a solid section. LSL is used in similar applications to LVL.



Figure 34. LSL

4.4.1.6 Parallel strand lumber

Parallel strand lumber (PSL) is a structural member made by cutting long thin strands (typically 3.2mm thick, 20mm wide and up to 3.0m long) from timber veneers. The strands are oriented so that they are essentially parallel to the longitudinal axis of the section before being coated with adhesive and fed into a continuous press and microwave-cured. PSL is used in similar applications to LVL.

LSL and PSL have recently become less widely available in the UK due to a preference for LVL and supply chain considerations.

4.4.1.7 Glued laminated timber

Glued laminated timber (glulam) is a structural member made by gluing together a number of graded timber laminations with their grain parallel to the longitudinal axis of the section. Members can be straight or curved, horizontally or vertically laminated and can be used to create a variety of structural forms (Figure 35).

Laminations are typically 25mm or 45mm thick but smaller laminations may be necessary where tightly curved or vertically laminated sections are required.

The requirements for the manufacture of glulam are contained in product standard BS EN 14080: 2013.



Figure 35. Glued laminated timber

4.4.1.8 Cross laminated timber

Cross laminated timber (CLT) is a structural timber product with a minimum of three cross-bonded layers of timber, of thickness 6mm to 45mm, strength graded to BS EN 14081-1:2005 and glued together in a press which applies pressure over the entire surface area of the panel.

CLT panels typically have an odd number of layers (3,5,7,9) which may be of differing thicknesses but which are arranged symmetrically around the middle layer with adjacent layers having their grain direction at right angles to one another (Figure 36).

The structural benefits of CLT over conventional softwood wall framing and joisted floor constructions, include:

- large axial and flexural load-bearing capacity when used as a wall or slab
- high in-plane shear strength when used as a shear wall
- fire resistance characteristics for exposed applications
- superior acoustic properties

Due to its arrangement as a panel rather than a framed construction comprising discrete loadbearing elements, CLT also distributes concentrated loads as line loads at foundation level. A variant of CLT developed in Germany in the 1970s is Brettstapel or 'massive timber', which is the term commonly used for solid timber construction that does not generally use glue or nails. Fabricated from softwood timber posts connected with hardwood timber dowels, the system works by using dowels with a moisture content lower than that of the posts. Over time, the dowels expand to achieve moisture equilibrium, thus 'locking' the posts together and creating a structural load-bearing panel system. CLT should be designed using the principles given in BS EN 1995-1-1 and -1-2 together with data from the manufacturer of the product.



Figure 36. CLT

4.4.2 Reconstituted wood-based board products

Reconstituted board products are typically manufactured by combining smaller wood strands or fibres with adhesive. There is a structural penalty when timber is modified from a sawn product to small strands and fibres used in board products, as the effects of creep increase as the amount of glue used to join the smaller wood elements increases.

The design of reconstituted timber board materials takes the resulting reduced performances into account by the use of relatively low values for the factor k_{mod} in BS EN 1995-1-1 for OSB, particleboards and fibreboards.

4.4.2.1 Oriented strand board

Oriented strand board (OSB) is a multilayer board made from strands of wood sliced from small diameter timber logs and bonded together with an exterior grade adhesive, under heat and pressure. OSB is manufactured in various grades with improving resistance to the effects of moisture. The minimum grade that should be used for structural applications is OSB/3 as given in BS EN 300:1997. OSB is commonly used as a structural sub deck material for floors and roofs and as a sheathing material for walls. It is also used for composite constructions such as I joist webs and structural insulated panels (SIPs).



Figure 37. OSB

4.4.2.2 Particleboard and fibre composites

There are a number of different board materials made from particle and fibre composites including fibreboards, tempered hardboard, cement-bonded particleboard and wood chipboard. The most common for structural applications is chipboard, which is made from small particles of wood and binder.

Chipboards are classified as grades P1-P7 in BS EN 312:2003 depending on their intended use. The minimum grade that should be used for structural applications is P5 which is a moisture-resistant grade.

The characteristic strength and stiffness values for OSB, particleboards and fibreboards for use in structural design are contained in BS EN 12369-1:2001.

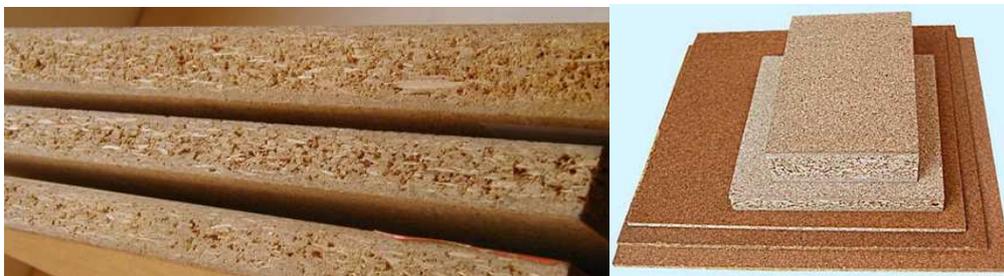


Figure 38. Particle boards



Summary of timber, engineered wood and board products and their structural applications

Product	Application	Common sizes
Sawn timber	Small structural framing, studs and joists, general carcassing, door panels, joinery	Length: up to 5.4m Width: 25-75mm Depth: up to 250mm
Finger-jointed softwood	Floor and roof joists, ceilings, loadbearing studs, cladding support, prefabricated multi-span 'cassette floors', laminations for glulam members	Length: up to 20m Width: 38-75mm Depth: up to 250mm
Glulam	Large structural elements, beams, columns, trusses, bridges, portal frames, post and beam structures	No theoretical limits to size length or shape. Common size range: 60 to 250mm wide by 180mm to >1000mm deep
'Massive' or cross laminated timber (CLT)	Floor slabs, roofs, beams, columns, load bearing walls, shear walls	Length: up to 20m Thickness: 50-300mm Width: up to 4800mm
Laminated veneer lumber (LVL)	Beams, columns, trusses, portal frames, post and beam structures, structural decking, I-joist flanges, stressed skin panels	Length: up to 20m Width: 19-200mm Depth: 200mm up to 2500mm
Laminated strand lumber (LSL)	Beams, columns, post and beam structures	Length: up to 20m Width: 30-90mm Depth: 90mm to >1000mm
Parallel strand lumber (PSL)	Beams, columns, post and beam structures	Length: up to 20m Width: 45-200mm Depth: 200mm to >1000mm
Particleboards	Flooring, ceiling and panel infill	Board materials typically available in 1220mm x 2440mm sheets and thickness ranges from 9 to 25mm
Oriented strand board (OSB) & plywood	Structural sheathing and decking	
Metal web or open-web joists	Floor and roof joists, ceilings, prefabricated 'cassette floors'	Length: up to 20m Width: 72-147mm Depth: 200-400mm
I joists	Floor and roof joists, formwork, ceilings, loadbearing studs, cladding support, prefabricated 'cassette floors'	Length: up to 20m Width: 38-97mm Depth: 200-500mm
Box beams, thin flange beams e.g. stressed skin panels	Beams, roofs, columns	No theoretical limits to size length or component sizes

Table 22. Summary of timber, engineered wood and board products and their structural applications



4.4.3 Advantages of EWPS as structural materials

Use of waste timber

Timber can be recycled and turned into strands and fibres and reconstituted into an engineered wood product.

Enhanced strength and stiffness

By building up a structural section from a number of smaller elements it is possible to reduce the variability inherent in natural timber, thereby improving the strength and stiffness of the composite section.

Increased size and scope of application

Engineered timber structures incorporate factory produced components where the constraints on length and section may be determined only by manufacturing, handling and transportation considerations rather than the constraints set by the size of log available. It is therefore possible to extend the range of timber engineering possibilities to large span and tall structures.

Reduced moisture content

The production requirements for certain EWPs may call for lowmoisture content e.g. gluing, which can result in lower movement upon drying out in service. However, in some cases (e.g. OSBs) the moisture content of the product following manufacture is lower than will be experienced during the construction phase, which can lead to problems due to dimensional changes of the product in humid environments.

Dimensional consistency

Engineered wood products disperse the natural defects inherent in solid timber and are manufactured to controlled tolerances. As a result, their dimensional consistency is significantly improved. This can be beneficial where tight tolerances may be required e.g. at connections. More regular joist depths also result in flatter floor structures than would be possible with sawn timber joists; thus avoiding some of the problems that can be associated with small variations in joist depth such as 'nail squeak'.

Ease of installing services and ease of handling

Service runs for mechanical and electrical infrastructure can easily be installed through open-web joists and, to a lesser extent, through I joists.

I joists and open web joists in particular are lighter in weight than equivalent solid timber sections and are therefore easier to handle.

Types of timber structures

Structural methods have been developed, incorporating EWPs, to provide timber structures which achieve a particular function with satisfying aesthetic form and performance e.g. timber gridshells and stressed skin panel roofs.

Portal frames and beam and post structures

Large open plan structures can be created by using portal frames and beam and post structures constructed from engineered wood products.

Platform frame construction

Methods of construction such as platform frame construction enable the construction of multi-storey timber frame structures for buildings which have a cellular arrangement of rooms and where internal loadbearing walls can be utilised.

Structural insulated panels

Other structural systems such as structural insulated panels (SIPs) are composite members which use a core of rigid insulation, not only

to provide a u-value for a building's thermal envelope, but also to form a longitudinal shear connection between plywood or OSB face layers; thus enabling it to act as a structural panel.

Table 23 provides a brief description of the types and scope of engineered timber structures that can be designed to provide structurally efficient and aesthetically appealing structures for a wide variety of building uses. These and other structural methods will be investigated in more depth in subsequent articles in this series.

Table 23. Types of timber structural systems and their applications

System	Application	Limitations
Platform frame construction (softwood construction)	Residential, care homes, hotels, student accommodation	Commonly used for cellular-plan buildings with internal load-bearing walls. Up to 7 storeys possible, however requirements for preventing building overturning may govern
Glulam or LVL beam and post frames	Schools, atria, commercial, supermarkets	Used to create 'open' framed areas but require separate bracing systems for stability. No theoretical limits on span or number of storeys
Glulam or LVL portal frames	Halls, industrial buildings, arenas, distribution centres	Usually single storey. Large open spaces with spans of more than 30m possible. The size of the portal frames is usually only limited by transportation
Cross laminated timber (CLT) or 'Brettstapel' (massive timber)	Multi-storey residential, schools, academies, auditoria, exhibition spaces, places of worship, sports halls, theatres where an exposed timber finish is beneficial	Platform and balloon-frame construction. Tall single storey wall panels possible and structures up to 10 storeys tall have been constructed. Large panels need careful consideration in terms of transportation and handling
Structural insulated panels (SIPs)	Residential, care homes, hotels, student accommodation; infill panels to steel and concrete frames; roof panels for 'room-in-the-roof' construction	External envelope wall panels within platform frame or frame infill construction. Up to 4 storeys possible for load-bearing applications. Good thermal performance. Roof spans may be limited by shear and creep deflections of core materials
Special structures	Gridshells, arches, domes, bridges	Project specific solutions which typically span 10-50m, though there are examples of 150m span gridshells
Engineered trusses	'Feature trusses' using glulam or oak, industrial, commercial and institutional	Spans between 10 to 50m
Trussed rafters	Roofs for residential buildings, care homes, hotels, masonry, steel and concrete structures	Typically up to 12m but for special designs spans of up 30m are practicable
Trussed rafters	Roofs for residential buildings, care homes, hotels, masonry, steel and concrete structures	Typically up to 12m but for special designs spans of up 30m are practicable



4.4.3.1 Design

Eurocode 5 has provided opportunities for designers to use timber for new applications that should give economic solutions, particularly as the code makes provision for the use of new materials, such as engineered wood products and new efficient jointing techniques. The code encourages engineers to gain a greater understanding of timber which will lead to more efficient and innovative designs for engineered timber structures.

Structural forms and detailing, together with examples of calculations for structural timber to Eurocode 5, will be discussed in future articles.

4.4.3.2 Limitations

In addition to the structural strength and stiffness aspects of timber engineering there are other considerations which affect 'wholebuilding' performance and must be considered. These include:

- Timber shrinkage and differential movement
- Design for robustness
- Architectural detailing including detailing for durability
- Fire during construction and service
- Workmanship and maintenance

4.4.3.3 WPCs

Wood-plastic composites (WPCs) are composite materials made of wood fiber/wood flour and thermoplastic(s) (includes PE, PP, PVC etc.).

Chemical additives seem practically "invisible" (except mineral fillers and pigments, if added) in the composite structure. They provide for integration of polymer and wood flour (powder) while facilitating optimal processing conditions.

In addition to wood fiber and plastic, WPCs can also contain other ligno-cellulosic and/or inorganic filler materials. WPCs are a subset of a larger category of materials called natural fiber plastic composites (NFPCs), which may contain no cellulose-based fiber fillers such as pulp fibers, peanut hulls, bamboo, straw, digestate, etc.

Wood-plastic composites are still new materials relative to the long history of natural lumber as a building material. The most widespread use of WPCs in North America is in outdoor deck floors, but it is also used for railings, fences, landscaping timbers, cladding and siding, park benches, molding and trim, window and door frames, and indoor furniture. Wood-plastic composites were first introduced into the decking market in the early 1990s. Manufacturers claim that wood-plastic composite is more environmentally friendly and requires less maintenance than the alternatives of solid wood treated with preservatives or solid wood of rot-resistant species. These materials can be molded with or without simulated wood grain details.



Figure 39. WPCs

4.5 Organisation, machines, and information flows of wood based off-site manufacturing in Europe

The production volume largely depends on the degree of automation. Whereas the smaller companies build on workshop-like factory organisation, the larger companies such use flow-line-like and production-line-based factory layouts. Similarly, throughput times vary considerably from a few weeks in the case of the smaller companies to a few hours in the case of the larger and more automated manufacturers.

For example, in the prefabrication of panelised wooden buildings by the larger companies, the wooden frames are first produced on the framing station, filled with insulation and then sealed on a multifunctional bridge station continuously. After these process, they are transferred to a moving final assembly line (assembly of windows, façade finishing, doors, electrical wiring, etc.) where they are finished in a hanging, upright position. If the production volume becomes larger, the relatively slow final assembly process (compared to pre-processing and framing, etc.) can be distributed on two parallel running lines.

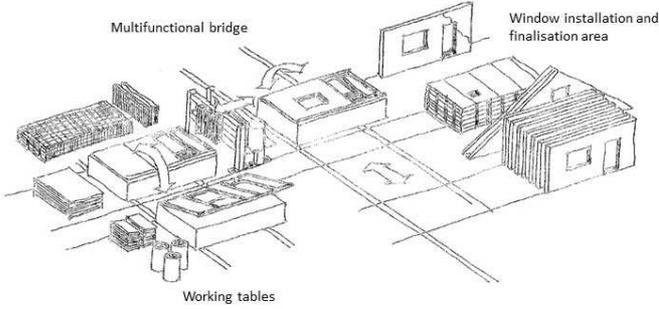
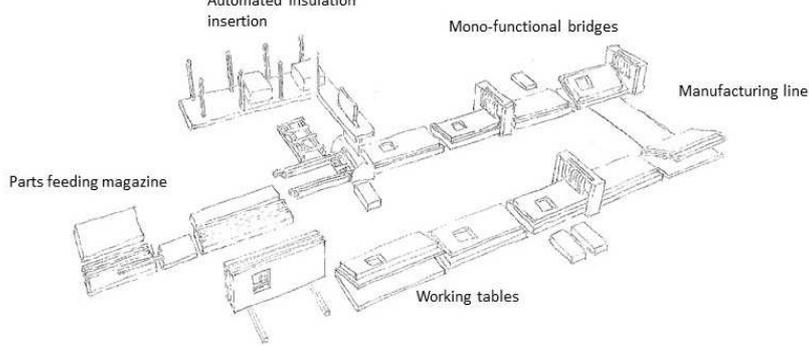
Most manufacturers of wooden panels are built on machine companies such as Hundegger in parts production (cutting and preparation of the studs, etc.) and Weinmann in assembly (framing, processing, and finishing of the panels, etc.). Weinmann, for example, provides workstations and machines (e.g. multifunctional bridges, laying tables, transfer systems, and butterfly tables) that can be used either as standalone solutions in a more workshop-like layout or as interconnected production lines. Modularity allows that individual workstations can be upgraded in a step by step approach from a low degree of automation (e.g. simple laying table) to a high degree of automation (e.g. a lying table with transfer system and a mechanism to automatically place the pre-cut insulation stripes). Similarly, framing stations are shipped with both lower degrees and higher degrees of automation.

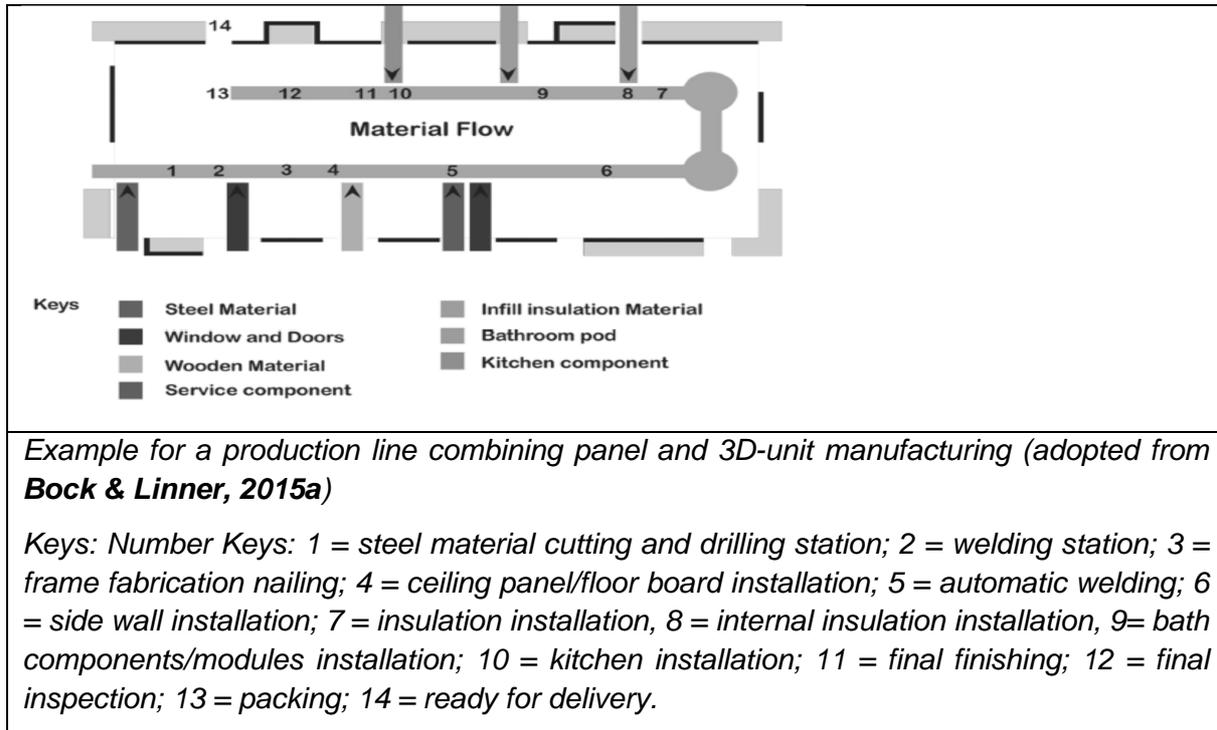
Manufacturing layouts for wood panel/3D unit manufacturing:

Manufacturing layout variants for wooden panels range from workshop like organisation in smaller firms and flow-line-like organisation in medium-sized firms to production-line-based organisation in larger firms with high-volume production. Some large firms add to the end of the actual frame manufacturing line another final assembly line along which the panels are

then moved, for example, in upright position for the assembly of finishing material. The material is supplied just in time just in sequence or over buffers to the location at the line where they are installed, however, in principle, the product (wall) comes to the worker and material to be assembled (mass production principle of Henry Ford). In contrast, smaller firms conduct final assembly with the product resting in a dedicated area (workstation or area in the workshop), and the materials are delivered from (central) supply shops. In some firms, mobile tool and workbenches (organising tools and materials) are used which individual trades/crafts men move to the location at the panel to assist in the assembly process. On the very top end, final assembly lines for panels are connected to manufacturing cells or lines for the assembly and finishing of 3-dimensional units. However, such systems can currently only be found in the Japanese prefabrication industry.

Table 24 Wood panels prefabrication


<p><i>Example for a wood panel prefabrication layout combining elements of workshop-like and flow-line-like manufacturing (adopted from WEINMANN Holzbausystemtechnik GmbH)</i></p>

<p><i>Example for a wood panel prefabrication layout with production line based organisation (adopted from Randek)</i></p>



Wood machining is quite automated and the use of different end-effectors in CNC machines is widespread in industrialized countries. Traditionally in manual wooden component manufacturing, each tool requires a specific machine. There is a workstation for sawing, another station for shaping, etc. Today, all these workstations have been linked and automated. Even though it could be difficult to saw, cut, plane, shape, mill, and drill in just one work station, nowadays, industrial robots can utilize different end-effectors that facilitate all facets of woodworking.

7. Automated cutting and shaping: Once either solid wood or engineered wood is produced, the first step to manufacture a component is to cut each element to an approximate size and shape. This step must occur before machining the element. The accuracy of the approximation depends on the element type. For a structural element, 5 centimetres can be left before final machining. For furniture elements, this allowable variation may be less than 5 millimetres before its introduction into a CNC machine. A circular saw is proper for linear cutting. This saw offers accuracy in linear shaping, and is rigid enough to maintain a straight cut. In manual cutting, circular saws were the cause of many injuries to carpenters' fingers. Band saws are flexible and better suited for cutting curved shapes. The band is continuous, normally turning in between two wheels and the element to be cut is placed between these two wheels. The band is normally less than 5 centimetres wide. Working with a manual band saw can be quite dangerous. If the curve of the incision is too small, the band could break apart or even burst.
8. Automated timber element machining: The main purpose of wood machining is to create a special shape for an adequate posterior assembly. When joining two wooden elements without any other special accessory, a void or channel is created in one of the elements



and a slot in the other one. The milling cutter is designed with a special shape. Tongue and groove, finger joint, and dovetailing, are some of the most used wood joinery systems. Sometimes, glue, adhesives, or nails are needed in order to make the joint permanent. Lately, special steel connectors are replacing permanent wood joinery systems. New furniture or even structural elements are a clear example for applying this concept.

9. Automated finishing: After the machining of the wooden element, normally the finishing of the wooden element is done before the assembly process. Wood must be protected against humidity, solar rays, fungus, and others threats (when wood is covered, this may not be needed). First, in order to open the pores and smooth the surface of the wood, sanding is required. This process can be done by robotic end-effectors. After this, the wood is impregnated with different chemical products. Painting and Varnishing must be done in special workstations, often closed cabins are used. To move from one workstation to another accurately, without inducing any scratches, robotic handling devices facilitate the transportation. In order to reduce time and space for wood machining, multi purpose CNC machines, by which an element can be cut, milled, drilled, and sanded, are used.
10. Tilting station: Wall and gable elements are transported from tables to the tilting station. The lateral procedure of the tilting table is carried out on the chosen track where the wall or gable element are subsequently positioned into the appropriate magazines.
11. Magazine for wall and gable elements: All walls and gable elements are temporarily or permanently stored in magazines whilst the walls are being processed. The plastering work or the painting of elements, as well as the assembly of doors, windows, and shutters are completed here. The walls or gable elements can then be directly loaded onto either a freight vehicle or dispersing wagon.
12. Nailing unit for the production of board batch elements: The individual boards are loaded onto the nailing unit using a conveyor belt or cross conveyor. This can be done manually or automated. A lifting apparatus sets up the boards that are then pressed together during the nailing process. During the automated nailing process, a nailing image is rendered containing defined protected areas that simultaneously control the nail entry and depth. The length and width of the board batches are variable. Key work stations/machines:

Machine and workstation solutions are available for all phases of manufacturing as the production of wooden parts (studs, beams, boards, sheets, etc.), the assembly of these parts into frames and their processing and final assembly, the assembly of frames and panels into 3D units and their final assembly, and last but not least logistics, transfer and storage solutions. Most equipment can be purchased by smaller firms as standalone equipment or combined by larger firms to production lines. Furthermore, most equipment or workstations are available as basic versions with low degrees of automation and as premium version with high degrees of automation. More and more researches are done regarding modularity and standardisation allowing that equipment can be upgraded gradually from low degrees of automation to high degrees of automation, and that stand-alone equipment can be extended towards full production lines.



4.6 CONCLUSIONS: GAP ANALYSIS FOR PROCESS IMPROVEMENT

The analysis of the current refurbishment processes in three different countries led us to some common conclusions:

- In general in Europe, construction industry is reluctant to accept innovation in processes, especially if we compare with other industries as automotive industry.
- The stakeholders' relationships are established by different contracts, agreements and working ways, depending on the country, size or complexity of the project. But, in general the interaction between the involved stakeholders and the information exchanges are not optimized.
- In complex refurbishment projects usually various different subcontractors and craftsmen have to be coordinated, each one using their own software and data formats. The lack of integration makes refurbishment a complex and error-prone process. The accuracy and consistency through all the process is difficult to obtain and requires high levels of coordination, discipline and compromise from the technicians.

Data gathering and desing:

- The data gathering largely depends on the scope, size and complexity of the project but there are not clear guidelines and protocols about the role of each stakeholder in data acquisition.
- The information requirements of the building are highly dependent on the prefabricated degree of the renovation solutions. The higher the prefabricated degree the higher the required quality of the information.
- The lack of planning in the data gathering phase makes the post-processing time demanding and with high risk of inconsistency. The lack of strategic data management makes very often necessary additional data acquisition in the posterior phases.
- The existence of building information with the geometric information linked to semantic information in interoperable formats would make the automatic or semi-automatic exploitation of the data possible.
- The use of diverse software tools and proprietary data formats introduce interoperability problems that require time consuming integration and harmonization efforts. The inexistence of a strategic vision about the data management and the use of multiple data models and the lack of coordination lead to redundancy, inconsistency and problems with data integrity and make more difficult the collaboration between the stakeholders.

Manufacturing phase:

- There is a lack of interaction between the prefabrication industry and conventional construction industry. The latter is usually averse to involve companies that provide solutions with a high degree of prefabrication since they are seen as a menace for their own business that is strongly related to on-site construction.



- To introduce prefabricated solutions, the existing information of the building have to be highly accurate and the manufacturing of these elements must ensure minimal tolerances. As they must fit exactly to the existing facades (including window opening and openings for guiding HVAC systems).
- The automation of the manufacturing process depends on the prefabrication degree: the lower the level of prefabrication of the solutions the higher the automation potential of them.

Installation phase:

- If prefabricated solutions are adopted, the timing of the building renovation processes is improved since some of the tasks are carried out in a factory, but then the off-site and on-site tasks have to be considered and coordinated.
- The sophistication of the installing tools and processes depend on the prefabrication level of the renovation solution components and their size.
- The complexity of the technique and the initial investment of the different types of installation, as well as the efficiency of the performance (time and cost) influence on the marketing of the building/product.
- New load solicitations of the prefabricated component have to be carefully analysed.
- The logistics of the installation of big prefabricated elements have to be studied as they can determine if the large prefabricated solutions are adequate or not. The existence of specific temporary storage at the site and the need of cutting the traffic in the surroundings in order to operate with the heavy mobile cranes have to be considered..

5 BERTIM HOLISTIC RENOVATION PROCESS DEFINITION

The objective of BERTIM renovation process is to adrees all the previous aspects of current retrofitting process in order to improve the identified lacks for a more efficient and holistic process.

The main objectives of BERTIM renovation process are threefold:

- ✓ To develop a data management procedure: from the data gathering to the analysis and assement in order to assure the harmonization of all the required data and the interoperability of the formats so that all the involved stakeholders can use and check the data for their specific needs.

The data management procedure should be based on BIM technology. BIM is information modelling and information management in a team environment.

- ✓ To develop a prefabricated module for building renovation that will be manufactured off-site and installed with lower time need and disturbance to the tennants of the building. The module desing and manufacturing should be the result of the holistic renovation process based in BIM.
- ✓ To define a mass manufacturing methodology for each of the three timber industries in the project. The methodology will onlcude the manufacturing of the components but also the transport and installation for a more cost-effective building retrofitting.



The process includes four main steps: Buildign Survey; Retrofitting project desing; Mass manufacturing and transport and installation along with an optional phase for assessing the feasibility of the renovation.

5.1 Feasibility phase

In big or complex projects, a feasibility phase can be necessary in order to assess the suitability of BERTIM process and products for a given building before significant resources are invested. The aim of this phase will be to carry out a feasibility study that will analyse the following issues:

- The compatibility between the building and BERTIM process and products
- Project targets and owner requirements
- Legislative restrictions and applicable standards
- Initial estimations regarding building performance, project timeline, cost and return of the invest (ROI)

This phase should be executed with a minimum information level in order to avoid waste of time and resources. In order to get the required information, the expert judgement of the design team and the manufacturers will be preferred rather than field work. The specifications of the BERTIM products that are going to be developed in task 2.3 could be a useful tool in order to make a first filtering of the non-suitable building typologies. The involvement of all stakeholders from the very beginning of the project is considered a good practice, since it fosters the coordination and commitment of the complete project team from early stages. But in projects with high levels of uncertainty could be preferred just to involve the key actors in orders to keep it flexible.

Once the feasibility is assured the normal process can start. The next figure shows the amount of stakeholders involved in each of the steps. All the stakeholders that are the building retrofitting team members should be working to the same standards as one another. BIM allows to create value from the combined efforts of people, process and technology.

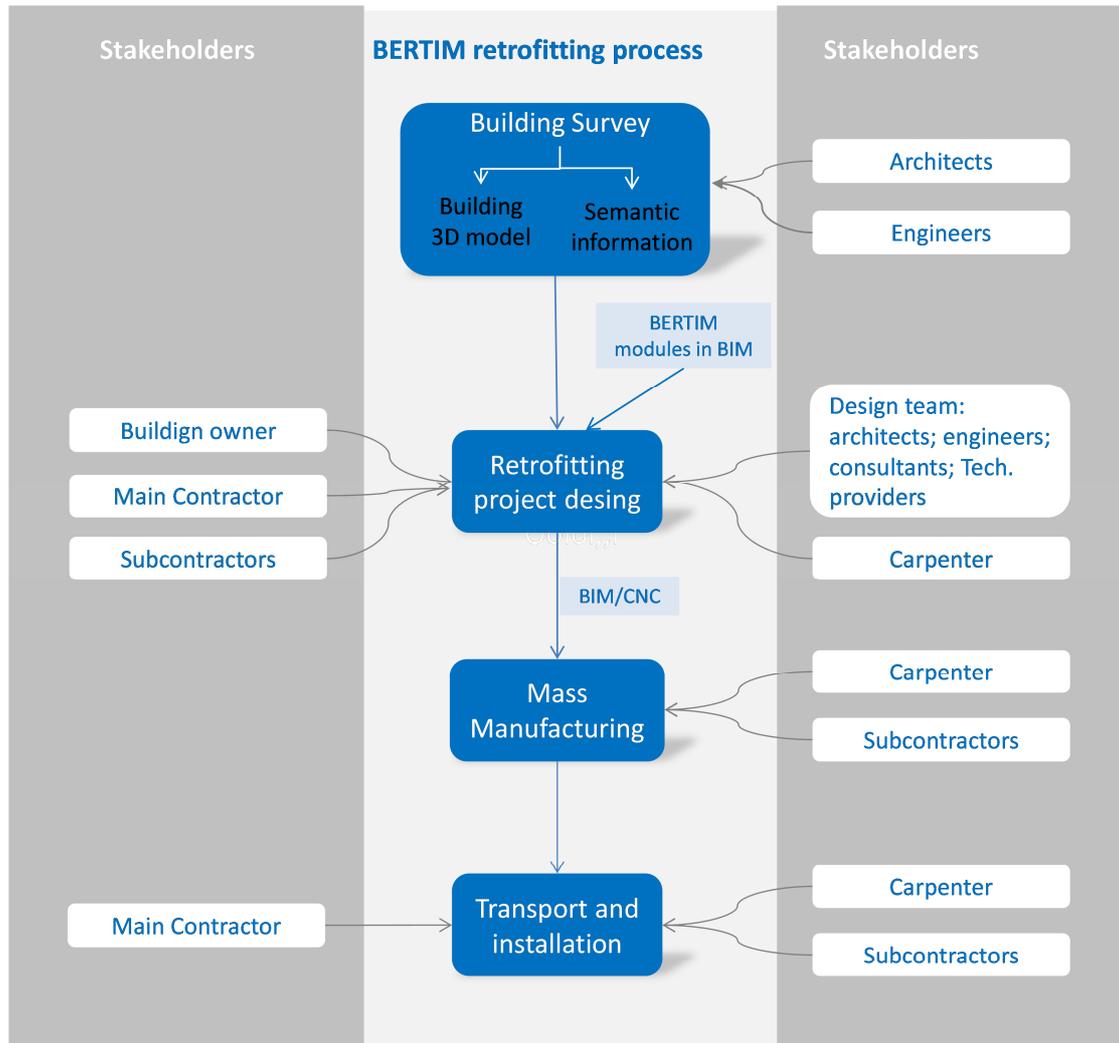


Figure 40. BERTIM retrofitting process and involved stakeholders

5.2 Buildign Survey

In order to design the digital workflow, the first step is to build the information model. Theoretically, the BIM could be updated or built from scratch depending on its existence or not. But, in Europe, the percentage of the building stock that have been built before 1991 ranges from a 81% in the North and West to a 86% in the South⁴, therefore the probabilities of finding a building in a renovation process with information in BIM format are quite low. For simplification purposes it can be assumed then that the BIM have to be build newly.

In order to develop the digital 3D model of the “as-built” BIM, the process from “scan-to-BIM” have to be implemented. Although some basic structures, such as walls, ceilings, floors and windows, can be detected and modeled automatically, this is a process that still is mainly manual. In this stage the model has not any semantic informatio, therefore it has to be added manually. The process will be the following:

⁴ Economidou et al. 2011



- Building survey and data capture
- Data processing (registration, merging/stitching, cleaning, decimation)
- Object recognition (semantic labeling)
- BIM modeling: creation of geometric and semantic building information.

The data gathering of the building has as objective to allow the assessment and decision making in the retrofitting project definition. Some of the collected information will be introduced in a Building 3D model in BIM and the rest will be kept in files (text and pictures) that will be linked to the BIM 3D model.

During the building survey two type of information should be collected:

➤ **Geometrical and topological information of building elements:**

- Geometry of the building (area, volume...)
 - Orientation
 - Façade length
 - Height (m)
 - Façade wall area (m²)
 - Roof area (m²)
 - Ground floor area (m²)
 - Glazed areas (m²)
 - Number
- Buildign structure: structural beams location and material
- Surrounding constructions
 - Transmittance schedules for surrounding obstacles that project shade over the building
- Shading element types
 - Local shading: Overhangs, sidefins, louvers
 - Window shading: Blinds, drapes, etc

➤ **Semantic information about the building:**

The semantic information along with the geometric information will provide the necessary input to the whole cycle of the renovation process from the assessment of the existing building to the interoperability with other sectorial tools. The semantic information will be of two kinds.

- Generic information regarding the building necessary for the identification and characterization of the building (e.g. address, year of construction, climatic zone, cadastre reference, state of building, degradation, use, sector site (urban, suburban, rural),...)
 - Buildign services and technical equipment existing in the building
- **Thematic information:**
- **LEGAL INFORMATION:** any legal barrier concerning urban planning etc. that could hinder the implementation of BERTIM prefabricated modules.
 - **ENERGY ASSESSMENT:** Based on ISO-13790 the following data could be required.
 - Geographic data



- City (Altitude, Latitude, Elevation)
 - Building orientation
- Climatic data (hourly values)
 - Outdoor air dry bulb temperature (°C)
 - Wind speed (m/s)
 - Wind direction.
 - Atmospheric pressure (Pa)
 - Global horizontal radiation (W/m²)
 - Direct horizontal radiation (W/m²)
 - Diffuse horizontal radiation (W/m²)
 - Global horizontal illuminance (lux)
 - Direct horizontal illuminance (lux)
 - Diffuse horizontal illuminance (lux)
 - Ground temperature (°C)
- Comfort conditions
 - Heating, Cooling and Ventilation:
 - Monthly availability schedule
 - Weekly availability schedule
 - Daily temperature set point profile
 - Lighting
 - Total installed lighting power (W/ m²)
 - Illuminance level (lux)
 - Monthly availability schedule
 - Weekly availability schedule
 - Daily working profile
- Internal heat gains
 - Occupancy
 - Occupancy (person/ m²)
 - Activity description / occupancy heat gain (W/ m²)
 - Monthly occupancy schedule
 - Weekly occupancy schedule
 - Daily occupancy profile
 - Equipment description (office, etc)
 - Total installed power (W/ m²)
 - Office equipment description / office equipment heat gain (W/m²) /
 - Monthly availability schedule
 - Weekly availability schedule
 - Daily working schedule
- Natural ventilation
 - Infiltration
 - Detailed infiltration schedules (monthly, weekly and daily)
 - Natural ventilation
 - Monthly natural ventilation availability schedule

- Weekly natural ventilation availability schedule
 - Daily natural ventilation schedule.
 - External envelop
 - Opaque area
 - U value (W/m²k)
 - Colour
 - Transparent area
 - U value (W/m²k)
 - Window frame material
 - Window frame colour
 - Shading elements
 - Partition area inertia
- STRUCTURAL CALCULATION: Once the method and tools for structural calculation are identified the required data will be defined.
- CNC SOFTWARE: The data and format necessary for ensuring the interoperability with the CNC Software will be defined later in the project.

Building survey technologies:

The gathering of the required information could be made by different techniques depending on the needed level of detail:

Decisive features	Data capturing techniques			
	Laser scanning	Photogrammetry	RFID tagging	Barcode tagging
Applicability in existing buildings	Yes	Yes	Limited	Limited
Cost	High	Medium	Medium	Low
Time	Medium	Fast	Fast	Fast
Spatial accuracy, Level of Detail (LoD)	High	High	Medium	Medium
Influence of size and complexity of the scene	High	High	Low	Low
Influence of environmental conditions	High	High	Low	Low
Importability into BIM	Yes	Yes	No	No
Data volumes	High	Medium	Low	Low
Degree of automation	Medium	Medium	Low	Low
Operability	Low	Medium	Medium	Medium
Equipment portability	Low	High	High	High
Equipment durability and robustness	Medium	High	High	Medium

Figure 41 Characteristics of the main data capturing techniques. Source: (VOLK et al. 2014)

In summary, the only data capturing techniques suitable for existing buildings are the laser scanning and the photogrammetry. The selection of one of these techniques could be made depending on the data volumes and the available resources.

5.3 Retrofitting project desing

The retrofitting project desing will define the BERTIM prefabricated modules that are required for building retrofitting. The definition will include the energy desing, the geometry nd the number.

The input data for the project desing come from the building survey. On the one hand the building 3D model is developed and in the other hand we already have the semantic information in order to take decision. The sematic information gathers the generic information about the building the legal aspects and the input data for the energy assessment.

The retrofitting project will be carried out by means of BERTIM prefabricated modules. The modules will be defined in BIM format and the geometry of the modules will be defined as a function of the Building 3D model in BIM.

Depending on the climatic zones where the retrofitting will be performed the required insulation thickness will vary. On the other hand the existing building systems will also define what kind of installations must be included in the building. The building structure will define if it is possible to install BERTIM prefabricated modules fixed to the existing façade or an structural reinforcement is necessary.

At the same time the feasibility of including one added storey in the building roof is assessed in order to define the required investment and the possible business models.

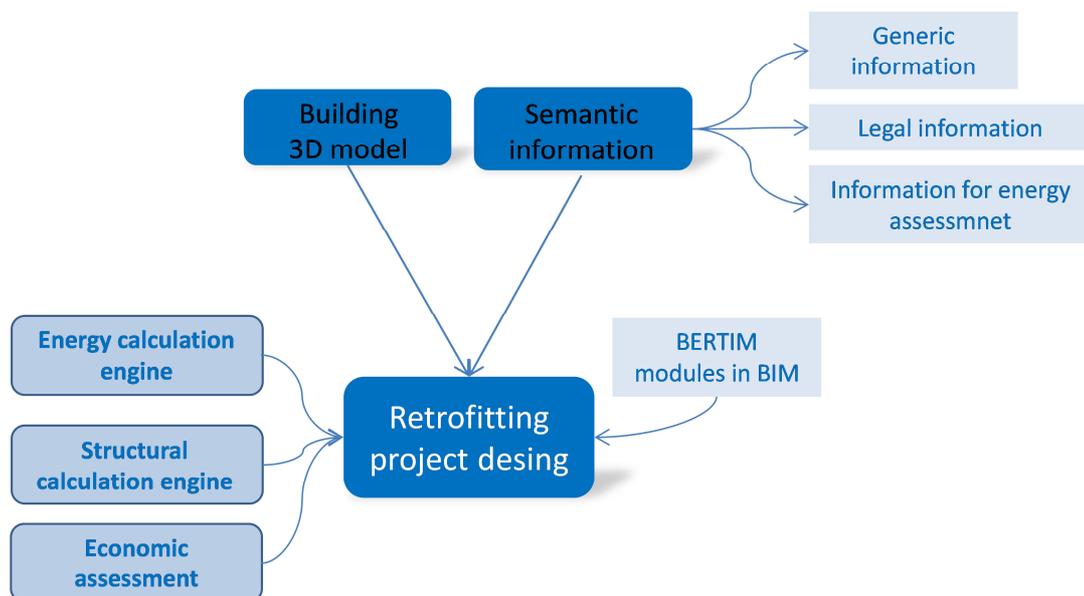


Figure 42 Retrofitting project design



The building 3D model is in BIM format and the BERTIM modules are also modelled in BIM. The result of the process is the required modules also in BIM format that are afterwards converted to CNC to send the manufacturing orders to the carpenter machines.

5.3.1 Energy efficient desing of the modules

Dependign on the location of the building to be developed the energy efficiency requirements will be different. The type of envelop and the existing HVAC systems in the building will also define the insulation that should have the prefabricated module, and the installation and distribution pipes and ducts that should be introduced in the modules.

So the design of the module will imply a desing of the insulation and energy systems to be introduced in the prefabricated modules. So the renovation should include a calculation of the energy consumption reduction achieved due to the installation of BERTIM prefabricated modules.

In order to carry out the energy efficient calculations the 3D model in BIM format will be used. The prefabricated modules will be also modelled in BIM and introduced in the calculation engine. So a energy calculation engine that can import and export BIM format is required.

The consultants, engineers and architects will share the building model in BIM and will use it for their calculations. At the same time they will provide the outputs of their calculations in the same format.

5.4 Manufacturing of prefabricated modules

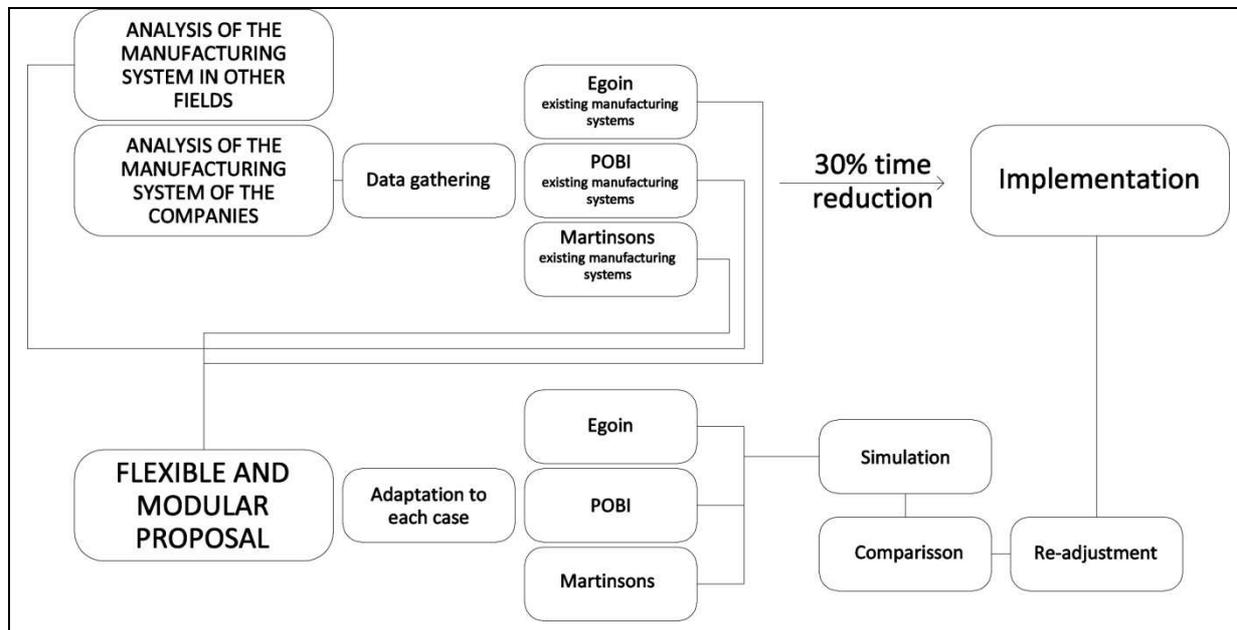
The objective of the mass manufacturing is the reduction in time (and cost) of the manufacturing process. BERTIM will allow the conversion of the BIM format to CNC in order to directly send the manufacturing orders from the retrofitting project desing modules to the machines.

On the other hand, the mass customization methodologies will also be implemented in the three timber manufacturers. The definition of the mass manufacturing process to be developed in BERTIM project will be defined by means of a research method, and the steps to be carried out will be the following:

- Analysis of the manufacturing system of the three participating companies.
- Analysis of solutions in some other industries, such as car manufacturing.
- Proposal of the mass manufacturing process: this proposal must be adapted to each case, it has to be flexible and modular.

Before the implementation of the proposed solution, some simulations and re-adjust it in order to acquire an optimal performance will be developed. Finally, the customized solution for each company should be implemented.

Table 25. Brief scheme of the research method.



5.4.1 Analisis of the manufacturing system of the companies

The participating companies have developed different automation levels in their manufacturing processes. The information has been obtained, for now, from one visit to the Egoin Factory. POBI has several videos uploaded to the website showing the production process. The information about Martinson is still missing. With that information, we can say that Egoin presents a low automation level; it is still a workshop like working place. This initial situation is challenging for Egoin. Even though they have a low automation level, they might a high automation level in the next 5-10 years. Martinsons is more industrially oriented and do offer a chain type production system. Finally POBI's components are produced in a partly continuous production line.

Second, we will consider the manufacturing process as the assembly of different elements or units. We can see that the different companies do already have a specific production of elements, such as CLT panels, windows etc. But besides the production of those elements, one needs to consider the different steps and phases that in each company are normally held for the assembly. The solution that has been taken is considered as an overall assembly process of components. But this overall process can be split in multiple work-stations. One can say that the workstations are modules were specific tasks are performed. One work station can be for the assembly of electric installation devices, the other for the installation of window and so on.

Third, we should consider a connected array of work steps and workstations from manufacturing to installation. Our goal will be to create a material and component workflow in a just in time just in sequence.

Resuming, the manufacturing system of BERTIM must

- a) be adaptable to various levels/degrees of automation

(principle 1: adaptable levels of automation)

b) be highly modular: separate work-stations
(principle 2: modular, changeable factory kit)

c) linked with the rest of the processes, especially with the on-site installation
(principle 3: integration of off- and on-site manufacturing)

5.4.2 Analisis of the manufacturing system in other fields

We have in this context studied the case of some manufacturing processes in the automotive industry.

The production of highly customized cars offers approaches that we must take into account. Besides, we have analysed some other examples such as, the cooperative robots that coordinate with worker and the use of smart glasses must be considered to.

Table 26. Case Studies

<p>Tilting unit where the workers can attach different elements easily</p>	<p>Individual manual work station in combination with logistics automation for advanced customization</p>	
<p>Examples: VW factory of the Phaeton car. Courtesy of Volkswagen.</p>	<p>VW factory of the Phaeton car. Courtesy of Volkswagen.</p>	
<p>Carrier robots instead of a production line for providing</p>	<p>Cooperative robots assist the highly flexible human</p>	<p>Smart glasses guide workers through complex customization</p>



extended demanded in customization	flexibility in product	worker in production	customized processes.
Examples:BMW Courtesy of BMW	factory.	Examples:BMW Courtesy of BMW	factory Examples: Courtesy of Vuzix Corporation

In the automotive industry, there is a clear organizational system that arranges the relation of the suppliers and the main manufacturer. The participating companies in BERTIM could be considered as Final Product Manufacturer or Component Integrators. The suppliers (subcontractors) could be differenced by its TIER level (1,2,3...), depending on the level where they supply their goods.

5.4.3 Proposal of manufacturing process (2D and 3D modules).

With the premises presented on the previous sub-chapter, we have developed a modular work-station system that can be adapted to different degrees of automation and that can be easilly linked to the CAD-BIM information as a start point and to the external transport and the installation process as the end of the process.

It is proposed a modular frame that accompanied the module and component along all the manufacturing process. On this frame, we could implement different tools that would facilitate the manipulation of module (handling, gripping). Besides, this frame can be useful for the linkage of the manufacturing process and installation process.

BERTIM will focus on the assembly of different sub-components such as prefabricated walls windows and similar ready-made units.

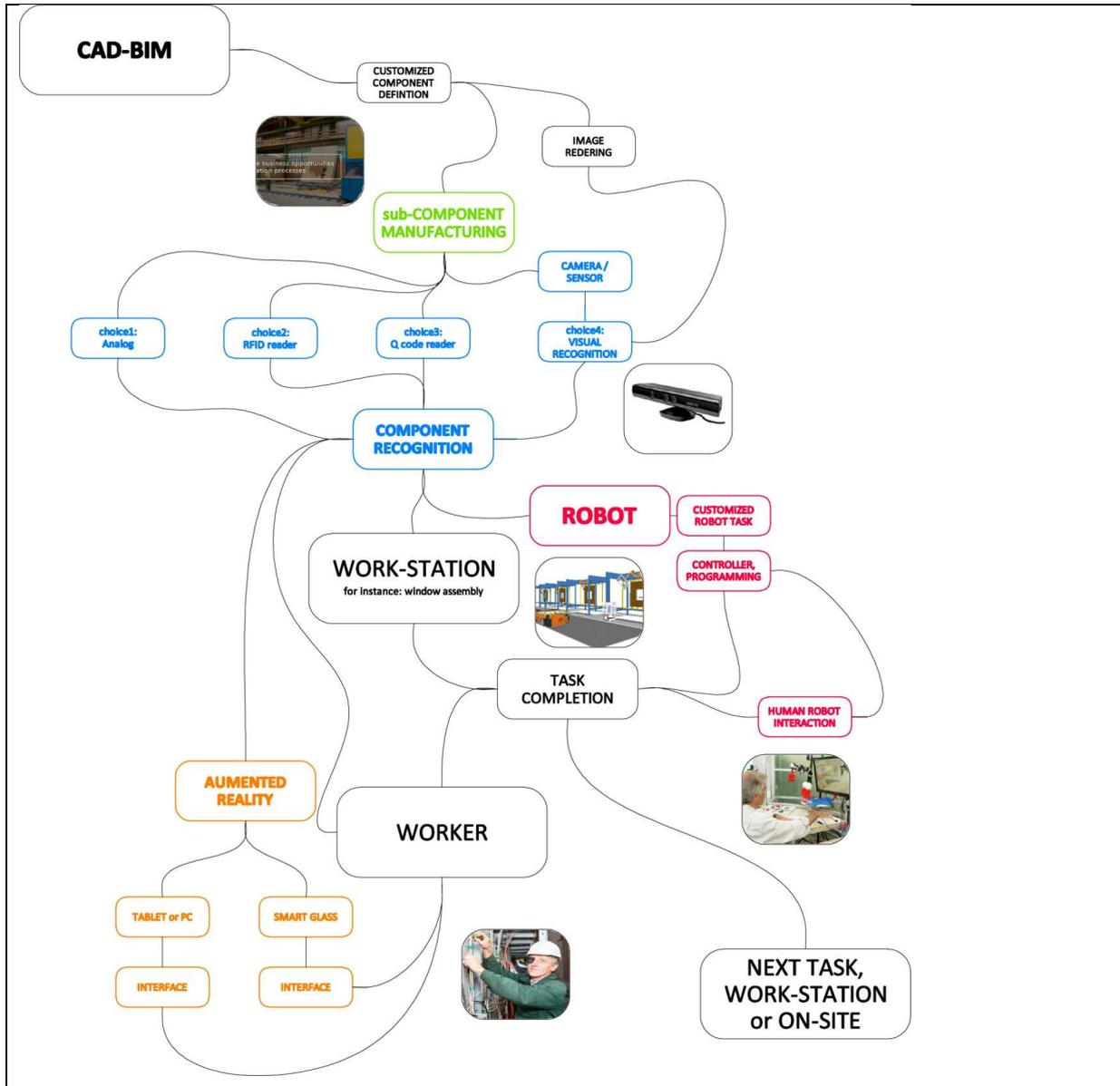


Figure 43 Scheme of the proposal [Examples: Linner, Iturralde, br2 TUM]

On the previous scheme, we can see that there are several options for developing a mass manufacturing process. Depending on the needs and possibilities of each company, the different features (robot, augmented reality, object recognition...) could be implemented accordingly.

5.4.3.1 Robots for mass manufacturing:

Several types of robots could be used. Hereby the use of different robots within the workstation is presented:

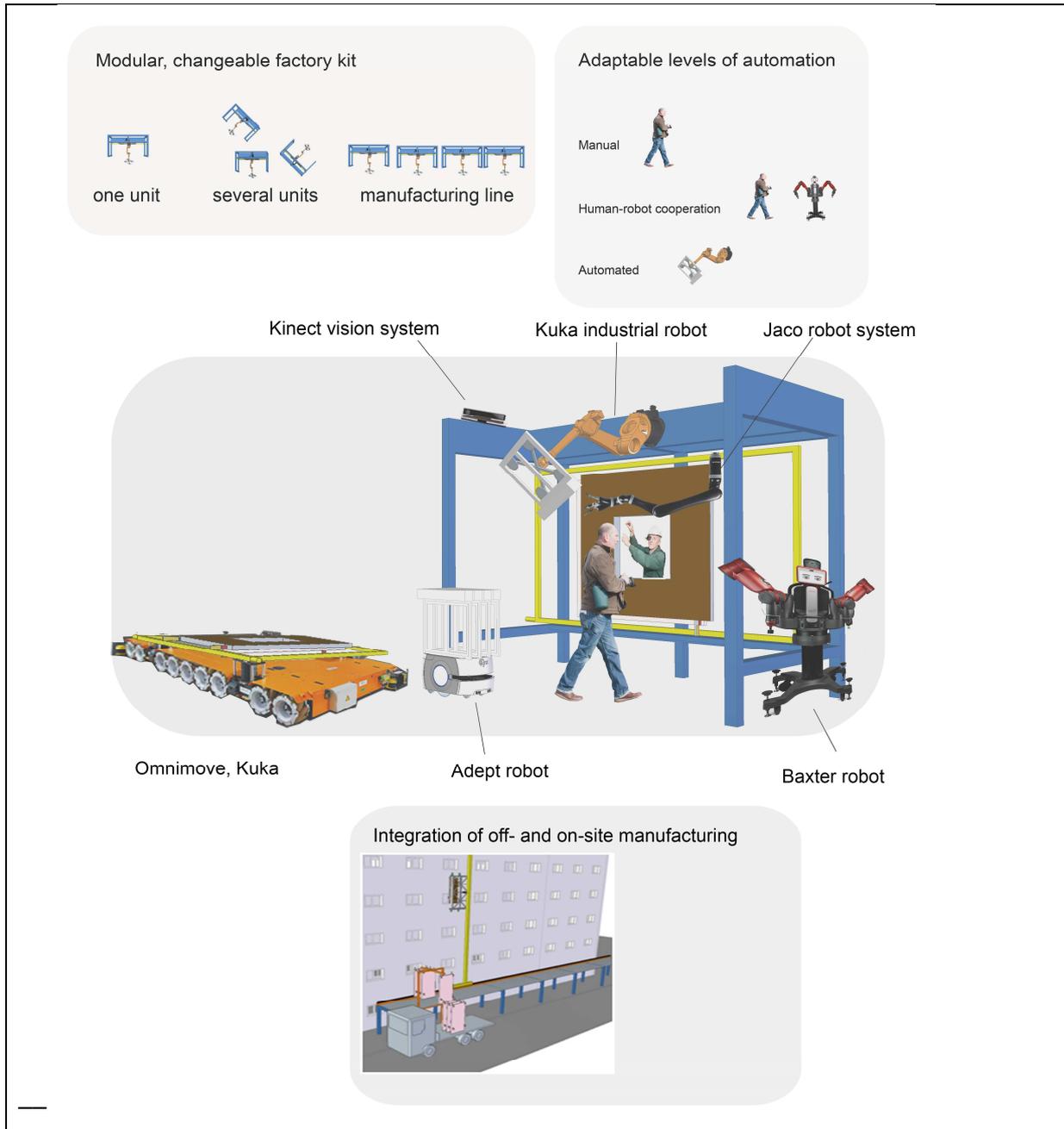


Figure 44 Possible implementation of different robots within the work-station [Examples: Linner, Iturralde, br2 TUM based on Kuka, Baxter, Adept and Jaco robots and Kinect visual Systems].

We found out that there are some possible tasks that can be automated or/and robotized within the assembly process of the component:

- Drilling and machining.** Before the installation of an extra element, such as rafters, electric boxes, or sub-structural profiles, a whole or a cavity must be made. Making those holes can be considered as repetitive task. For that purpose, the use of a **lightweight robotic arm**, such as Baxter, Jaco or Universal robots, can be suitable. If the needed end-effector needs to be heavier, then an industrial robot would be more suitable.

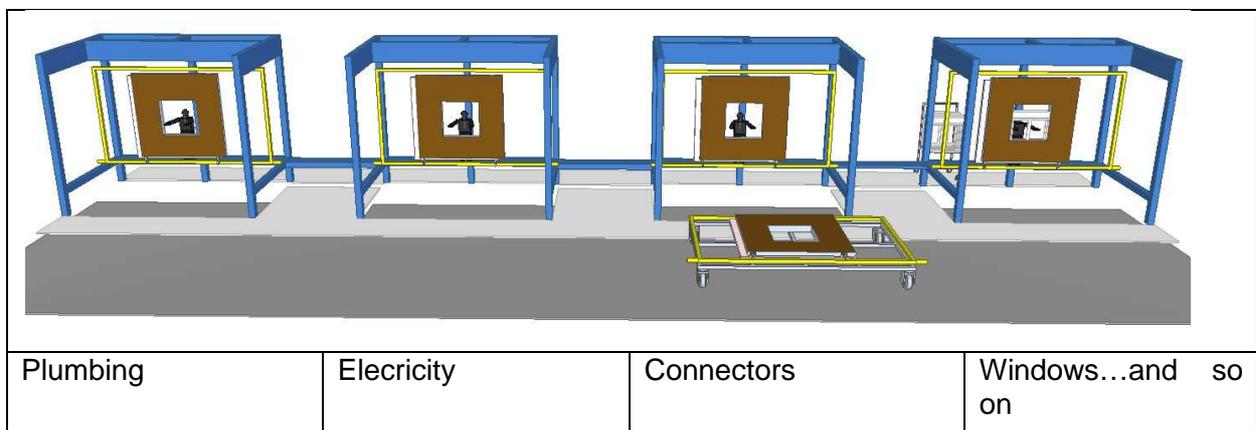
- **Gluyng, spraying and painting.** Some elements need to be glued in order to be fixed properly. There is already some experience on the installation of windshields with **robotic arms**. Besides, the envelope of the building might need a moisture barrier, which could be spread also by a robot.
- **Placement** of elements with robotic arm. Here, the payload of the robot must be bigger, therefore we should consider the use **industrial robotic arms**.
- **Fixation of elements.** The Baxter robot or any other robot are suitable for screwdriving fasteners, even in complex surfaces.

Besides, the tasks of puerely assembly process, there are logisitc issues that can be solved by special robots too. For the movement and approximation of the component, there are robots such as the Omnimove by Kuka, that can handle speciallu big loads. Besides, for smaller loads, such as screws, connectors and or even small tools, the Adept Lynx can facilitate the movement of those objects within the factroy. There are some complex tasks that might need the assistance and cooperation of the worker. The Baxter robot, Jaco robot, any other lightweight robot from Kuka or Universal can offer this feature.

We have also analyzed the logistics between the work-stations. In these sense, there are two choices. We have three levels. One is the transportation of the main component. Then we have the accessories; windows, plumbing and electricity devices.... And finally we have the movement of workers. Each level needs a specific path. The next picture shows the logistics with carriers: The main component travels in a carrier along its specific path (dark-grey). The accessories too are moved along its path (light-grey). The workers can move along the blue lines.

In the case of the workers, those are elevated from the ground so they can reach more points within the component. There are two approaches:

- One is based on a **conveyor**. This is more suitable for larger production volumes and higher degrees of automation
- The other is based on **carriers**, which are betterfor smaller production volumes and lower degrees of automation On the case the of the carrier the floor area needed is bigger.



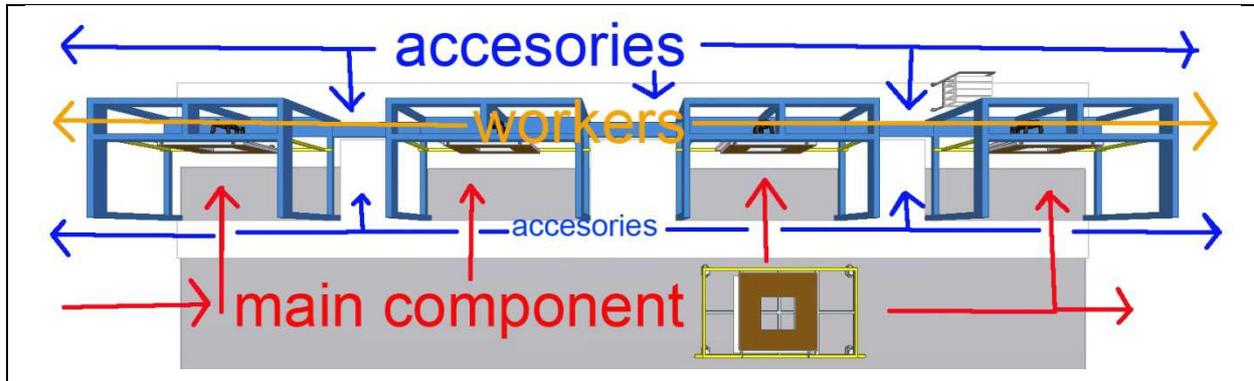


Figure 45 Modulation of the work-stations and circulation of elements, products and workers, logistics. The case of the carrier. [Examples:Linner, Iturralde, br2 TUM]

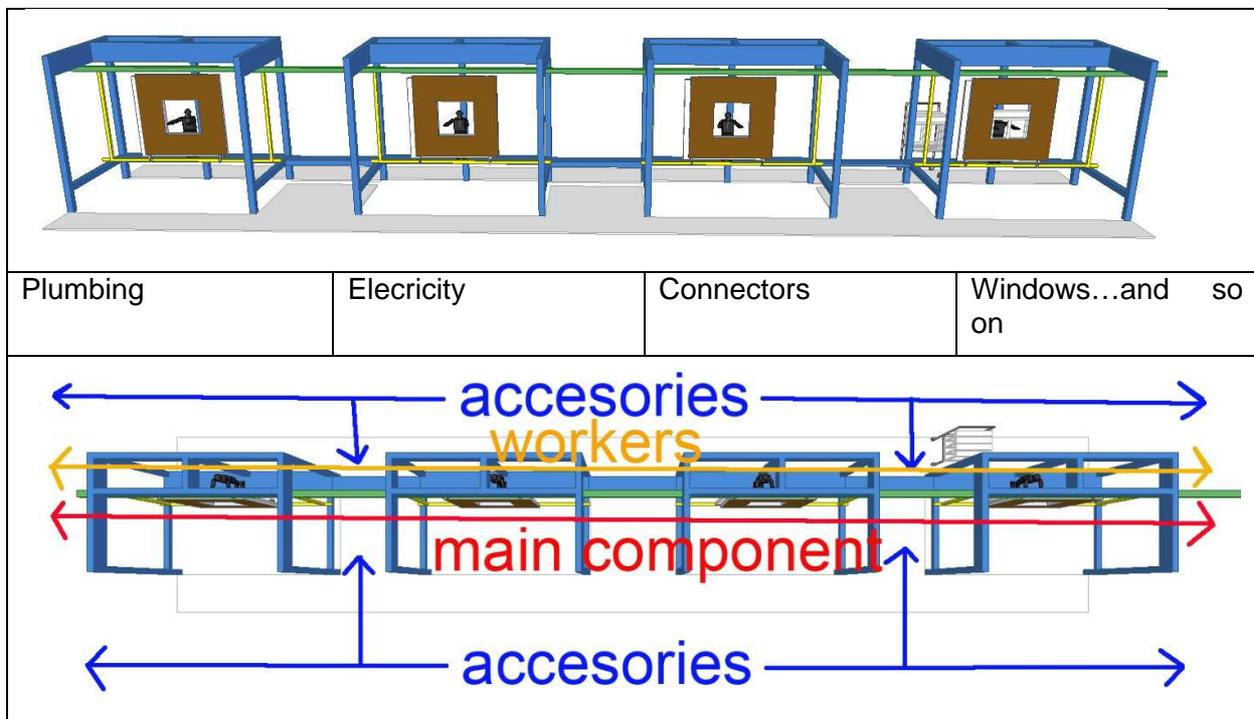


Figure 46 Modulation of the work-stations and circulation of elements, products and workers, logistics. The case of the conveyor. [Examples:Linner, Iturralde, br2 TUM]

Instead of a carrier, the conveyor passes through different work stations. On the case of the carrier, we have taken into account the **insertion** of the component within the work-station. Besides, we must consider the **tilting** of the component so the workers can assembly the elements properly.

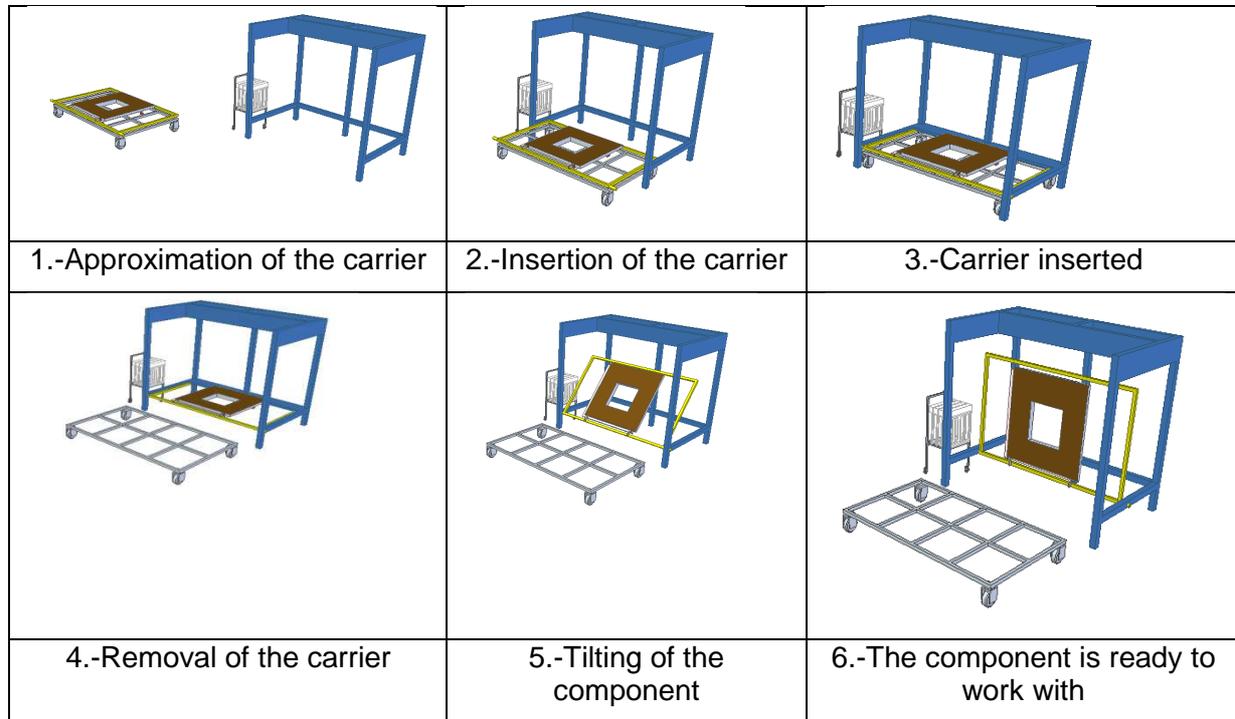


Figure 47 Logistics, the case of the carriers and the insertion and tiling the components [Examples: Linner, Iturralde, br2 TUM]

On the previous cases or solutions shown, the assembly process is held **manually**. But we must consider different **degrees of automation of the different work-stations and the logistics**. We've considered that the work station can be used either manually or robotically. Therefore, if the companies cannot afford purchasing some of the automated systems now, they can do it on the future: the work-station should be compatible.

As seen in next picture, the component can be adapted to different positions in order to facilitate the workers tasks

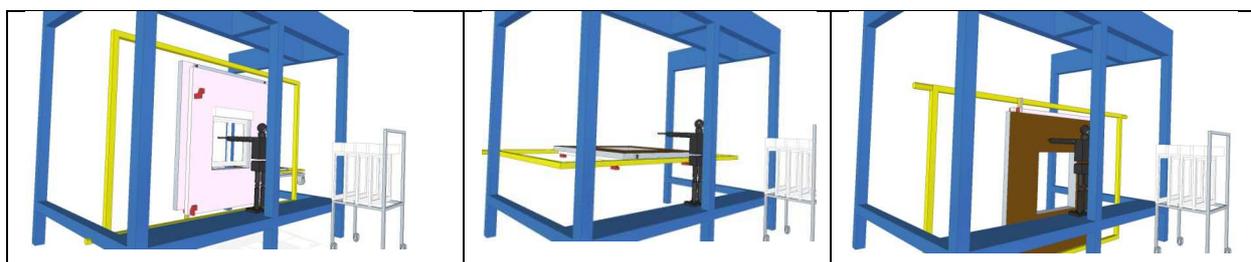


Figure 48 Manual work station [Examples: Linner, Iturralde, br2 TUM]

Another aspect that must be treated is the human-robot collaboration for the tasks where, due to its complexity, cannot be automated. In that sense, tools such as the RFID and Smart-glasses can provide the recognition of objects and workers positions.

It is proposed to use of a modular frame (in yellow in the pictures) that accompanies the component through all the process. We consider this frame is necessary for providing a stable coordinate-system that can be used in case of robotic assembly. The modular frame could be useful for the transportation of the component to the site. In case of a robotic installation

process, this frame would be useful also on the on-site installation process in order to facilitate the placement. Nowadays, the most used systems don't provide stability to the component. We will start with the 2D modules manufacturing solution. However, this solution will be built up in a way that the same system (workstation approach) could be used for 3D modules assembly.

5.4.3.2 Information tracking and information exchange among stakeholders

We need take into account concepts such as Cloud Manufacturing for the tracking, control and information exchange of products that are manufactured on the factory. The ideal solution would include also the products that are subcontracted outside the factory. As said before, this study will consider the use of different systems for the implementation of an efficient system for the tracking and control of objects and workers and the coordination between human and worker. Within cloud manufacturing, we must differentiate some concepts. We must consider that, in our case, the components are **totally customized**. Therefore, in order to facilitate a smooth **object work-flow**, some concepts should be implemented.

Component recognition:

Here we have the choice of adding identifiers to the object. Those identifiers can be useful not only in the production phase as integral part of the components but also for the on-site installing and the future monitoring of the building performance. The mainly used identifiers are:

1. RFIDs, which need specific printers and readers.
2. QR which only need reading system

We can say that the implementation of RFID or QR codes is already spread in the manufacturing industry. Besides these, there vision systems may offer a more suitable procedure to recognize objects without the need of an extra interface. For that purpose we can use vision systems such as Kinect and also regular cameras.

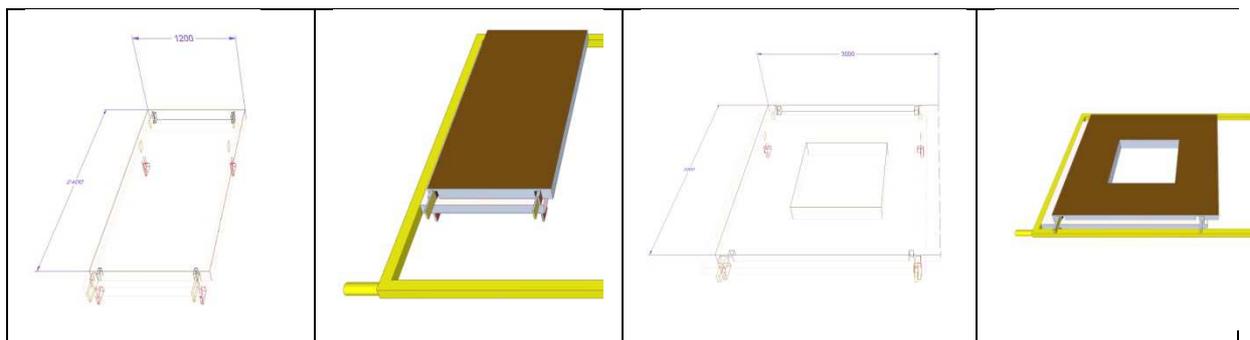


Figure 49 Object recognition. Link between the CAD drawing and the real object [Examples: Linner, Iturralde, br2 TUM]

Augmented reality:

Once the object is recognized, augmented reality can be used for facilitating the worker the information about a component and the tasks that must be carried out onto this component. The variety of components to be produced in such factories is big. We must foresee the

worker must have the whole information in advance achieving one task. This information can be provided by:

1. Smart Glasses
2. Tablets
3. Computers

The augmented reality will need to be linked to the object recognition and therefore we need to process the raw images.

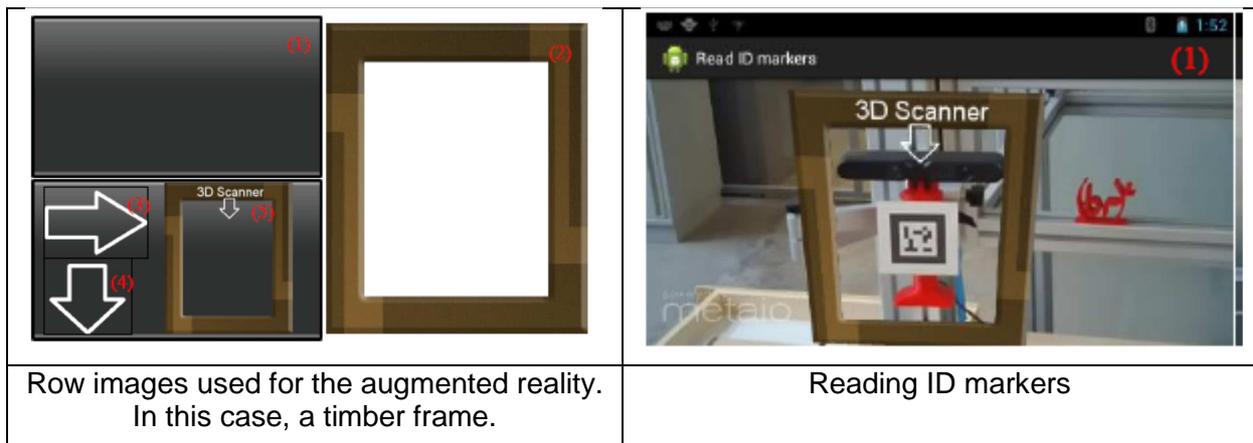


Figure 50 AR and object recognition [Examples: USA 2 project. By br2 TUM]

Parametric robot controllers:

In our case, we need to control the path and the tasks of the robot for each customized (but similar) component. If the objects that we are dealing with are parametrically designed, the path and tasks of the robot can be also controlled parametrically. The industrial robots manufacturing companies may offer this capability. Though, there are some other choices. For instance, the ``Association for Robots in Architecture`` has developed a controller that can be used with by Grasshopper 3D and Kuka Robots. This software is still in experimental phase. Besides, in case of other specifically designed and developed robots, we can also use Moveit and Gazebo within the ROS environment.

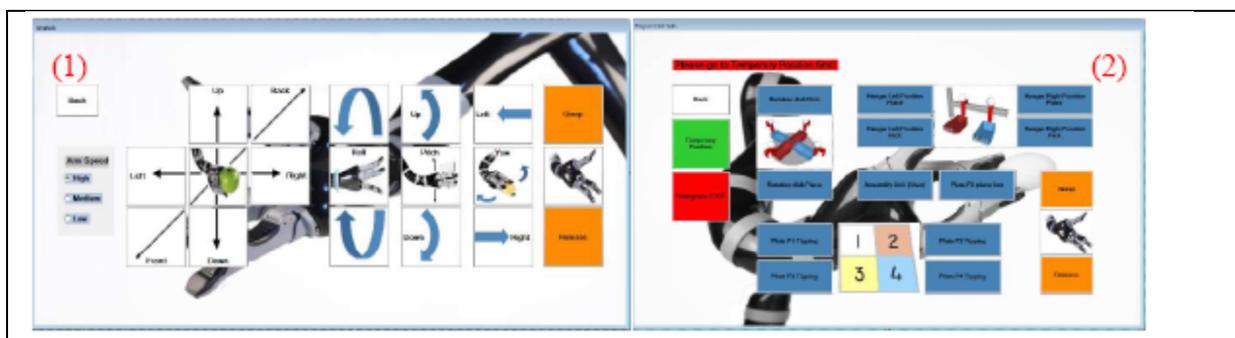


Figure 51 Robot controllers. Touch screen based GUI for robot control. [Examples: USA 2 project. By br2 TUM]

Human-robot cooperation:

This is far beyond the approach of BERTIM but this trend in manufacturing is included as a possible future implementation.

Human robot interaction is performed for achieving a **cooperative task completion**. In the case of the manipulation of construction components, this is very useful since normally the objects tend to be very heavy. The next devices are useful:

1. Leap motion controller for human-robot interaction as used in the research project USA² by br2 /TUM.
2. Any other remote control systems.

The next figure shows a human-robot cooperative task completion using Leap Motion Controller



Figure 52 Object recognition. Link between the CAD drawing and the real object. [Examples: USA 2 project. By br2 TUM]

Furthermore, the human-robot cooperation in the research project USA² has been used also to analyse the hand movements of the user regarding tremor and bradykinesia, which are typical symptoms of nerve diseases like Parkinson. The implemented algorithms are working in the background, providing the user information about his “health status”, while the user is fulfilling his tasks, using a gesture instructed robotic arm (see figure above).

5.5 Transport and Installation

Similar to the manufacturing phase, we will be guided by a research method. Here also, the goal is the **reduction in time** (and cost) of the **installing process**. The main steps of the method are next:

- **Analysis** of the **transport and installation systems** of the three participating companies.
- **Analysis** of solutions in some **other industries**
- Define an **adaptable** and **flexible** a **proposal**.



- **Simulations and re-adjustment** of the proposal.
- **Implementation** of the **customized solution** for each company.

According to the uploaded information on their respective websites, the installation of the modules differs from one company to the other. As overall, the installation of the POBI modules are ready to install and it is faster than the process performed by Egoi. There are some facts that affect to the installation process efficiency:

- Prefabrication level of the component.
- Types of Connector. In the case of POBI, they use a connector that facilitates a fast clipping.
- Use of specific tools for installation
- Information exchange.

Anyhow, the **installation system of BERTIM** must be adaptable to various levels/degrees of automation and **integrated with off-site manufacturing**)

Before the improvement of the whole installation process, we have defined the main tasks that will be carried out on-site. Our proposal will be based on three major steps:

- **Building preparation** before the installation of the new modules.
- **Reception** of the component on-site. There must be a link between the manufacturing process and the installation phase. We need to consider the time and place for **storage** of the components on site; from the reception of the module till its installation/placement, there is always a gap when the module stays stored. Our proposal will try to minimize the time of storage on-site.
- **Connector fixation** onto the existing building. Those connectors will need to be designed specifically to provide a fast clipping of the modules on its place. **Measure the exact coordinates of the connector**. Once this is achieved, the modules can be adjusted off-site exactly to the measurements that are required. **Placement of the component and modules** onto its place and **fixation**.

5.5.1 Building preparation

Considering BERTIM project two main strategies will be carried out with the existing envelope:

- **Maintain the existing key elements of the building**; wall, roof and windows. In this case, normally, the building users or inhabitants continue to use the building when the works are being held. And the most important point is that the added component needs to be accurately adjusted to the existing geometry. This means that the manufacturing needs to be fully customized and that on the installation process the component has to be installed with minimal tolerances (millimetre precision). In the renovation of the envelope of the Westend-Gate Hotel in Frankfurt, some of the cladding were removed, but the existing windows were kept to allow the customers to use the rooms.
- A **hybrid solution** is to keep the wall but remove the window including its frame and sill (Haus der Zukunft, Kapfenberg). This way, larger tolerances for installing the component are permitted compared to the first case. Sometimes a partial demolition of the façade can be useful for sanitizing the wall and removing old elements (see: Oulu project of E2Rebuild). When installing a classic EIFS system, in some cases the

previous mortar cladding of the building is removed in order to have more adhesiveness of the panels. Another solution for not being so constrained is to keep the existing window and add a new one.

There are some approaches on the use of automated tools in the field of dismantling elements and building demolition. For the case of finishing layer removals, Takenaka Corporation from Japan developed a robot delaminating the finishing material of the wall (Iturralde, Bock, 2013). Besides, some tasks such as ceiling dismantling have been tried with robotic tools (Ashizawa et al., 2009).

5.5.2 Installation, on-site logistics and support-bodies.

If we focus on the logistics of the component of big prefabricated elements, we can see that normally, the material needs to be delivered according to the speed of the installation time. Usually, there is no specific temporary storage at the site so the deliver truck spends less time on site. This issue has been already partially solved (Figure 53, right) on the first attempts.

Neither the cranes nor the scaffoldings are specifically prepared for the arrival of material and prefab components, the storage and its placement, so the solutions are mere adaptations of a general device for this specific requirement.

	
<p>Tower crane+scaffolding->big sized fully prefabricated [Source: E2ReBuild, Augsburg]</p>	<p>Tower crane + aerial work platform->big sized fully prefabricated. [Source: ECBCS Annex 50, Dieselweg 3-19, Graz]</p>

Figure 53 Examples of the use of different installing tools

Support systems are normally combined; it is rare to use only one type during a renovation process. For instance, in the case of big prefab elements, we can see that the component is usually lifted and held in position by using a tower crane or a mobile crane while the worker that is in charge of the fixation, can be supported either in a scaffolding or either in an Aerial Work Platform.

Table 27. Use of different installing devices for carrying out specific works

	Main support systems for workers	Main support systems for uploading and positioning
Manual procedure (EWIS // EIFS)	Scaffolding // Mast climbing	Hoist // Mast climbing
Semi Prefab (rain-screen)	Scaffolding // Aerial Work Platform	Tower crane or mobile crane
Fully Prefab	Scaffolding // Mast climbing	Hoist // Mast climbing

In that sense, it is quite a revealing procedure described for the case in Augsburg of the E2Rebuild (big fully prefab component), where the scaffolding was installed upwards simultaneously with the installation of the panels.

5.5.2.1 New approaches on installation, on-site logistics and support-bodies

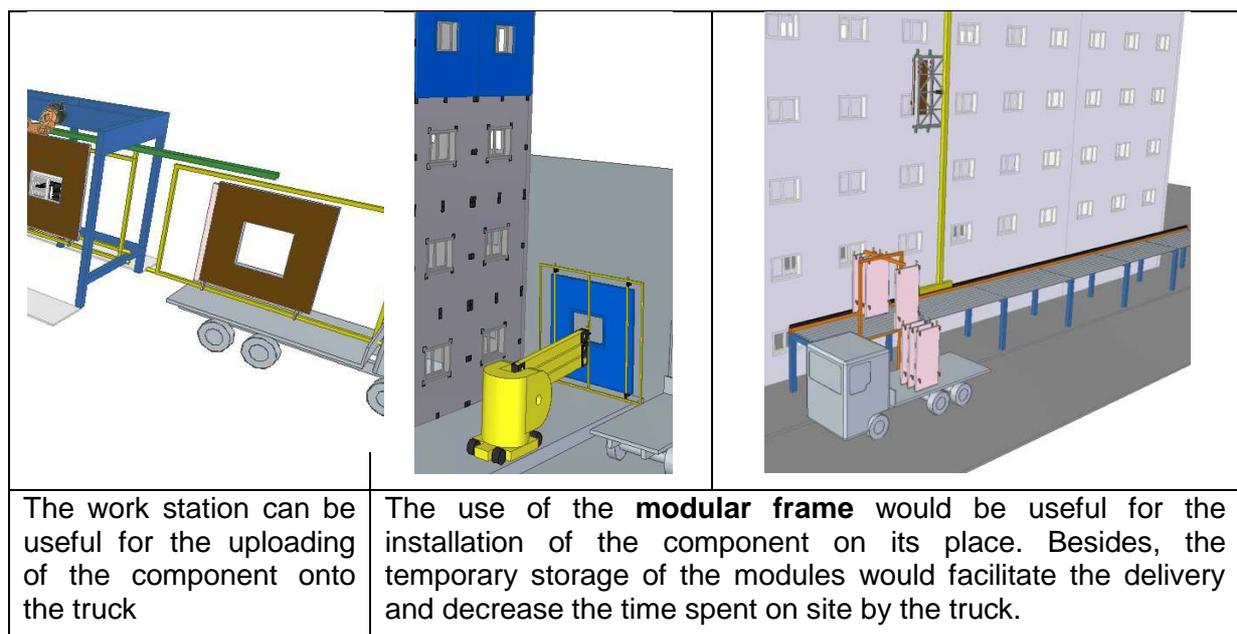


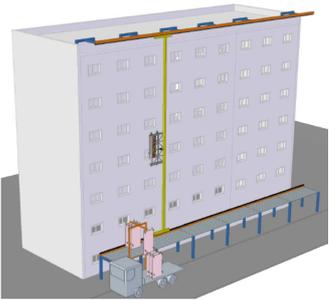
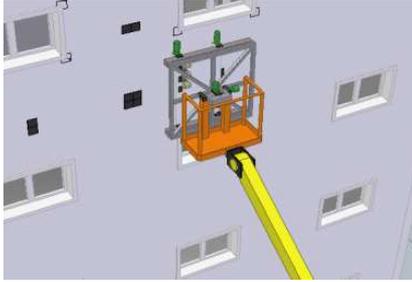
Figure 54 Link with the external transportation system and the installation process [Examples: Linner, Iturralde, br2 TUM]

Apart from these support devices, there are some other innovative attempts to create support devices. These are not so frequently used or they are still in a experimental development phase.

- Brunkeberg (Brunkeberg, 2015) re-cladding system. The studied system is based on horizontal conveyors and vertical hoists. According to the simulation, the existing curtain wall is removed and there must be some worker helping from the innerside of the building.

- The University of Hanyang has developed several robots for the installation of curtain wall systems. The first is based on a robotic arm standing on a mobile crane (Lee et al, 2008). The second is a robot that works from the interior (Yu et al, 2006)
- The br2 lab at TU Munich also conducted a research on some specific support devices. On the images, we can see three main types of support devices (Iturralde eta al. 2015).

Table 28. Approaches for ameliorating support devices [Examples: br2 /TUM (Iturralde et al., 2015)]

		
<p>Support device based on Automated Storage Systems</p>	<p>Semi-Automated device based on Mobile-cranes for the fixation of the connectors</p>	<p>Automated devices based on Hanging Systems</p>

5.5.3 Connectors and Joining system

Each type of new added panel needs a specific fixation to the existing wall. Nowadays, we can say that there are three main existing types: 1) punctual, 2) linear and 3) surface adhesive. The bigger and heavier the component, the higher load solicitations the connector must fulfil.

- ✚ Punctual is when a connector, or better said a group of connectors holds the component. Take into account that we need to fix the fastener or connector to structurally reliable elements. The base material also needs to fulfil some hardness requirements so the fastener doesn't get loosened. For heavy components, normally the anchoring point is on the concrete slab.
- ✚ Sometimes, due to heavy loads of the component, the anchorage must be lineal (Haus der Zukunft Kapdembeg, Annex 50), in order to distribute the loads all over the border of the structural slab. In this case, we have to take into account that timber profiles, unlike steel elements, do offer some flexibility and can be adjusted, re-shaped on site, by only applying some compression force or even grinding some surface. Again, if the strength of the structure of the existing building is not reliable, the component might need to be supported on the ground by a new linear foundation.
- ✚ The surface adhesive connection is based on chemical products. A surface adhesive fixation by itself cannot hold the weight of the added layer, therefore, a join is normally added too. This choice is mainly used for the cases of EIFS insulation panels. The insulating panel manufacturer (STO, Dow...) do provide special material for the adherence of the element to the existing wall.

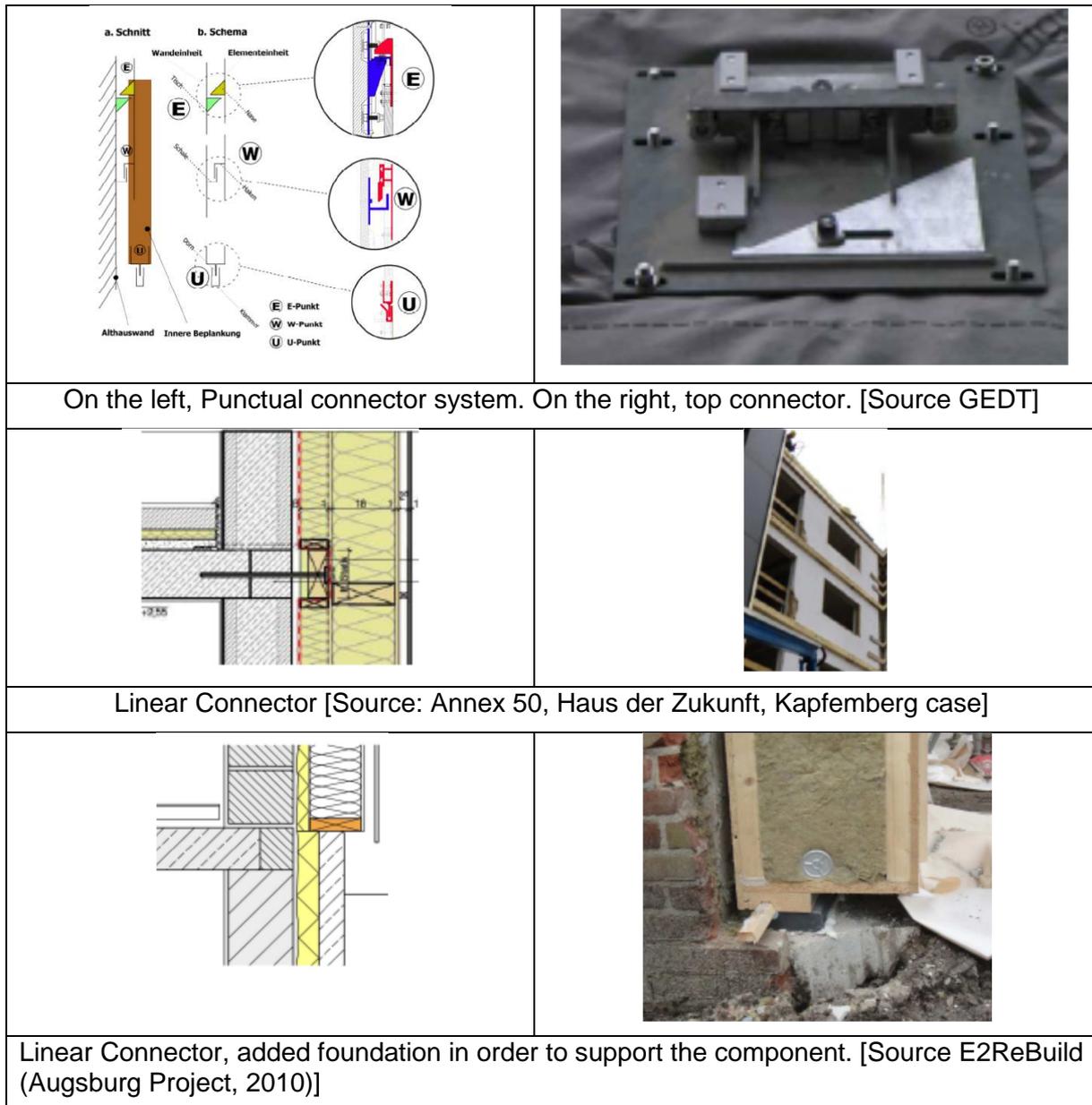


Figure 55 Different types of connectors

5.5.3.1 New approaches on connectors

If we look for the possibilities for the future research, there have been some attempts for improving the installation phase of big-medium sized and fully prefab components. One of them is related to the devices used at the site itself. The other attempt is related to the connection or joining system (Bock, 2001). This kind of connectors usually **guide the placement** of the module into its approximate coordinates. After that, the module can be **adjusted** to its specific coordinates. And finally, once the module is adjusted, it can be **fixed** either manually or automatically. This final fixing step might be organized in a different phase too, and the connector wouldn't take part in it.

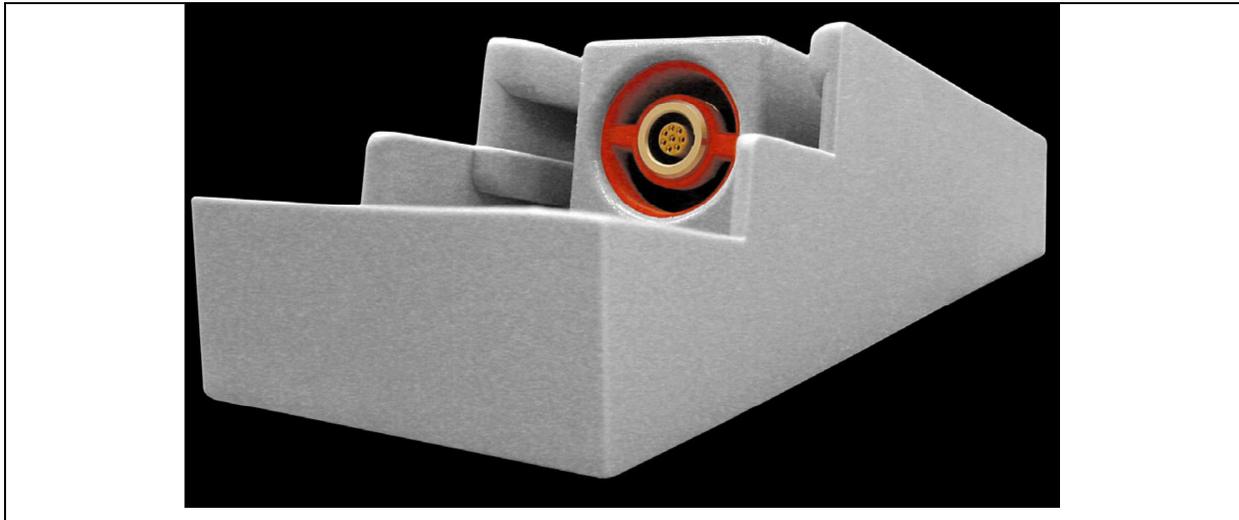
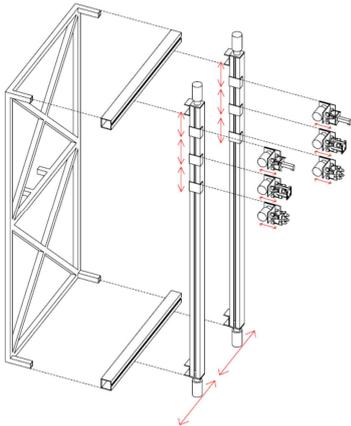
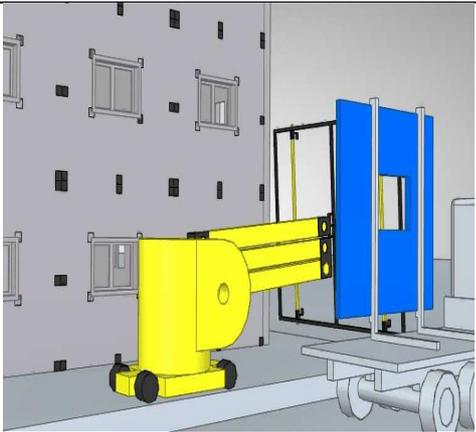


Figure 56 Fast joining system [Source: Prof. T. Bock (2001) / Br2 / TUM]

5.5.3.2 New approaches on fixation tools and end-effectors

There are some tasks that can be automated more easily than others. For instance, the connector fixation is a repetitive task that, under some circumstances, can be performed using robotic tools. Besides, we need to decide which kind of fixation fasteners and tools will be used. This issue will be limited by the size of the component and its weight. Briefly, we can show some experimental examples for handling with and installing components. Some robotic tools, or End-Effectors, have been developed for the installation of big panels onto existing building façades (Iturralde et al., 2015). The objective of these tools is to fix a connector first, and after that, the positioning of the component on its place.

Table 29. New conception of machinery for element and component installation [Examples: Iturralde et al.]

	
<p>Modular End-Effector system</p>	<p>The End-Effector attached to a Aerial Work Platform</p>



6 GENERAL CONCLUSIONS

The aim of this deliverable has been to define the BERTIM holistic renovation process as the basis for the methodological and technological developments foreseen in the project. The first step has been the analysis of European building stock. Although a deeper market analysis is going to be carried out in task 2.3, it has been considered necessary to study the requirements for the process that come for the building characteristics of the different countries represented in the project (Sweden, Germany, France and Spain).

It has been concluded that the age and, consequently, the level of insulation of the envelope are two of the key parameters for selecting the most suitable target building typologies for BERTIM process and products. In Sweden, the houses built in the period from 1955 to 1970, due to the poor energy performance of their envelopes and the lack of cooling and air recovery systems have been considered as priority for the project. In Germany, the age of the building stocks plays also a key role, but in this case residential buildings built between 1969 and 2001 shall be considered as relevant. Of particular relevance in Germany are large housing estates which account for 20% of the rental housing market since their “serialised character” facilitates the pre industrialised refurbishment. In Spain, the most interesting typology for BERTIM products will be the multifamily blocks and apartment blocks constructed between 1941-1980, since the insulation levels are very low and as a result the energy performance of the building envelope is very poor.

The second step to define the BERTIM process has been to study the current refurbishment practices and processes in order to carry out a gap analysis for the process improvement. The stakeholders have been defined, the different phases of the process addressed and the retrofitting solution and their industrialization level analysed.

One of general conclusions that have been drawn is the general reluctance of the European construction industry to accept innovation in processes, especially in comparison with other industries. As a result, the interaction between the involved stakeholders and the information exchanges are not optimized. The lack of integration and holistic vision makes refurbishment a complex and error-prone process, difficulting the accuracy and consistency through all the process. The use of diverse software tools and proprietary data formats introduce interoperability problems that require time consuming integration and harmonization efforts. The inexistence of a strategic vision about the data management and the use of multiple data models and the lack of coordination lead to redundancy, inconsistency and problems with data integrity and make more difficult the collaboration between the stakeholders. Another of the detected obstacles is the lack of interaction between the prefabrication industry and conventional construction industry, since the construction industry usually sees the prefabrication as a menace for their own business.

The final chapter address the BERTIM holistic renovation process in all its phases, from the feasibility phase to the transport and installation.



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