Industrial Energy Efficient Retrofitting of Resident Buildings in Cold Climates

D4.2, D4.3
Guidelines to Off-site Production / On-site Assembly and Logistics

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Executive Summary

Building renovation is the second chance for architecture if we succeed to answer the challenges with intelligent, added value solutions balancing ecological, economic and social impacts at the same time.

This deliverable explains the workflow in a set of recommendations and guidelines for off-site production, logistics and on-site assembly of prefabricated construction elements for retrofitting of existing buildings. The document is based on various individual experiences made in the E2ReBuild demonstration projects and will serve as an important input to the industrialised platform (work package 6) which summarises and structures the experiences drawn from all RTD-work having been carried out within E2ReBuild.

E2ReBuild demonstrates sustainable renovation solutions based on a holistic industrialized process that will greatly reduce energy consumption, minimize waste and improve recycling rates, reduce technical and social disturbance for tenants and increase quality at the same time. Five of seven E2ReBuild demonstration projects were conducted with prefabricated construction systems to enhance the building envelope.

Lessons learnt focus on

- General planning and survey
- Production
- Logistics & assembly
- Tenant’s needs

Recommendations and guidelines for off-site production (chapter 2) and on-site assembly (chapter 3) describe the process and its control and highlight key aspects and important details. The description of workflow responsibilities is followed by practical recommendations and guidelines providing the reader with a red line of hints which can serve as a structure for future projects. The document does not claim to be complete as every project in reality causes issues which need specific answers.

E2ReBuild demonstrations have revealed the complexity of holistic building refurbishment which can be tackled successfully by a team of architects, engineers and construction specialist cooperating and working together for common set goals. Construction work based on industrialized methods offers advantages, new collaboration models are the key to reach the potential advantages.

→ Highlight

> To enhance readability, important knowledge and messages are highlighted in a green box.

Note: D4.2 and 4.3 refer to the E2ReBuild document D4.1 Guidelines to Preliminaries/Survey

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1 Prefabricated Solutions for Retrofitting

1.1 Context of Work

This deliverable explains the workflow in a set of recommendations for the production and assembly of prefabricated construction elements for retrofitting of existing buildings based on experience made in E2ReBuild demonstration and research work.

A large number of existing buildings are in need of maintenance and bigger repair interventions in order to not only maintain a status-quo but to enhance buildings to meet future economic, social, energetic, thermal and technical requirements. Current craft based construction is often a rather time and resource intense process. Construction work, especially renovation, is traditionally characterized by in-situ investigation, on-site decision making and handling building materials stepwise as small items piece by piece. Usually one ends up in a rather lengthy and inefficient process which requires a high degree of discipline of all those involved and great effort for the coordination of individual works. Under the given conditions, careful work, synchronization and respect of the work of others and high quality is thus often missed. In contrary, experience made in E2ReBuild using prefabricated systems proves, the more decisions and production processes can be conducted off-site beforehand, the easier and faster the construction process works on-site.

E2ReBuild demonstrates sustainable renovation solutions based on a holistic industrialized process that will greatly reduce energy consumption, minimize waste and improve recycling rates, reduce technical and social disturbance for tenants and increase quality of construction work at the same time. Five of seven E2ReBuild demonstration projects were conducted with prefabricated construction systems to enhance the building envelope.

	Duration	**Inhabited**	**Envelope**	**Services onsite**	**Interior onsite**
2.1 Munich	2011 - 2012	No	**offsite**	x	x
2.2 Oulu	2012 - 2013	No	**offsite**	x	x
2.3 Voiron	2012 - 2013	Yes	onsite	x	x
2.4 Augsburg	2011 - 2012	Yes	**offsite**	x	x
2.5 Halmstad	2012	Yes	onsite	x	x
2.6 Roosendaal	2010 - 2012	Yes	**offsite**	x	x
2.7 London	2013 - 2014	Yes	**offsite**	x	x

Table 1 - Offsite / onsite construction work of E2ReBuild demonstrators

Prefabricated or off-site produced solutions for building and construction components are commonly used in concrete or timber construction as wall, ceiling or roof elements as well as some parts of technical components. Advanced prefabrication methods can be found in the timber construction sector where wall or roof elements are built in workshops containing the entire structure, panelling, insulation, windows and cladding. The size of these elements is conditioned by production and transportation limits.

Possible application of prefabricated solutions:

- Building envelope
- Extensions (e.g. roof top)
- Encasement (e.g. winter garden)
- Elements (e.g. stair, ceiling)
- Building services (e.g. bathrooms modules)

The chances of applying broader prefabricated solutions in building modernization are to be seen in the development of elements which can be adapted to an individual situation as well as to advance the efficiency of construction work in inhabited status or narrow inner city building sites.

The workflow from a preliminary project approach to complete project documentation is based on team work of architects, engineers, building service engineers and production planners. The project content is developed over different planning stages. The main difference to in situ based processes is a detailed consideration of almost every decision in the planning phase.

Complete production planning on the basis of a holistic building survey and measurement respects in addition to the configuration of construction and building elements, time slots for logistics and production procedures.

One of the big advantages of off-site production is the rational production of components in a controlled workflow in the workshop under constant conditions with better utilization of building materials and less waste. Machines (e.g. digital joinery machines and assembly tables) which increase production precision and rationality are used here.

The intense planning phase is a significant basis to detect critical details, elaborate a prefab project in depth and a chance to successfully conduct work on-site [Figure 1].

Figure 1 - Process: Measurement, Production planning, Production, Assembly, Maintenance

→ Reference

Find information on survey and planning: D 4.1 Guidelines to Preliminaries/Survey

The chance to elaborate a project effectively is given especially in the early design phase with respect to technical requirements (e.g. structure, building physics), definition of budget and schedule frames. The design phase offers greatest freedom to develop complete solutions and test different options to best match set requirements. Decision making on-site seldom offers an equivalent variety of different possibilities but is more a reaction plan to a single situation with an uncertain economic effect. Moreover, late changes during the building process often cause higher cost at the end as decisions taking at an early project stage have to be amended. Especially changes to construction elements in production or even on-site are expensive [Figure 2].

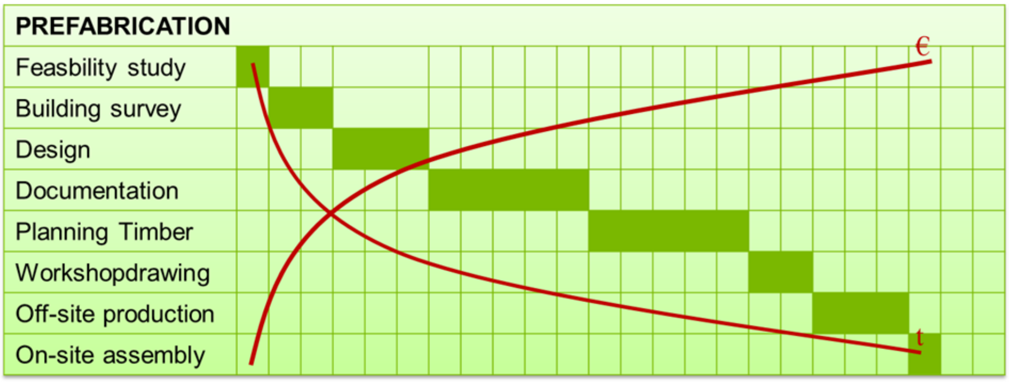


Figure 2 - Ratio of decision making to cost development

1.2 Lessons Learnt in E2ReBuild Demonstration Projects

E2ReBuild offered the possibilities to learn from the planning, production and assembly stage of the demonstrations 'behind the scene' as some partners were directly involved in the planning and construction process. Experience made was openly discussed and shared at all stages[1].

6 out of 7 projects were retrofitted using the application of partly (Voiron, Oulu) or fully off-site fabricated timber frame elements for the improvement of the building envelope. The integration of windows, insulation and even cladding is a standard timber fabrication method used particularly for new buildings. The solution used in the E2ReBuild demonstrations is based on the *TES EnergyFacade*[2] system.

TES EnergyFaçade stands for the application of prefabricated timber elements offering solutions for the energy efficient building envelope refurbishment as well as building extensions.

TES EnergyFaçade provides a structured guideline for the application of prefabricated large-sized timber framed elements along the workflow from planning, digital measurement, off-site production and on-site assembly. The elements combine a self-supporting structure with an infill of insulation and a panelling offering the possibility to utilise a great variety of cladding materials (e.g. timber panels, sawn boards, tin, plaster etc.).

[1] Compare D 4.5 'Demonstration interaction'
[2] TES EnergyFaçade supported by ERA-NET "WoodWisdom-Net..Project partners: TU München, NTNU Trondheim, Norway, SINTEF Norway; Aalto University Helsinki, Finland. Praxispartner u.a. Gumpp & Maier, Amboros Huas GmbH

BUILDING ENVELOPE		Prefabricated envelope	Insulation	Cladding	Windows	HVAC	Integrated solar	Load bearing
2.1 Munich		x	x	o	x	x	-	-
2.2 Oulu		x	x	o	x	x	-	roof
2.3 Voiron		x	o	o	o	-	-	-
2.4 Augsburg		x	x	x	x	x	-	-
2.5 Halmstad		-	-	-	o	-	-	-
2.6 Roosendaal		x	x	o	x	x	x	roof
2.7 London		x	x	x	x	-	-	roof

Table 2 - Project synopsis. x - off-site integration , o - on-site integration

Following lessons learnt describe the major challenges which were met during construction work at different stages in the E2ReBuild demonstration projects. This summarizes specific insight gathered throughout the project phases.

General planning and survey

The application of completely prefabricated construction elements requires a precise management of the workflow, tasks and responsibilities. The design concept must follow fabrication and handling principles such as element size and structure, logistics and transportation measures as well as assembly and joining with tolerances. E2ReBuild demonstrations have proven the practicability of a high prefabrication standard based on prior precise building survey for a refurbishment project[3]. Comprehensive and accurate building analysis is a vital part in the early planning stage. A thorough recording of the building is recommended and necessary in order to identify the requirements of building codes, fire and sound protection, structural use and technical equipment as a basis for a coordinated action plan.

Consistent and precise measurement of the building geometry is the key to successful façade or element application. Existing methods guarantee sufficient results as a basis for planning and production. The deliverable "*D4.1 Guidelines for survey and measurement*"[4] describes advanced survey and measurement methods prior to planning and production.

→ Information

The quality of information collected in the survey is crucial for the planning phase. As important as the geometrical survey is the construction and structural assessment. A destructive survey must take place, in order to obtain relevant information for planning, and for better assessment of future work. An empty unit is a great advantage, which can be assessed without disturbances.

In Parkview HUB, London the most relevant issues were[5]:

- Removal of existing windows: we could learn, that the windows could be removed from the inside having already installed the new envelope. This allowed carrying out the whole construction process with the existing windows in place as a protection during construction.

- Survey of the structural slabs: demolishing part of the flooring and screed allowed us to locate it precisely and design a proper fixing system according to its complex geometry. Failure to allow a proper investigation on the1st floor decks led to delays and problems, causing a modification of the structural design during the demolition phase.

- Survey of the foundations: failure to survey the real shape of the foundation lead to increase cost, changes in the structural design and delay.

- Survey of the roof: failure to determine precisely the thickness lead to structural design problems, causing again increased costs and delay.

Given the experience of the E2ReBuild demonstrations, a step wise planning and procurement process has so far proven realistic. Architectural design on the basis of existing plans and /or a rough survey as a set of 2D drawings has proven a sufficient basis for tendering and further workflow (production planning) for the following contractors. Timber manufacturers use similar CAD software tools for production planning. Hence the process is established on the basis of the experience of carpentry for

[3] Compare WP 2 'Démonstration documentation'
[4] D4.1 Guidelines to Preliminaries / Survey
[5] Description by Sebastian Hernandez, Gumpp & Maier GmbH

new buildings[6]. For a larger building renovation model building in 1:1 scale may be applicable for decision making. At the Roosendaal demo project two strategies were realized in advance – two house with a system based on external thermal insulation composite systems [ETICS] and another one with prefabricated timber frame renovation modules. These test houses brought the necessary knowledge for the tender specification and further planning stages and revealed significant advantages of the timber frame based method: reduced time on-site, independence from weather conditions and cost reduction based on time saving.

The demonstration project in Augsburg was contracted to a design team of architects and engineers as a result of an architectural competition. Design, construction and structure of the building envelope was planned and described in a tender package as well as a set of construction documentations. The design documentation was based on the existing plans, the precise building measurement was part of the tendering package and thus in the responsibility of the timber manufacturer. The building was measured entirely by the contracted carpenter *Gumpp & Maier*, Binswangen. A Leica total station was used to gather the relevant geometry point by point. A connection to a laptop enabled to develop a 3D model on site with the advantage to guarantee completeness through complementary ocular investigation. Production design of the timber frame was later done on the basis of the 3D model defining every piece of timber with parametric information to be processed by a digital cutting machine. These production plans had to be approved by the client prior to production. The workflow was structured in tasks with specific responsibilities, as shown in below figure:

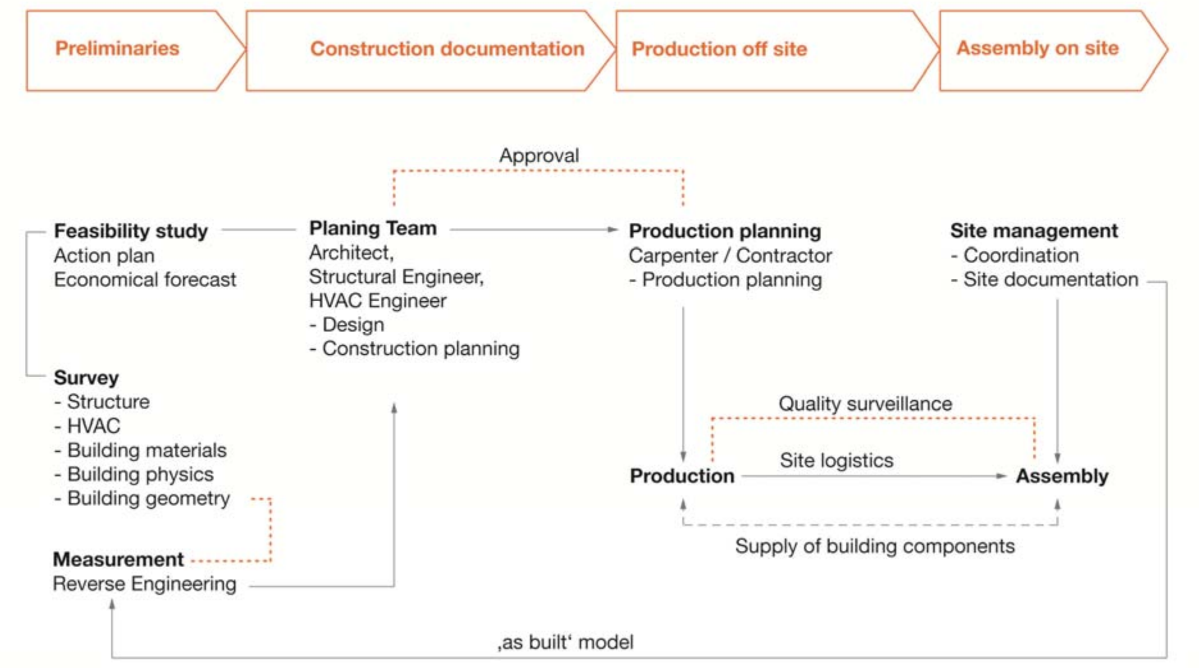


Figure 3 - Process workflow, Grüntenstraße, Augsburg

[6] Lattke F., TES EnergyFacade – proven practice, sb13 Munich

Production

Some E2ReBuild projects focused on the application of timber construction elements for façade (Augsburg, Munich, Roosendaal and Oulu) and roof (Munich, Roosendaal). The elements included timber frame, insulation, cladding and windows and fitted well on to the existing structure of the building.

The highest level of prefabrication was achieved with complete façade panels including insulation, windows and cladding (Augsburg) and entire roof elements including roof membrane and solar collectors (Roosendaal) [Figure 4]. The parts were produced by small and medium sized timber manufacturers and transported to the sites.

Figure 4 - Element production (Gumpp & Maier, D-Binswangen). Roof element Roosendaal

→ Prefabrication level

A maximum level of prefabrication of timber elements (wall and roof) is state of the art and can be assessed using current planning and production technologies of a highly advanced timber manufacturing sector. Definition of all details is a key condition.

For Grüntenstraße, Augsburg panels were produced as timber frame elements including cellulose fibre insulation. Windows and cladding were based on a digital survey with a few centimetres tolerance. The method allows rather large dimensions. In the case of Grüntenstraße, the façade panels for the encasement of the balconies with two sliding doors, integrated air inlets and cladding measured 9996 x 2.830 mm with a weight of app. 5 tons and a width of 345 mm.

The renovation method using timber frame elements is based on planning[7] and production standards for new buildings in wood which is a common procedure throughout the European timber construction sector.

Timber frame elements are designed in compliance to national and international regulations (e.g. ISO standards[8]) regarding structural properties, performance and design values of materials, fire safety, building physics and material properties.

Timber frame elements are produced by timber manufacturers in a workshop environment with constant temperature and working conditions. The process is based on competence of the timber

[7] J. Kolb, Holzbau mit System, Birkhäuser 2012
[8] ISO/TC 165 Timber structures, http://www.iso.org/iso/home/store/catalogue_tc/catalogue_tc_browse.htm?commid=53584&published=on

construction sector, which is known for its high quality. Timber manufacturers are committed to internal quality control as well as existing production regulations. National norms (e.g. DIN[9] in Germany, DTU[10] in France) define relevant regulations for wood, product properties and timber frame construction[11]. Quality management (e.g. Ü, CE, RAL) is well established.

Further technical specification for design, production and assembly can be found in *TES Manual*[12], the documentation of the WoodWisdom Era-Net research project *TES EnergyFacade*[13].

Logistics & assembly

The degree of prefabrication and the alignment of the façade panels are determined by the geometry of the building. The situation of storage and moving space at the construction site affects transport and assembly logistics. Elements are prefabricated including frame, Insulation, panelling and windows and transported by truck weather protected to the site. A splash of rain does not hurt, but the elements need to be weather protected if they are exposed over a longer period. It has proven best to seal the surface, finish the cladding and joints or use elements with mounted cladding.

Construction material, such as adhesives, plaster or seals are weather depended. A realistic calculation of construction work with respect to site preparation, management, assembly time is climate depended. In Augsburg, the decision made by the client to start with the 6 story building at the end of October ended in a longer break in winter (December to March) when surfaces could not be finished. The alternative to start the smaller three story building was not accepted due to the fact that the heating system for both buildings was already replaced by smaller capacity.

Main issues identified throughout E2ReBuild demonstration production and assembly phase:

Risks

- Weather dependency: long term interruption due seasonal impact or short term due to wind or rain
- Complexity: underestimation of detailing and coordination at planning stage
- Conflict potential: multiple disturbance of tenants (bathroom renovation, window replacement, blocking of access routes)

Opportunities

- Process: fluent workflow (impressive mounting speed of elements)
- Building site management (“clean building site”)
- Logistics (safety, contact to tenants)
- Quality of construction work

[9] Deutsches Institut für Normung e.V. http://www.din.de
[10] Documents Techniques Unifiés, http://boutique.cstb.fr/fr/
[11] Informationsdienst HOLZ, HOLZRAHMENBAU | FERTIGUNG UND MONTAGE, holzbau handbuch | REIHE 1 | TEIL 1 | FOLGE 7 |
[12] Heikkinen P., Kaufmann H., Larsen K., Winter S. (eds.) (2011) TES EnergyFaçade, Research report, München http://www.tesenergyfacade.com/index.php?id=4_downloads
[13] TES EnergyFaçade supported by ERA-NET “WoodWisdom-Net..Project partners: TU München, NTNU Trondheim, Norway, SINTEF Norway; Aalto University Helsinki, Finland. Praxispartner u.a. Gumpp & Maier, Amboros Huas GmbH

→ Logistics and transportation

Transportation requirements limit the size of elements which are carried on trucks or trailors from the factory to the site. Timber manufacturers are equiped with necessary transportation vehicles or contract transportation companies and have weather protected loading procedures (in house).

In Roosendaal, prefabricated elements were produced by *VDM*, a company that is based 250 km away from the site. The process of renovating 134 units was streamlined in order to allow the renovation of 4 houses per week. The elements for one house were transported on one truck load which travelled during the night and installed the next day. Tenants experienced only one day when there was no roof and no windows. At the day of mounting, the prefab elements, also the compact heating and ventilation system was craned into the attic. The whole process from start to completion took only six weeks.[14]

Figure 5 - Loading bay at *Gumpp & Maier*. Roosendaal: elements for one house on one truck

Free site access and proper site management is one key to success in construction and assembly. Handling large sized construction elements requires space for parking, unloading and lifting. Especially construction sites in urban areas often lack space around the main working area. In this case, prefabricated systems result in faster construction work and therefore shorter occupation of surroundings. 'Just-in-time' delivery is an advantage to keep construction sites tidy.

"We have never had such a clean building site" stated Jürgen Winterholler, project manager of *WBG Augsburg* following his experience of the E2ReBuild demonstration in Grüntenstraße, Augsburg.

Possible crane locations are chosen in relation to the accessibility, the dimensions and the weight of the elements. Safety of all participants is a supreme premise during the entire construction phase. During the assembly process the handling of the elements requires thorough attention. Distances to loads under cranes as well as dangerous works have to be conducted with respect to health & safety regulations.

[14] IEA ECBCS Annex 50 report, Passive renovation, De Kroeven 505, Roosendaal, NL

Figure 6 - Augsburg: elements are lifted by tower crane

Some of the E2ReBuild demonstrations were retrofitted in inhabited status (Augsburg, Roosendaal, Voiron) causing a challenge for construction and site management. Clearance to construction work, delivery site routes and material storage need to be signed out and safeguarded.

In Augsburg, plenty of space on the own property allowed two large storage places. The site was organized into two mayor working areas:

- Façade storage and crane zone (*Gumpp & Maier GmbH*)
- Zone for interior construction workforce (plumbers, builders etc.)

Tenants were informed about disturbances and to keep off dangerous areas. Routes to their apartments were secured to guarantee access at all times as delivery route crossed existing paths and the parking lot.

Material transportation and delivery of façade elements were made by truck and trailer on the existing pathway along the taller building (Grüntenstraße 34-64). This is also the main route for the fire brigade in case of emergency, thus it had to be cleared at all times.

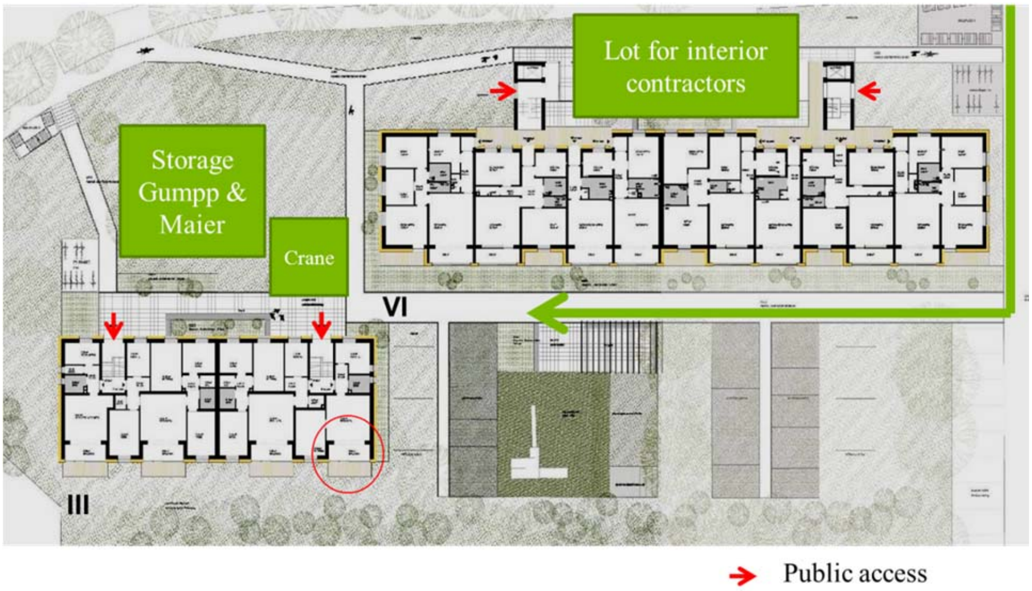


Figure 7 - Site Management at Grüntenstraße, Augsburg

Scaffold or lifting platform?

Utilizing an assembly scaffold offers accessibility and flexibility during the mounting phase. Façade elements are lowered between the existing wall and the scaffold platform directly to their final position. In Augsburg, the scaffold was built up in stages during the assembly process[15] with a distance of up to 500 mm from the existing brick wall. The first two stories were freestanding and braced to the outside, the following sections were freestanding over two stories. The scaffold was fixed into the *TES* façade with suitable anchors[16]. Product declaration and documentation is necessary, to maintain the possibility to later erect a scaffold without causing destruction to the façade.

Assembly with lifting platforms suits well for lower houses and façade elements with only few fixation points. Regarding the overall workflow, the time for rearranging the platforms needs to be respected as well as the space required for the machine.

Figure 8 - Oulu: mounting with lift platform. London: crane mounting with scaffold

Site preparation and tolerances

Before new façade elements can be mounted, site preparation is necessary to dismantle parts of the building, erect foundations or other fixations, smooth surfaces or airtight parts, which later are covered by added elements.

Dealing with large prefabricated panels requires the scheduling of appropriate tolerances, to absorb bumps and deviations, without having to destroy and adapt one's own work on site. Joints and connection details, which have been proven in the field of new built timber construction, ensure the structural function and viability of the facade on the outside. The structural condition of the existing building is decisive for correct connection to the stock to ensure fire protection, air tightness and sound insulation. Cavity-free design is a premise to prevent uncontrollable convection and fire spreading in the construction. Tolerances can be bridged by using soft fibre insulation or blown in cellulose fibre. In Oulu, a layer of soft insulation (mineral wool) was fixed to the wall prior to mounting façade elements. Augsburg has proven a way of blowing in cellulose fibre into a 6-8 cm wide gap between the TES element and the existing brick wall.

[15] Gumpp & Maier, Montageanweisung 21.10.2011
[16] EJOT JA3

→ Replacing windows

Existing windows are commonly replaced. The new window is preferably positioned within the new façade element to reduce thermal bridges around the reveal. The old window may be removed after assembly of the façade (e.g. London case) or prior to the mounting process.

In Augsburg, the brick overlay of the reveal towards the window frame was cut and removed to the outside [Figure 9]. After loosening the screws of the window frame an interior dust screen was installed to protect the inhabited apartment. The frame was removed to the outside prior to the assembly of the *TES* elements, thus closing the building envelope very quickly.

Figure 9 - Facade assembly, window removed to the outside

Airtightness

The enclosure of an existing building with a new envelope provides the chance to improve airtightness which is one of the main measures to reduce energy losses and a functional criterion for mechanical ventilation.

Experience from demonstrations indicates[17] that existing concrete structures or brick walls can have leakages, mostly caused by gaps or unknown weaknesses. For example in Oulu old precast concrete sandwich walls with extensive gaps in the interior panel needed extensive filling of existing joints to improve airtightness.

[17] Input from WP 3, Sonja Geier

The improvement of airtightness can only be done in parts that are renewed – others remain as before. While the separation to staircases or other public spaces might be possible, the airtight division between apartments remains a challenge especially in inhabited apartments.

Oulu was renovated in an unoccupied situation – hence a serious internal renewal was possible. Air tightness among the apartments was not an issue because only one concrete wall as division between the apartments and the entire interior of the apartments was renewed.

In Roosendaal a blower door test was made after completion of the renovation works resulting in an airtightness figure of 1.0 air changes per hour at 50 Pa.

Within high-performance buildings, leakages within the airtight membrane are more sensitive – even small leakages act like pressure valves and bear moisture and mold risk within the construction and are (due to complex component composition) very often undetected for a long time.

Tenant's needs

Building renovation at inhabited status requires special attention to the needs of tenants or temporary occupants of buildings (e.g. school, commercial use). A concept with respect to the interests of inhabitants needs to be developed in the planning stage taking into account information and treatment as construction works may interfere with people's privacy and indoor comfort [Figure 10]. A high degree of prefabrication of construction elements and building envelope reduces construction times and stress of all participants to a necessary minimum. While prefabrication provides lower disturbance for tenants, the removal of windows and the closure of the airtight membrane or vapour barriers require work inside apartments that has to be planned and coordinated carefully.

Although building owners and project coordinators (such as architects or total contractors) are aware of the importance of the communication towards tenants – different strategies were pursued. Tenants who feel well-informed have less complaints and bear disturbances to a greater extend. The E2ReBuild demos showed that a big personal effort from representatives of the building owner is necessary to get «tenants on board»[18].

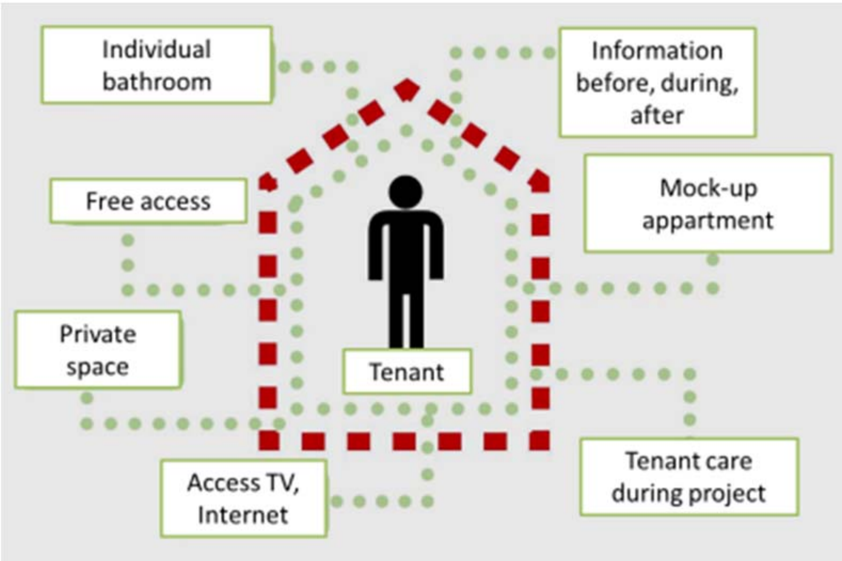


Figure 10 - Tenants needs during construction work

[18] Input WP 3, Sonja Geier

1.3 Added Values of Industrialized Construction Methods

E2ReBuild has conducted highly ambitious demonstration projects offering cutting edge solutions that were balancing the gap between innovation and economic boundaries. Holistic building modernization including envelope, technical services and even the adaption of floor space to today's requirements is one of the major tasks of the present architecture and construction sector. Most challenging are large-volume buildings, e.g. schools, offices or residential buildings, which must be refurbished in an inhabited state due to missing provisional space for the users in the construction period. In this case, modernization methods which can be implemented fast, precise and as trouble-free as possible, are required. With a view to the future durable, economic and ecological solutions are necessary to transform our buildings and meet future-oriented standards regarding energy efficiency, CO2 neutrality and contemporary floor space plans.

Exemplary, one part of the Roosendaal demo- was renovated with the standard external thermal insulation composite system (ETICS). This was based on the two demo houses built within the preparation phase. And the experience showed the long time span that is needed to bring this system up (3-4 weeks needed for gluing the boards until the final priming). The experience of the third house with the timber frame method showed the significant advantages of reduced time on-site and the independence in relation to climate and weather conditions.

A holistic planning phase based on collaboration of different competences is the essential part of an industrialized process, as it was the key lesson learnt from the E2ReBuild demos. The application of prefabricated construction systems based on such a standard workflow from planning to production and assembly offer a great variety of performance, process and technical benefits.

Resource efficiency in the context of environment, ecology and economy is one of the challenging issues today. The common renovation practice can be characterised as follows: craftsmen like, non-ergonomic procedures, tailoring and processing on site with high dust and noise emission, great offcuts and pollution, disturbance of neighbourhood. Production off-site in a workshop causes less waste and left overs as cutting and assembly are optimized already in production planning. Timber manufacturers like Gumpp & Maier[19] tune the order of raw material (e.g. glue lam beams) according to final dimensions of later elements (e.g. studs, plates).

Off-site production processes offer a possibility to enhance the performance of construction systems.

→ Performance

- Quicker and cleaner construction processes on site[20]
- Less production waste
- Less disturbance in inhabited status
- Improvement of the energetic performance and the comfort of a building
- Use of renewable raw materials for the building modernization
- Optimization of workflows
- Optimization of productivity on site

[19] Interview with Sebastian Hernandez, Gumpp & Maier GmbH, Binswangen
[20] Compare with D 3.4 'Holistic Strategies', chapter 3

In depth planning of intervention in architecture, structure, fire safety, costs and time management is the key to a quick and sound construction process. E2ReBuild demonstrations have proven a great reliability concerning these tasks.

In Roosendaal for example the process of renovating 134 units has been streamlined in order to allow the renovation of 4 houses per week. Tenants experienced only one day when there was no roof and no windows. At the day of mounting, the prefab elements, also the compact heating and ventilation system was craned into the attic. The whole process from start to completion took only six weeks[21].

→ Process advantage

- Collaborative design is about counting on all necessary knowledge and setting the right goals from the beginning
- Early identification of potential problems in planning stage
- Tackling complexity in an early stage of decision-making ("action instead of reaction")
- Involving all stakeholders of planning process
  - Client
  - Architect
  - Structural Designer
  - Building contractor(s) and/or Manufacturer
  - Specialists
- Cost optimization and synchronization of planning processes

E2ReBuild has exemplary conducted prefabricated, highly insulated timber framed elements which are mounted in a short time on site and represent an interesting alternative to the common methods (e.g. ETICS) of the energy-related modernization of the building envelope. A maximum degree of prefabrication is the key premise for the production of large scale wooden panels which can be adapted in different ways to the building geometry and spatial design structure: from the highly thermally insulated panel element to the space module for an extension.

→ Technical advantage

- Use of renewable raw materials for the building modernization
- Enlarge recyclability
- Precision and quality of prefabrication
- Application of a variety of different cladding materials
- Extension with space modules based on a coordinated construction system
- Integration of building services and/or solar-active components
- Integration of structural components such as a balcony platform
- Optimization of productivity on site
- Short construction time = less dirt and noise on site

[21] IEA ECBCS Annex 50 report, Passive renovation, De Kroeven 505, Roosendaal, NL

2 Off-site Production

2.1 The Process and its Control

Prefabrication or off-site production describes construction systems and processes which are completely (building elements, e.g. wall panel) or partly (building components, e.g. windows) fabricated in a workshop in a different place than the construction site. Production plans are the sound basis for the actual production process, from cutting different pieces (e.g. studs for frames, panelling), their assembly into building elements (e.g. wall or roof panel), integration of components (e.g. window, ductwork) and finish of cladding. Thoughtful planning in a holistic design team results in production plans which are based on the design documentation of architects and engineers.

Production plans specify the timber structure built by the manufacturer whereas design documentation of architects and engineers cover the entire project complexity.

Design / planning	**Production planning**	**Off-site production**	Logistics / Assembly

Controlling the process of off-site production asks for following preconditions:

- Definition of the overall project target → set standards
- Company (e.g. timber manufacturer) under contract
- Establish project team and empower stakeholders
- Building survey (geometry and construction) completed
- Construction and detail planning completed
- Coordination of requirements completed
- Schedule for decision making, design, process and work
- Mock-up to support material, colour and component choice
- Coordination during design to cover 3D-nodes over different batches and before /during work

The level of prefabrication depends on the project specification and its complexity, the building structure and construction as well as the type of cladding, determining joints and surface finish. Adaption on-site to specific in-situ situations (e.g. bridging tolerances) needs definition in plan. Proper measurement and building survey as well as thorough planning is a precondition to a goal of 100 % prefabrication, meaning the application of a complete element with only a few adaptions.

TES EnergyFacade, a prefabricated timber construction system, which has been exemplarily applied to five E2ReBuild projects, demonstrates such a system with different levels of production and prefabrication. The façade elements are produced in manufacturing workshops under constant conditions using digitally driven cutting and assembly machines. Through a rational process production quality is significantly increased compared to traditional craft based construction.

Figure 11 - Digital cutting and assembly machine (*Weinmann*)

Figure 12 - Production line of timber frame elements

The contracted manufacturer and builder (if applicable) guarantees a proper result of his product and is thus responsible for transportation of all construction parts, elements and materials from the workshop to the site. Appropriate protection of all goods is highly recommended to avoid damage during transportation and assembly. Transportation routes, accessibility and equipment should be checked prior to any action.

Figure 13 - Protection during transport

Figure 14 - Protection during site storage

Workflow responsibilities

A clear regulation of workflow responsibilities at the beginning of the project supports the design team to successfully manage the project. In the construction sector various collaboration models are known with different partners involved in a project (e.g. general contractor, architects & engineers, timber manufacturers); at the end of the day the tasks need to be fulfilled by a team. Following overview demonstrates an example of specific tasks in a team of architects, engineers and timber manufacturers.

Phase	Architect	Engineer	Timber manufacturer (TES)
Project design	Detailed design & construction documentation Coordination of specialists. Planning leader	Structural design & calculation	*Early Involvement recommended!!!*
Production planning	Participating	Optimization of connections according to production limitations	Further detailing! (implies changes in architecture and engineering)
Production		Quality surveillance	Production according to quality standards

Table 3 - Workflow responsibility

Following list exemplifies specific tasks for a collaboration team model of architects [ARC], structural engineers [ENG], HVAC planners [HVAC] and timber manufacturers for TES EnergyFacade elements [TES] as it was conducted in the E2ReBuild demonstration projects in Augsburg and Munich.

	Planning	ARC	ENG	HVAC	TES
1.1	Structure and construction	P	**E**	(P)	P
1.2	Materials	**E**	P		P
1.3	Building physics | Fire safety	P	**E**	P	P
1.4	Surfaces | Colours	**E**	-	-	P
1.5	Building components (e.g. windows)	E	(P)	(P)	P
1.6	Time schedule	P	P	P	**E**
1.7	Team coordination	**E**	P	P	P
	Production design				
2.1	Construction and joints	P	P	P	**E**
2.2	Materials	P	-	-	**E**
2.3	Elementation | Size | Weight	-	P	-	**E**
2.4	Transportation / assembly concept	P	(P)	-	**E**
2.5	Components (e.g. windows, ducts)	P	-	P	**E**
2.6	Time schedule	P	-	-	**E**
	Off site production				
3.1	Off-site production	-	-	-	**E**
3.2	Production quality control	-	-	-	**E**

Table 4 - Task list E - Execution, P - Participation, (P) - Participation if applicable

2.2 Recommendation and Guidelines

Following recommendation and guidelines for off-site production processes are based on lessons learned from E2ReBuild demonstrations.

Off-site production	Recommendation
Production planning	• Detailed building survey (geometry and construction) made • Realistic survey model (3D digital model) • Solution developed for all structural, building physics and fire safety issues • Solution developed for handling tolerances between new and old structure • Load bearing conditions of existing structure checked • Decision made by the client on all materials and details • Design freeze
Data transfer	• 2D files, prints (dwg, dxf) and/or 3D model to element manufacturer
Material	• Use of building materials according to their specification, i.e. strength category, thermal transmittance, water vapour transmission rate etc.
Production	• Elements are manufactured according to element design • Marking TES elements according to their final position • The timber contractor must operate within the relevant national regulations and in additional, voluntary quality assessment systems (e.g. RAL Gütesicherung, Germany) and document the internal and/or external quality surveillance system • Approval by client / architect
Logistics and transportation	• During fabrication and transportation it must be ensured that elements are protected against rain, dirt, breakage and moisture • Max. size of TES elements according to transportation restrictions • Protection of TES elements during transportation and site assembly

3 On-site Assembly

3.1 The Process and its Control

On-site assembly describes the mounting of construction elements (e.g. wall, façade, roof) which have been produced in a workshop off-site. A high quality result emerges out of a thorough design and planning basis.

Reducing construction time on-site can only be achieved by very detailed scheduling and planning of logistics and storage in advance. Any friction within the process chain causes significant chain reactions. The entire renovation time can only be shortened in case of experienced teams and well organized procedures. Preparation of work processes in advanced are thus a necessity for successful logistics and assembly at the end of the industrialized workflow.

Design / planning	Production planning	Off-site production	**Logistics / Assembly**

Controlling the process of logistics and assembly asks for following preconditions:

- Production completed
- Coordination of requirements completed
- Schedule for site process
- Assembly plans ready
- Site access: transportation and assembly possible
- Site infrastructure (incl. lifting equipment) ready
- Coordination of workforce during assembly
- Impact analysis of each activity on-site and checked with health and safety instructions
- Fixation points defined
- Existing structure checked for load bearing connection
- Dismantling of facades, balconies and foundation finished
- Risk management and responsibilities

Prefabricated façade elements in an addition to the existing building structure are self-supporting, non-load bearing in the sense of not being part the main building structure. Nonetheless, wind and weight forces have to be lead into the existing structure. Appropriate solutions need to be planned regarding load introduction and existing reserves. The existing construction is thoroughly analysed prior to the planning stage. All new load bearing structures have to fulfil the requirements according to building codes, common technical rules and standards or guidelines.

Foundation

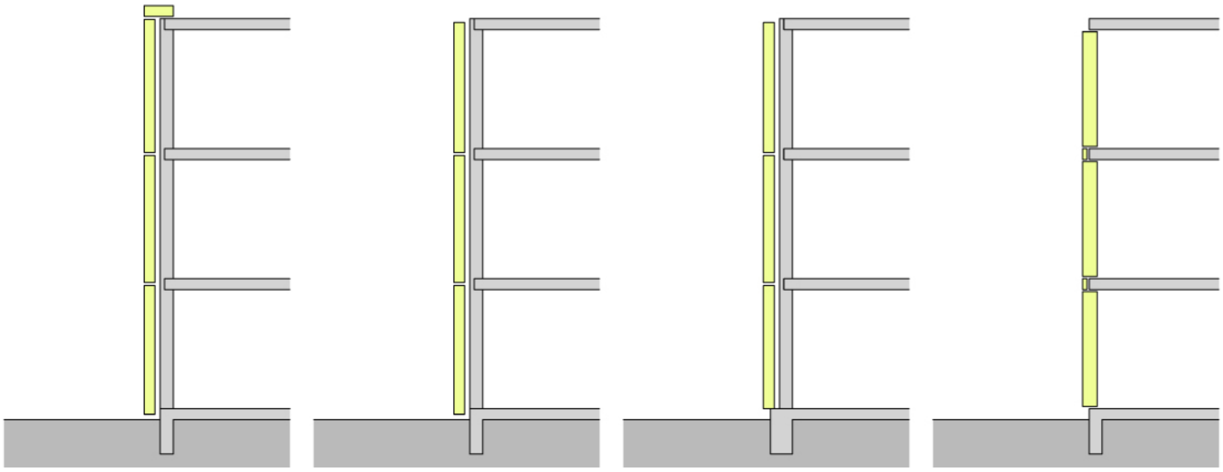


Figure 15 - Mounting typology a) hanging, b) storey wise mounted, c) standing, d) storey wise

Vertical loads

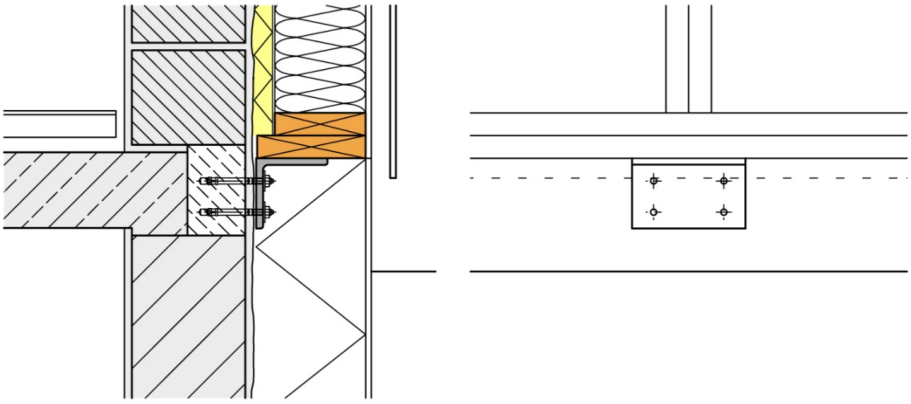
Vertical loads (e.g. weight of façade element) are best introduced into an existing or extra foundation [Figure 15}. Various solutions for a load bearing foundation at the bottom of a TES element are possible; these have to be adjusted to the load bearing capacity of the existing structure. The constructive protection of the timber elements at the base section of the wall always has to be considered and detailed according to relevant standards.

New foundation is a good opportunity to reduce thermal conductivity of basements by adding extra insulation or renew vapour seals on the outside of cellar walls as conducted in Grüntenstraße, Augsburg.

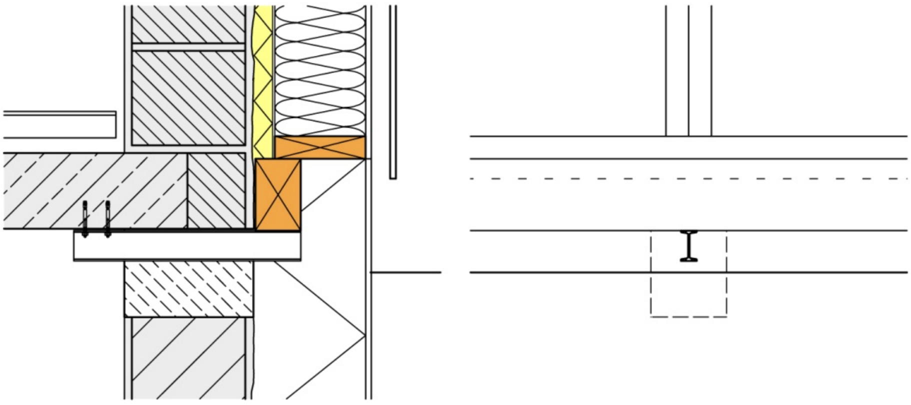
A foundation of double layered wall construction (e.g. double brick wall) may well be used to introduce additional loads into the construction as has been executed in Roosendaal [Figure 16]. Preparation and load bearing test need to be done prior to mounting.

Figure 16 - Additional foundation, Augsburg and Roosendaal

L- bracket with a sill beam. Exchange of brick layer in front of the ceiling, grouting closer.



Cantilever beam (e.g. IPE rocker). Fixation under basement ceiling, grouting closer



Extra foundation, frost resistance founded, adaption layer thermal insulation.

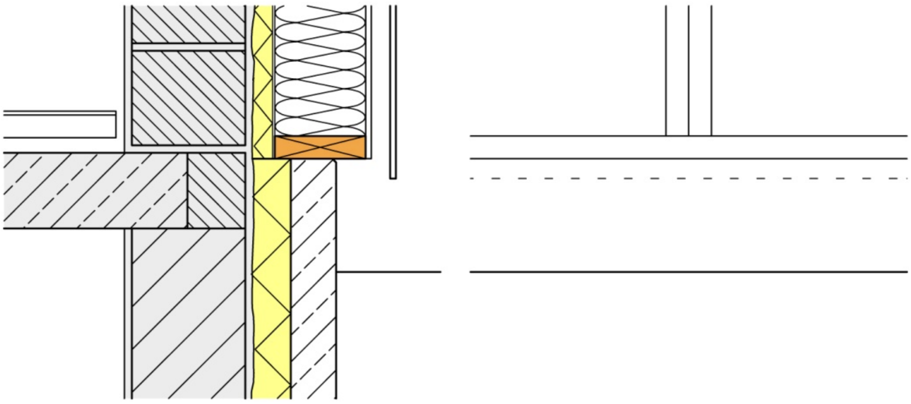


Figure 17 - Different solutions for foundation

Horizontal load

Horizontal loads (e.g. wind loads) can be lead into the existing load bearing structure of the building at the height of the ceiling. Anchoring a beam to the concrete ceiling and later screwing the façade elements into the beam has proven a feasible solution of the practice. The beam is put exactly into the level required adjusting the façade elements in their right position [Figure 18].

Optional steels brackets can be used to connect the new and existing parts.

Figure 18 - Joint at ceiling level with anchoring beam and facade element

Site access

Frictionless site access is necessary for tenants and craftsmen alike. In occupied construction sites early and thorough communication between tenants, landlord, planners and builders is a key factor at an early project stage. Information prior to construction is mandatory.

Information to tenants or apartment owners needs to be given especially on

- Type of action
- Level of interference
- Time schedule
- Responsible people on site
- Claim management
- Expected impact
- Expected result

Communication with the residents can be organized in board meetings or seminars. Strict appointments to enter the properties should be managed in advance of any action taken.

Facilitate temporary infrastructure for the residents, especially:

- Stairways or access routes
- Bathroom / toilet (when bathroom is renovated)
- TV / Internet access at all times

Workflow responsibilities

Following overview demonstrates an example of specific tasks in a team of architects, engineers and timber manufacturers.

Phase	Architect	Engineer	Contractor (TES)
Transportation		Check weights, transport loads, loading, etc.	Safe transport, protection of elements
Preparation	Detail planning	Check structure	Low preparation up to partly/totally dismantling
Assembly	Site coordination Quality control	Quality control	Site management Assembly according to plan

Table 5 - Workflow responsibility during construction

Following task list gives an example of specific tasks for a collaboration team model of architects [ARC], structural engineers [ENG], HVAC planners [HVAC] and timber manufacturers for TES EnergyFacade elements [TES] as it was conducted in the E2ReBuild demonstration projects in Augsburg and Munich.

	On-site | Assembly	ARC	ENG	HVAC	TES
1.1	On-site assembly	-	-	-	**E**
1.2	Quality and compliance control	**E**	P	(P)	P
1.3	Site management	**E**	P	P	P
1.4	Time schedule	P	P	P	**E**
1.5	Team coordination	**E**	P	P	P

Table 6 - Task list. E - Execution, P - Participation, (P) - Participation if applicable

3.2 Recommendations and Guidelines

Following recommendation and guidelines for on-site logistics and assembly processes are based on lessons learned from E2ReBuild demonstrations.

On-site assembly	Recommendation
Building site facilities	• Choice of appropriate heavy lifting equipment, positioned with consideration of operation space • Planned assembly process with consideration of time slots for preparation, dismantling of structures and/or layers of the existing envelope and lifting / mounting of the new elements
Precision	• Utilization of fixed base grid and points at assembly • Measurement of fixation points (e.g. brackets)
Construction surveillance	• Quality surveillance according to national and international standards • Protection from contamination of the existing substance during the assembly if the building is retrofitted under operation • Visual check of tightness of joints and air tight layers • Blower door test
Assembly	• TES elements and components must be stored, moved and assembled on-site without any damage. Respect precaution measures • TES elements must be lifted and assembled according to the assembly plan and instructions by the element manufacturer.
Training	• Establish assembly routines. Inexperienced teams need an initial coordination; necessary requirements have to be considered already in tender specifications
Scaffolding	• Prepare a scaffolding plan for approval • Scaffold must be placed and fixed according to regulations of health and safety • Prepare specific fixation points in new façade • Document fixation points for future use
Health and safety	• Respect regulations, especially for the work on the scaffolding while lifting large scale elements between the building and the platform • Facilitate escape routes and access for fire brigade at all times if building sites are inhabited
Communication and service	• Detailed plan of every building activity including buffers to minimize time and disturbance for tenants • Management of tenant requirements. Organization of communication with residents (e.g. seminars, meetings) • Plan appointments to enter private property • Temporary infrastructure for residents (e.g. access, restroom)
Protection	• Protection of building, *TES* elements and components in addition to factory protection with tarpaulins from rain, wind and dirt if needed

3.3 Quality assurance

Quality assurance in construction work of building modernization, also with prefabricated elements is commonly achieved by following recognised norms and rules of technology as well as relevant national building regulations.

One of the key objectives of national building regulations as well as harmonized European regulations is that any construction work or completed construction shall satisfy the requirements in regard to safety, health, the environment and serviceability.

The existing norms and quality regulations cover definitions for material and product properties as well as procedures for internal and external production control. In addition, timber contractors may commit themselves to voluntary quality assurance systems such as RAL (Germany).

The following example specifies regulations and surveillance measures to assure defined quality standards of building materials, production and assembly of prefabricated timber elements (e.g. *TES EnergyFacade*[22]):

Stage	Requirements
Construction material	• Conformity (Ü and CE) • Technical approval • DIN EN • Incoming goods inspection (humidity, specification)
Production	• Internal (self-) control • External monitoring • RAL quality label (RAL-GZ 422/1)
Timber frame element	• Conformity (Ü and CE) • DIN EN
Assembly	• RAL quality label (RAL-GZ 422/2) • Blower Door / thermal imaging • Metrological coordination (referenced grid) • Visual check • Caution of workers on-site

Table 7 - Example for quality requirements for *TES EnergyFacade*

[22] Compare TES manual, page 152 and following

4 Conclusion

Contemporary timber construction is characterized by standardized planning and construction processes with a high level of prefabrication. This offers great opportunities for the task of building modernization by enhancing facades and extending buildings and thus generating added value. Timber manufacturing based on CNC[23] production technology offers the chance to adapt prefabricated timber elements to even complex geometry. Using maximum sized prefabricated elements has the potential to increase quality and reduce construction cost. It requires increased planning effort, in which on the basis of a thorough building analysis, the design of the elements, their production, transport logistics and assembly are considered.

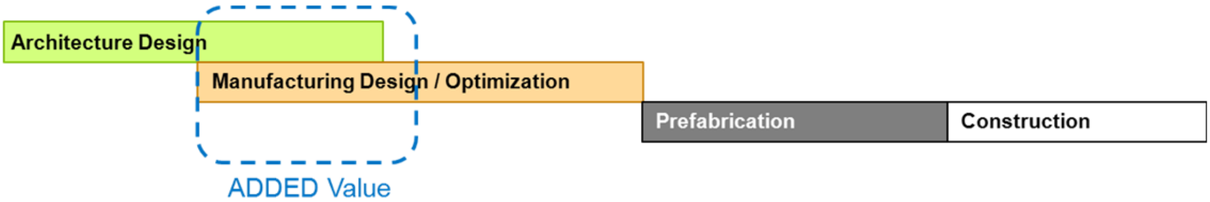
Rationality and precision determine the manufacturing process. Standardized, optimized and monitored production processes from the inventory management to the production allow a controlled and high standard of quality. The use of prefabricated construction elements improves productivity during the on-site assembly and thus leads to less disruption of operations and the living environment.

Quality

Construction quality is achieved in compliance with common quality standards. In case of timber construction, these are based on standards for the construction of new built timber structures (e.g. timber frame, CLT[24] construction). The E2ReBuild demonstrations, where prefabricated timber elements have been applied have proven to reach the goal of sufficient quality standards. For example the Munich project was monitored over a significant time period without registering changes or impacts from moisture within the construction[25].

E2ReBuild has further proven that process quality is a growing momentum for project success. Off-site production or prefabrication requires a certain standard of PROCESS QUALITY and is a precondition of realized QUALITY. The deeper the preparation and planning of a project, the sounder the execution of work and result will be.

E2ReBuild demonstrations have revealed the complexity of holistic building refurbishment which can be tackled successfully by a team of specialist cooperating and working together for common set goals. Construction work based on industrialized methods offers advantages and depends on new collaboration models.



Especially overlapping the design phase of architects / engineers and production planning of manufacturers offers the chance to build on holistic experience of all participating specialists' right from the project start to achieve the best solutions. E2ReBuild demonstrations have proven practicability and success of a renovation method based on industrialized principles. Advancing the method implies tackling the following challenges:

[23] Computer Numerical Control. Digital information of timber frame pieces is distributed to CNC driven cutting and assembly machines
[24] CLT – cross laminated timber boards or structural elements
[25] Compare D 5.2 – Measured data from demonstrations

- Overcome standard contract models
- Develop a new collaboration culture
- Define a set of rules for collaborative design teams

In addition to residential buildings, the renovation of public buildings such as schools, kindergartens and administration buildings require holistic refurbishment methods in the ongoing operation. Wood construction can offer intelligent and resource-efficient solutions in many areas. The opportunities lie in the individualized prefabrication to offer tailor-made solutions for the modernization of our building stock.

Appendix A - Information Map of other E2ReBuild Deliverables

Further information related to the Grüntenstraße project can be found in following other deliverables:

Deliverable	Information
D 3.4	Holistic strategies and cost break down. Further analysis and ratio of cost, energy performance and outcome
D 4.1	Measurement methods as part of the planning process as conducted prior to the planning stage
D 4.4	Building envelope: Solutions for the integration of building services into *TES EnergyFacade*
D 5.1	Monitoring scheme
D 5.2	One key issue that the building industry is currently facing is the issues of moisture transportation in the building envelope (building physics). This has been studied in the *TES EnergyFacade* and monitoring has taken place in all demonstrations. The results are presented in deliverable 5.2.

Appendix B - Identified Issues

Following tables reflect issues that were identified in the E2ReBuild demos and documented by WP 3.

Table 8 - Difficulties and consequences concerning legal or standard requirements

Difficulties	Consequences
Complex fire prevention measures within timber frame systems for façades of buildings > GK3	
Fire prevention measures are a barrier for timber-based structures applied at buildings with higher building classes.	Out of the experience of the E2ReBuild demo projects some struggled with difficulties caused by extended and hardly predictable compensation measures requested by local or fire protection authorities (for example Munich,…). A more elaborate planning phase and a big personal engagement by the architect were necessary. The owner GWG sees a big risk of over boarding costs caused by additional compensation measures and higher planning effort.
Adaption of buildings codes and standards and their handling by authorities	
The newness of the renovation system for the building envelope puts pressure on statutory requirements and their handling by local authorities. The request for European Technical Approval [ETA] and hence by building codes in European countries to approve new systems and components before their first application is widely unknown. Contrary local building codes are executed strictly by authorities without respect to changed basic conditions caused by industrialized renovation methods.	No Demo project applied (or had to apply) for the ETA, but some of them were confronted with strict requirements out of national/ local building codes, standards or individual requests by authorities (Munich, Oulu) The Oulu project, for example, was treated as new building and had to comply requirements as a new building – with the result that unexpected (high) requirements had to be fulfilled. Within the Munich project a high personal effort was necessary to “negotiate” compensation measures for fire prevention.

Table 9 - Difficulties and consequences concerning technical aspects

Difficulties	Consequences
Load bearing capacities of existing structures	
New prefabricated modules bring additional loads to the existing structure. The load-bearing capacity within existing buildings is mostly unknown – within existing brick walls and concrete structures. The density and reinforcement can only be checked by deeper structural analysis. Additionally soil tests should be done to prove capability of ground for new expected loads.	Too weak structures need other system concepts such as reinforcement of walls or foundation, etc. or new foundations at all. Redesign or reorientation in later planning stages if load capacity is overestimated. The methods to use additional foundations were seen as very elaborative
Load transfer with the new system and to the ground	
The transfer of loads from new roof to new façade systems and from new façade to existing load bearing walls determines the new structural system.	If the structural system is neglected in early planning stages a redesign could be necessary in later phases.

Thermal bridges	
A highly insulated retrofit is more sensitive to ground frost and cold bridges from old structures. The use of prefabricated modules needs awareness of such weak points already in the planning phase in order to design the new insulation layer without thermal bridges.	The challenges are hidden in three-dimensional nodes that have to be identified and solved – mostly as interface between different professionals. Neglected weaknesses may cause damages due to hardly detectable condensation. Examples like Oulu showed that special ground frost protection design needed.
Airtightness of existing building	
Unknown airtightness of existing building (to the outside and among apartments)	Airtightness is eventually underestimated and energy savings calculation might provide better results than possible.
Adhesion of airtight membrane to the existing building	
Closure of new envelope components to the existing building (such as integrated windows) or the connection of the new envelope components at joints or corners has to be airtight. Details have to be planned carefully and with respect to easily executable solutions on-site. 3 dimensional nodes are very often a challenge for trade-spanning solutions.	Within high-performance buildings, leakages within the airtight membrane are more sensitive – even small leakages act like pressure valves and bear moisture and mould risk within the construction and are (due to complex component composition) very often undetected for a long time.
Acoustic requirements	
Tightened acoustic requirements need to be met. Existing concrete walls and precast floor slabs transmit structure-borne sound very well. The interior situation cannot be improved easily – vastly it is not possible to exchange all floorings for example.	Adding a new exterior shell such as a prefabricated element improves sound insulation – as the interior sound situation is not improved (vastly this is not possible despite all floorings for example are changed), the inner sound transmission might get recognized stronger than before.

Table 10 - Chances and challenges concerning technical aspects

Chances	Challenges
Improvement of airtightness of building envelope	
The enclosure of an existing building with a new envelope provides the chance to improve the airtightness.	Unknown (bad) airtightness of the existing exterior building structures. Experiences from E2ReBuild demonstrations showed that existing concrete structures or brick walls can have leakages, mostly caused by gaps or unknown weaknesses. For example in Oulu old precast concrete joints with extensive gaps of the interior part of cavity walls needed extensive filling to improve airtightness.
	Adhesion of new airtight envelope by closing the new membrane to existing parts (such as window reveals or the joint to roof air barrier membrane) or the penetration of the new membrane by ductworks and pipes for the renewal of building service systems is difficult and need

Improvement of airtightness among different units (apartments)	
Partial renewal of interior provides the chance to improve airtightness among apartments and apartments and public spaces.	The improvement can only be done in parts that are renewed – others remain as before. While the separation to staircases or other public spaces might be possible, the airtight division between apartments is a challenge and can rarely be done. For example in the Oulu project, the air tightness among the apartments was not an issue because only one concrete wall as division between the apartments and the entire interior of the apartments was renewed. Further Oulu was renovated in an unoccupied situation – hence a serious internal renewal was possible. In case of extended big-volume multi-family houses more division parts provide a lot of potential weak points and in occupied situations the critical parts (flooring, existing concrete slabs or staircases,..)

Table 11 - Chances and challenges concerning assembly and logistics

Chances	**Challenges**
Weather independency	
Industrialized methods and especially prefabrication enables production of construction elements to be weather-independent from the processing method. Especially to be more independent from cold periods. While ETICS cannot be applied within the time of November until April (the risk of frost can be excluded) – it is possible to apply timber constructions over the entire year.	The application of prefabricated systems needs a more detailed and complex planning that is appropriate for industrialized renovation procedures. The high quality of the final result emerges out of a design and planning quality on a high level.
Shorter renovation times	
Within the interviews with the various E2ReBuild stakeholders the advantage of shorter times on-site could be verified in nearly all cases. Especially the Oulu project showed the opportunities of the application within shorter seasons for construction. The project could only be accomplished due to the short and quick procedures on-site which fit perfectly into the time before winter season. One part of the Roosendaal demo- was renovated with the standard external thermal insulation composite system (ETICS). This was based on the two demo houses built within the preparation phase. And the experience showed the long time span that is needed to bring this system up (3-4 weeks needed for gluing the boards until the final priming). The experience	The short time on-site can only be achieved by very detailed scheduling and planning of logistics and storage in advance. Any friction within the process chain causes significant chain reactions. Shorter renovation times are very often misunderstood. The smart and short procedures on-site need very careful and extended planning and scheduling in the planning phase (compared to standard renovation). The entire renovation time can only be shortened in case of experienced teams and well organized procedures.

of the third house with the timber frame method showed the significant advantages of reduced time on-site and the independence from the winter period.	
Tenants perspective	
The time of works seems to be shorter (prefabrication is not visible on-site) compared to tradition ways of ETICS and scaffolding maintained for the entire time. The mounting procedure of the large-scaled modules was impressive. An advantage is on one site the technological perspective of the quick and perfect work-flow on-site. Hence it is an advantage from the tenant's perspective: Standard renovation with ETICS is the entire time visible for the resident – very often claims are raised "when the site is finished"; within the implementation of prefabricated modules the entire work before (assembling in fabrication hall of carpenter) is not visible – and the real mounting is a very short spectacle.	The communication of advantages needs to be convincing. In case of troubles every difficulty is visible on-site.
Coordination of building site	
Owners praised the proper building site (clean and tidy) – contrary to standard renovations. This enables easier Health & Safety management and supports occupied building sites.	Routines have to be established, inexperienced teams need an initial coordination; necessary requirements have to be considered already in tender specifications.
Occupied building site	
To proceed an «energetic» renovation of multi-family houses without moving of residents. Many of the E2ReBuild demos honoured the renovation in an occupied situation – the risk of tenants who do not want to move back (London) was not given, no compensation payments (London, Roosendaal) or no search for appropriate vacant buildings nearby (Voiron) were necessary.	The E2ReBuild Demos showed that a big personal effort is necessary to get «tenants on board». Although building owners and project coordinators (such as architects or total contractors) are aware of the importance of the communication towards tenants – different strategies were pursued. Tenants who feel well-informed have less complaints and bear disturbances to a greater extend.
To be weather-independent for the occupied situation: Windows can be mounted outside, entire façade can be closed. Residents may remain in their apartments. After (nearly) completion on the outside – in a well-scheduled process old windows can be removed from inside the apartments and junctions can be closed.	While prefabrication provides less disturbance for tenants, the removal of windows and the closure of the airtight membrane or vapour barriers require work inside apartments that has to be planned, coordinated and communicated carefully.