Interreg
EUROPEAN UNION
North-West Europe
Housing 4.0 Energy
European Regional Development Fund

Housing 4.0 Energy Guidebook

Vlaams-Brabant · Elfi Tech · Gemeente Almere · TU Delft Delft University of Technology · South East Energy Agency · South West College · Open Systems Lab · KAMP C · Thoma

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Recommendations from the Housing 4.0 Energy Project.

It is no secret that in the coming decades, we face a huge construction challenge. Not only do we need to build millions of affordable, low-energy homes and neighbourhoods – but those homes need to be zero-carbon, zero-waste (what's known as 'circular'), and healthy.

It's also no secret that our legacy construction industries aren't ready for this challenge. Buildings are responsible for 39% of all emissions – with a huge part being the emissions resulting from their construction. The methods we use today are slow, wasteful, labour-intensive, and carbon-intensive.

The good news is that most of the solutions we need are already here. The H4.0E pilots exemplify some of the bio-based, manufactured, rapid-assembly building technologies that are going to help us rise to this challenge.

The problem is that the adoption level of these methods is still incredibly low.
So that's part of the challenge we're focused on. How can we make these solutions more replicable? Namely, how can we lower barriers to adoption, and make them easier to use? It's not enough to just reinvent the way we construct buildings. We also must reinvent the way we design and procure them. It's about how knowledge works during the design process.

What makes buildings especially complicated is that there are many different types of knowledge that you need – architectural knowledge, structural engineering knowledge, fire engineering knowledge, regulatory knowledge, construction knowledge, market knowledge... As a result, many professionals are needed throughout the planning to construction phases, and at each step, the project could go back to the architect causing a cost in time and money. The architect comes up with a sketch, not knowing how it will be built, or how much it will cost, then passes it to the next person. If their solution doesn't work, it gets sent back, revised and they try again. And so on.

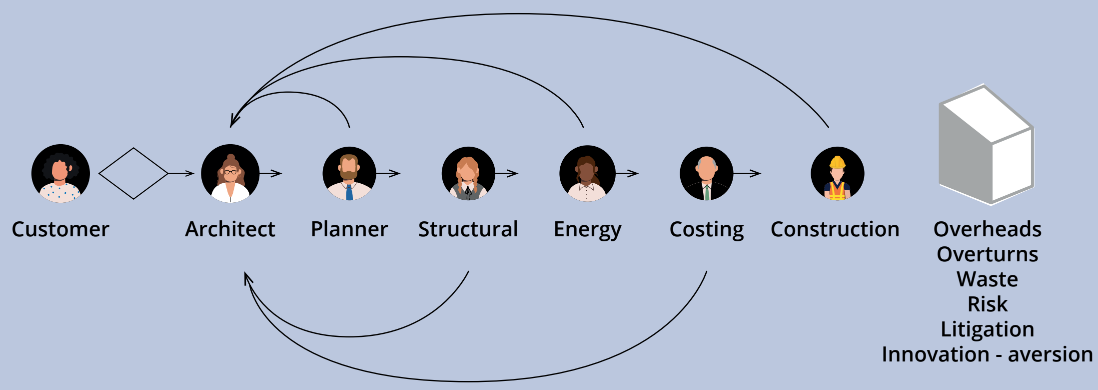


Figure 1: Current construction methods

The open secret at the heart of design and construction today is that not only do we design every single building from scratch every time, but we actually do it several times over. The result, of course, is massive uncertainty and cost. There's no way of knowing how your building will perform, or how much your building will cost until you've built it basically. Imagine how much a car would cost if, every time you wanted to buy one, you had to pay the engineers from BMW to come and stand on your drive in the rain with their sketchbooks and build a unique car from scratch.

We pay the price in quality, performance, waste, risk, and stress, but above all in money. It is estimated that for every euro we spend on a building today, only 51 cents are spent on the product itself and only 5 cents are taken as profit. 49 cents go on the cost of risk, overheads, fees, and so on. We have a suite of technology to solve this problem – BIM, parametric modelling, finite element analysis, and digital manufacturing. The problem is that what we've done is taken those tools and technologies and basically bolted them onto the same operating system. Using the World Wide Web could change all of this.

Imagine if, instead of an architect coming up with a sketch and then handing it to an engineer and a quantity surveyor to find out if it will stand up, and how much it will cost, we flip the process. Engineers build standardised products that incorporate thousands of hours' worth of knowledge into them. It's the equivalent of coming up with Lego blocks that are pre-engineered, putting a price tag on each, then handing them to an architect and saying, 'here design with these'. That way, as you design (within the rules of the product) you can instantly know that it will work, from an engineering point of view, and you know roughly how it will perform, and what it will cost, based on the latest available data. And of course, the really important bit is you can then gather the lessons you learn, and the data from the projects built, and send that back as feedback, so the product is constantly learning and improving.

If you can get product maintainers to document those modular products – those Lego bricks – and the rules and data behind them, you can then plug them into tools that make it much, much quicker, and easier to design projects that start with that knowledge baked-in. Anyone can use those tools to explore ideas in their own time, without sending any emails or picking up the phone.

And that in a nutshell was what we set out to prove with the H4.0E platform project. Can we put those tools on the web? This is where the H4.0E platform comes in. This will be explored more in detail in a later chapter but, simply put, this platform allows property owners or their architects to rapidly design from a menu of 'modules'. The user can design a building not by just drawing 'dumb' geometry, or by stacking blocks, but by using intuitive interactions, like stretching the building, adding windows, changing the cladding materials, and changing the internal layout. Every time you make a change, the estimated cost and performance of the building are instantly updated – something you'd otherwise have to pay a consultant to do, and it would take days or weeks. You can then review that expected performance on an analysis dashboard, and ultimately, you'll be able to then download models, and manufacturing lists and hopefully, at some point, when you're ready, send this order to the manufacturer.

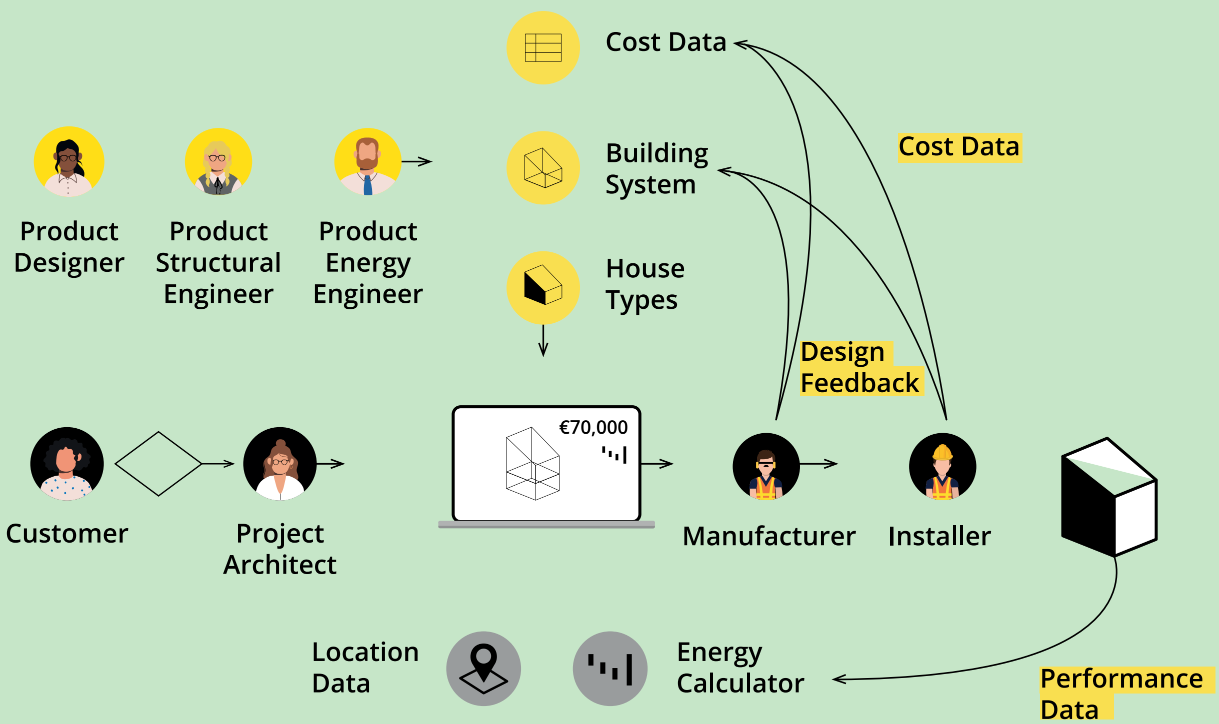


Figure 2: How the H4.0E platform will work (1)

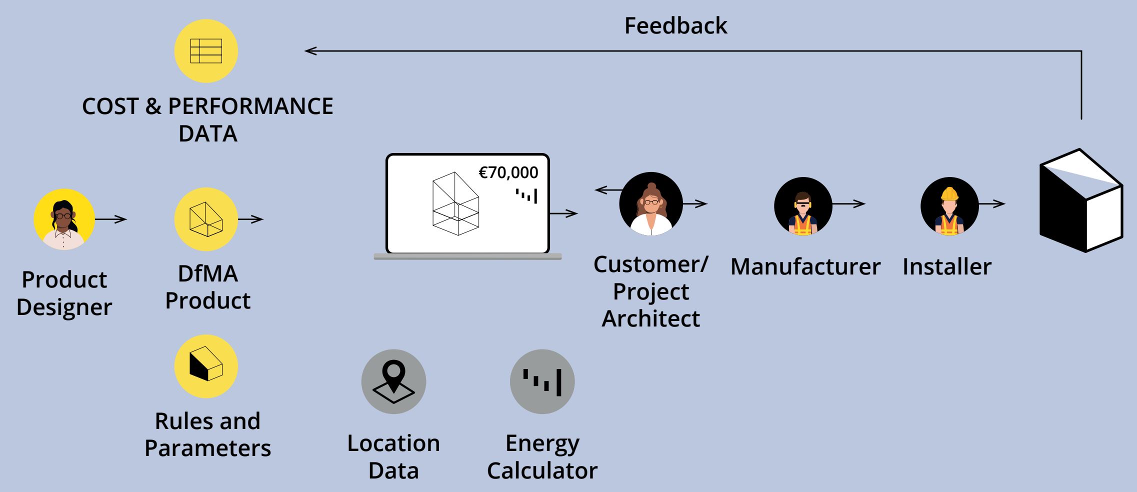


Figure 3: How the H4.0E platform will work (2)

The H4.0E project at its core seeks to change the approach to housing construction in Northwest Europe. We want people to consider the embodied carbon of their builds, looking at the materials being used, the efficiency of the building, and the process of construction more deeply. Below, you can see some highlighted recommendations from H4.0E.

- We need to invest in further digitalisation of the building process in order to maximise benefits in terms of cost, efficient use of materials, and awareness of the climate impact of design choices.
- We need to invest in smart DfMA models that democratise building by making the process more transparent, empowering end-users, or even allowing end-users to design and build their own houses.
- Apart from efforts to reduce operational energy use, bold steps are also needed to minimise embodied carbon in the building sector and to put the issue on the agenda.
- Specific demonstration projects are needed to showcase affordable and achievable combinations of new techniques and new materials. Important target groups for these demonstrations include social housing agencies, self-builders, and project developers.
- Careful monitoring of energy use and user habits is key to maximise the benefits of new techniques and materials.
- Cooperation among all stakeholders is needed in order to upscale new solutions (and thus further decrease costs) and overcome financial, legal, and cultural barriers.
- Use the passive house approach to minimise operational energy use.
- Use circular construction and the use of re-use platforms: this optimises the re-use of materials and thus minimises building-related Greenhouse Gas (GhG) emissions.

- Use low-carbon building materials such as solid timber (in timber frame constructions), plywood, and dowel laminated timber. Apart from answering climate concerns, they allow for fast fabrication, rapid and easy assembly on-site, and reduce the need for internal finishing. This often results in lower total building costs. The effect is multiplied if combined with industrial prefabrication. Where cement is still needed, opt for alternatives such as Ground Granulated Blastfurnace Slag (GGBS), offering similar properties but results in less net GhG emissions.
- Try to build maximum flexibility into the design, considering the entire life span and the various uses of rooms and dwellings. Allow for reduction, expansion, and changes in layout. This will enable low-cost and low-resource adaptation to changing needs.
- Bundle technical installations to minimize maintenance or replacement impact and to minimize perforations of the outer shell.

Welcome to the H4.0E Guidebook.

What is H4.0E?

Figure 4: Housing 4.0 Energy Introduction Video

In 2018 the Housing 4.0 Energy (H4.0E) project proposal was finalised and began with the objective of enabling a significant switch of small households to new affordable, zero energy/low carbon homes, leading to an extensive reduction of housing-related CO_2 emissions. Working with social housing associations, end-users, and other stakeholders in the building industry, the partners intended to lead the way in the application of digitization techniques and the use of low-carbon materials, and zero energy techniques adapted to smaller housing units, creating essential changes across the entire construction supply chain. The project planned to deliver 45 affordable, low carbon, and ZEB/NZEB housing units (with one demonstration unit), a digital platform for the construction of further units outside the project, training materials, and a series of actual training, and this guidebook to highlight the journey of the H4.0E project and assist stakeholders in replication of its principles.

How to Use the Guidebook:

This book serves two purposes. It will tell the story of H4.0E, describing the policy, legal, and financial frameworks that needed to be navigated, the platform that was developed, and the housing units constructed. It will give the reader insight into the research and activities undertaken by several partners during the project's four-year run. This guidebook also serves as a springboard for anyone wishing to replicate the houses that we have built. By reading this book and following up with the additional resources provided (such as the training courses and digital platform) we hope a reader will be able to build on our work and develop either their own ZEB/NZEB houses or even attempt replication of this project. Thus, this guidebook should help to ensure the longevity and continued relevancy of our work.

When using this resource, you do not need to follow it chapter by chapter, but rather can read the sections you feel are relevant to you. Reading it as delivered will, however, give a sense of narrative as we move from the early stages of the project to the learnings such as the training programmes. You will also notice indications towards further reading resources online. Depending on your own objectives, we encourage you to follow these when relevant to you. There was only so much we could place in this guide and so each partner has further information or interactive media available. The training programme and H40E platform are examples of this.

If you are moving into a Housing 4.0 Energy house, we strongly recommend you read the chapter on Online Training by South West College. Specifically, we recommend unit 3; Occupants Guide to Near Zero Energy. This will allow you to better understand some of the key features of your new home and will inform you of any important maintenance that is needed for the upkeep of your home.

In this Guidebook, you will learn about the H4.0E Benchmark. The H4.0E Benchmark links mainly to the Passive House Approach and a Low Carbon Fabric First Approach when constructing houses. It also champions a Design for Manufacture and Assembly (DfMA) model, which serves as one of the elements keeping building costs affordable. You will learn more about these concepts, how the H4.0E approach covers them, and how they were integrated into the H4.0E Testbed Pilots.

We wish you all the best in your ZEB/NZEB journey and hope that the guidebook assists you along the way.

Climate Change and the Northwest Europe Housing Crisis:

Housing Europe released its study; The State of Housing in the EU in March 2021, looking at the social housing climate across Europe. The report found that there is "a greater demand or social services and in particular for social housing" and a "widely recognised need to turn to long-term, inclusive strategies to guarantee a greater availability of (better quality) social and affordable housing". The need for more social and affordable housing is being felt across Europe. A report by FEANTSA & Foundation Abbé Pierre estimates that at least 700,000 people are sleeping rough or in emergency/temporary accommodation on one night in the EU. This number, the report finds, is a 70% increase compared to 10 years prior. In addition to this, rising house prices and rents are pushing more and more people into living in social housing schemes or overcrowded houses, with a 2019 Eurostat figure finding that 17.2% of the EU population live in an overcrowded home.

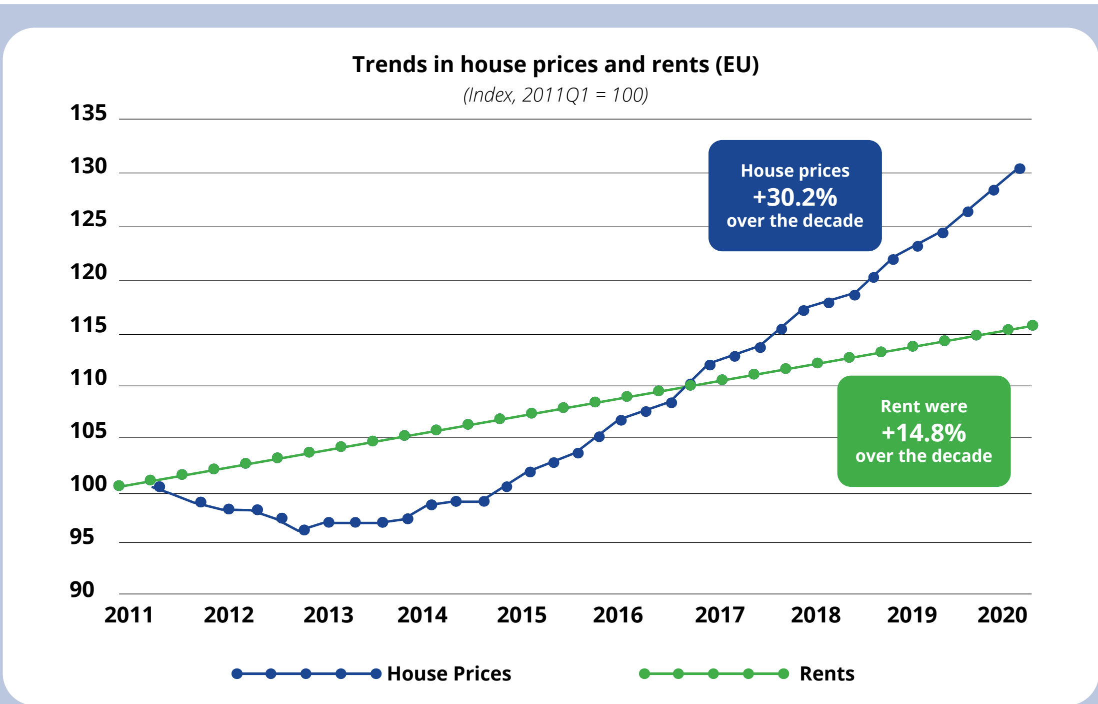


Figure 5: Trends in House Prices and Rents in the EU (source Eurostat)

Along with the social problems around housing in Europe, there are also real issues with emissions from the construction of houses in the form of embodied carbon. The EU 2030 Framework for climate and energy sets targets for cutting 40% of CO_2 emissions, increasing the share of renewable energy to greater than 27%, and providing at least 27% energy savings across Europe. The Northwest Europe (NEW) region is the most industrialised region—as well as the most prolific CO_2-emitting region—in Europe. Within this region, the private housing sector alone accounts for nearly one-third of all CO_2 emissions.

There is currently no great push within this industry to achieve EU targets. Meanwhile, decreasing household size, changing patterns of regional population density and other social factors have led to a significant decline in demand for large, expensive, and energy-inefficient homes. Between the climate and social issues mentions, there is a clear need for a change in the industry to move towards smaller, affordable, energy-efficient homes that can be made in bulk to meet the demands within Europe. The main goal of Interred Northwest Europe Housing 4.0 Energy, therefore, was to offer people in NWE access to new affordable near-zero energy/low carbon homes (NZEHs) and zero-energy/low carbon homes (ZEHs), effectively aiming to reduce home building costs by 25% and carbon emissions by 60%.

How Housing 4.0 Energy Proposed We Solve These Issues.

The Project Beginnings:

The Housing 4.0 Energy partnership includes nine organisations from five different countries in Northwest Europe. These are Provincie Vlaams-Brabant (Belgium), Europäisches Institut für Innovation – Technologie e. V. (Germany), Gemeente Almere (Netherlands), TU Delft (Netherlands), South East Energy Agency (Ireland), South West College (UK), Open Systems Lab (UK), Kamp C (Belgium), and Thoma Holz GmbH (Germany). The five-year H4.0E project is intended to facilitate the uptake of low-carbon and digital technologies, products, processes, and services in the NWE housing sector to reduce carbon emissions and improve the quality of life and affordability for residents in the region and beyond. The eventual goal of the project was to assist in developing an affordable ZEH market. H4.0E was funded by €2.5 Million in European Regional Development Fund (ERDF) funding with a total budget of €4.2 million.

Figure 6: Google Earth View of Partner Regions

Housing 4.0 Energy Deliverables:

There were three key deliverables agreed on for H4.0E. These were:

- A digital platform for digitization of housing construction.
- An online learning platform to communicate the H4.0E techniques and principles.
- Pilot testbed houses in four partner regions (five pilot sites).

The H4.0E digital platform sought to facilitate the digitalization of building homes and the transferability of these techniques beyond the project's lifespan. The partners hoped that this would ignite fundamental changes in design, manufacturing, and construction within the housing industry to meet both EU targets and the needs of homeowners in NWE. This platform was developed with inputs from key stakeholders (local authorities, housing associations, architects, self-builders, construction companies, and current homeowners). It allows future developers and even laypeople to design homes using the H4.0E principles, based on a menu of modules listed by regional manufacturers. It further allows users to instantaneously see the estimated impact of their design decisions on cost, carbon, and energy use.

The H4.0E principles were tested and monitored for viability in five pilot sites (in IRL, DE, NL, BE) representing varying levels of industry and carbon emissions, ranging from cities in low-carbon regions to rural areas in less carbon-conscientious regions.

The building sites of the five H4.0E pilots are:

Almere (Netherlands)

Kilkenny (Ireland)

Huldenberg (Flanders, Belgium)

Lahr (Baden Wuerttemberg, Germany)

Carlow (Ireland)

All pilots feed data into the main output: the H4.0E Energy Building Technology that enables affordable zero energy/emission housing building on a larger scale. These pilots were one of the key deliverables of the project and stand as an example of what could be achieved in each region. An important part of the houses were constructed by self-builders, another part belongs to local municipalities, others are privately owned but let by a social letting agency and one will be used as a showroom for what timber frame construction can accomplish. These will be explored in much more detail in a later chapter.

Finally, training modules for future proprietors of the H4.0E practices were developed and delivered to stakeholders. These allow users to better understand principles such as NZEB, Passive House, Fabric First, and the H4.0E Platform. The training units have been put online and are available for anyone that would like to learn more about Housing 4.0E principles. Each unit also contains quizzes for examination of learnings to reinforce the training. Training modules exist to assist individuals who are living in the H4.0E testbed pilots or are responsible for their maintenance. It is strongly recommended that any such persons read and complete these modules to have the best understanding possible for the homes.

The Housing 4.0 Energy Pilots

To test and prove the principles of H4.0E, pilots were constructed in some of the partner regions. These are the pilots in Almere in the Netherlands, Huldenberg in Flanders (Belgium), Lahr in Baden Württemberg (South West Germany), and Carlow & Kilkenny in Ireland. Typically, an H4.0E house is an NZEB or ZEB house built with a Design for Manufacture and Assembly (DfMA) model. It looks to reduce the operational and embodied carbon and cost of house construction by using low-carbon materials and the DfMA model. However, some of the pilots built during the project were unable to follow the DfMA model due to local constraints.

WikiHouse in Almere, Netherlands:

At the Stripmaker project in Almere, 27 WikiHouses have been built by self-builders. WikiHouse is a manufactured building system for houses. It uses plywood sheets that are cut to 0.1 mm precision and assembled into basic building blocks, which can be delivered to the site. They are then rapidly and accurately assembled. This is a simple process that could be done by almost anyone, even if they don't have traditional construction skills. This is one of the key pillars of the Wikihouse build, that untrained individuals can construct their own houses using this process. H4.0E hopes to also be able to empower individuals in this same way through the digital platform.

WikiHouse parts can be digitally fabricated using a CNC machine. This means that parts can be manufactured by small and medium enterprises (SMEs) in local micro-factories, that can be set up for a fraction of the cost. In fact, thousands already exist. Timber panels, e.g., plywood, are the perfect material for fabricating WikiHouse. Plywood is stronger and less sensitive to humidity variations than traditional sawn timber, and it is lighter than bricks, concrete, and steel. This is translated into a much faster fabrication, more rapid assembly on-site without heavy lifting equipment, and appealing internal finishing.

Figure 7:
Artist Impression of WikiHouse Stripmaker Project in Almere, Netherlands

Wikihouse democratises house building, making it completely transparent, and puts end users in the driver's seat. In short, this means houses are customised to the demands of end-users. They are more affordable and of a higher quality.
Self-builders use a toolbox with standard modules (see figure 4) which they can put together to make their own design. This toolbox was also used in the group design process (see figure 5) which facilitates an early exchange between future neighbours of their design ideas and wishes. The toolbox is also used as a VR tool, in which end users can make their own designs in virtual reality. An estimate of the costs of the design is real-time calculated. By doing this, they can walk around their own house before it's built and adjust the design if wanted.

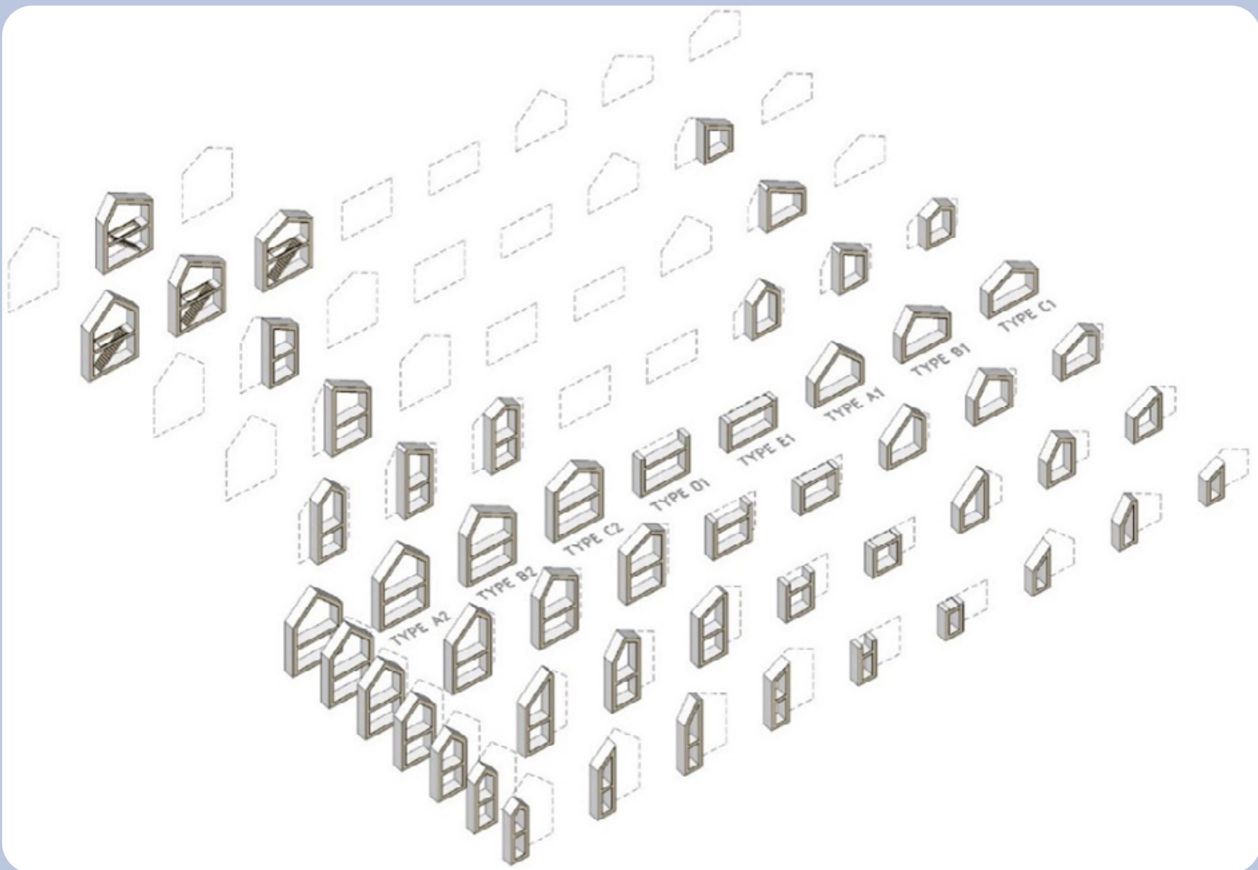


Figure 8: Example of the Toolbox With Standard Modules Available for Self-builders Through WikiHouse

Creation and Future of WikiHouse:

Nine Wikihouses entered construction in the summer of 2020 with most of these now finished and inhabited. Another Eighteen WikiHouses started construction in the summer of 2021. The first of these are now inhabited and it's expected that by the end of 2022, all will be inhabited. Sixteen of the Twenty-seven WikiHouses are being built by future owners, financed by a mortgage. The other eleven are being built by future tenants with their homes being financed by Steenvlinder Inc. After completion, these self-builders will pay a social rent (max €725 a month) to Steenvlinder Inc. After 2 years they have the right to buy the house from Steenvlinder Inc for not the value, but the indexed costs (inflation).

Huldenberg in Flanders, Belgium:

The construction sector in Flanders is conservative and averse to change, lagging in the transition to sustainability. However, it seems that things are now gaining momentum in terms of compact living, and sustainable building, even circular building. The Flemish H4.0E partners - the province of Flemish Brabant (PVB) and Kamp C - looked to build on this momentum by constructing small-scale, NZEB pilots that could easily be (adapted and) replicated.

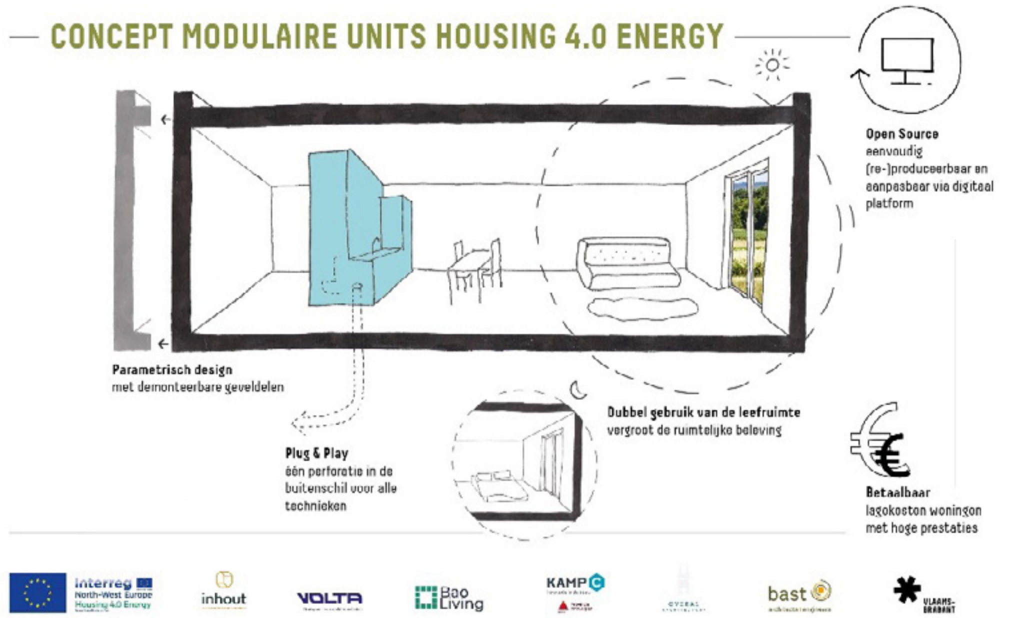


Figure 9:
Concept modular units

Three pilot-types were developed to be built in Huldenberg by the Province of Flemish Brabant and Kamp C, differing in size, technical equipment, and design. Two of the modules are 63 m² and are equipped with 2 bedrooms. The other four smaller modules are 46 m² and have one bedroom. In the smaller dwellings, the modules differ further in the design of the bedroom/living space and the technical equipment. One type has a sleeping area that can become part of the living area during the day and partitioned off at night. The other type has a separate bedroom. The Flemish pilot team used renders of the furnished houses to imagine the liveability and spaciousness of the two types of small units once furnished: the one with a double function of the sleeping area using a sliding wall and the other one with enclosed bedroom (figure 7)

Figure 10.1: *Artist's impression of Huldenberg Pilot in Summer*

Figure 10.2: *Artist's impression of Huldenberg Pilot in Winter*

These pilot houses were built on a privately-owned former recreational site in a rural area, close to the centre of the village of Huldenberg. You can have a good idea of the building site and its surroundings by watching the drone images here.
An introduction to the Flemish pilot by KampC, you can find here.

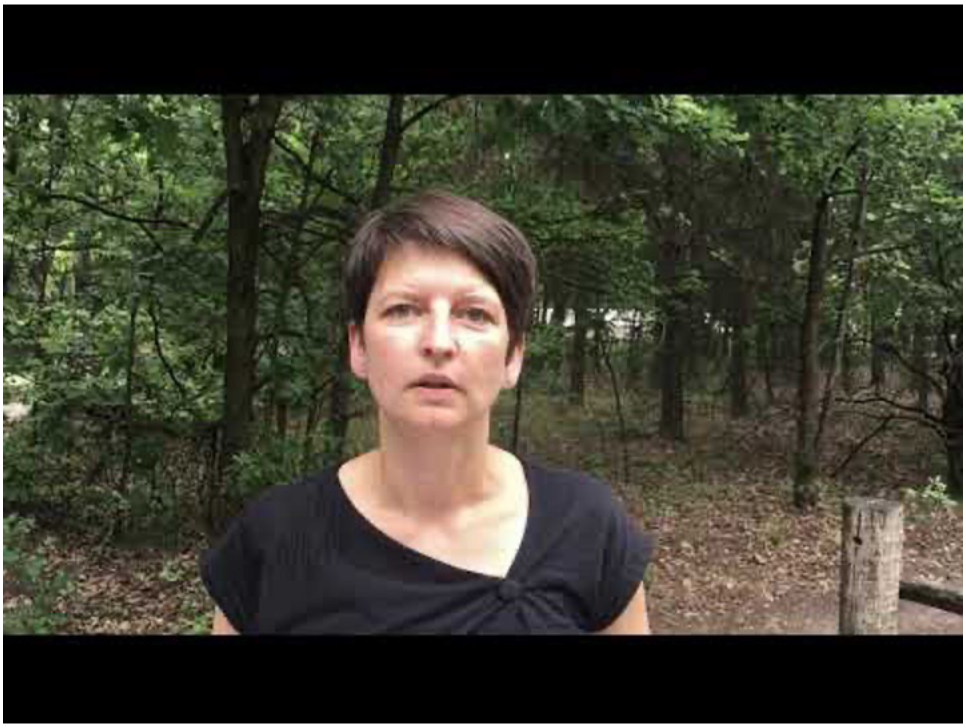


Figure 11: Sofie Torfs from KampC gives an introduction to the Flemish pilot

What makes the Huldenberg Pilot unique:

A key focus was finding solutions that would contribute to affordable housing and lower energy consumption and CO_2 emissions at the same time.

Huldenberg Building System:

The houses were built by Inhout, a company that focuses on bio-ecological materials but also aims at the affordable building. Inhout uses the Mobble building system: a modular ecological and affordable building system developed by the University of Ghent. This timber-frame construction is flexibly adaptable. Maximum flexibility is built into the design for the entire life span and the various uses. This makes it easy to anticipate changing needs. The walls have no load-bearing structures and can therefore be easily dismantled. In the event of any expansion, a new module can therefore be added to the existing volume. The walls can be reused elsewhere. Circular construction avoids the inextricable connection of materials. This method of construction also makes it easier to replace or repair parts. The outer covering is removable so that you can easily reach the next layer. This level of flexibility in design allows customization. In the below video (*Figure 12*), Kristof De Jaeger from Inhout explains what the advantages are of building with the Mobble.

The production time off-site of the pilot houses would be two months in replication. The modules were transported to Huldenberg and finished on-site; this took about 2 weeks.

You can watch here the time-lapse of the fabrication, transport, and installation of the 6 units.

Figure 12: Kristof De Jaeger from Inhout explains the advantages of building with Mobble

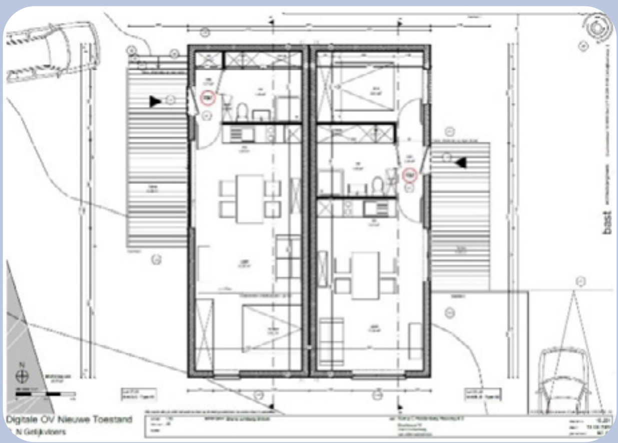
Design

When designing these pilots, several considerations were needed.

Lode Goethals from BAST architects explains in this video the difficulty of designing on a small surface

- Light is very important in a small home. Proper window placement can create a more spacious feeling. The size of window openings can enhance the indoor/outdoor relationship. Each house has a sliding window that opens onto a terrace. The use of windows should always be weighed against the possibility of overheating the home as a result of too many windows or heat loss. An additional consideration is that in small homes, it must also be possible to place the necessary furniture. A floor-to-ceiling window makes no sense if a dresser is placed in front of it because there is no other place available.
- Since the pilots in Huldenberg will be marketed as social housing, flexibility is an important consideration. The layout has been approached as uniformly as possible so that tenants can add their own touches to make it a home, bring their own furniture, etc.
- The materials used had to be as resistant as possible to rental damage.
- In the largest type, it was opted to install a reused kitchen. The dimensions of such a kitchen must be taken into account in the layout of the small house and the standardized grid. You can learn more about the upcycled kitchen in this interview.

• To allow for expansion or relocation, doors, and window widths were made uniform wherever possible so that standardised components could be used as far as possible. In the event of expansion or relocation, it is possible to continue building on the same grid. Because of this alignment, it is sometimes necessary to adjust the plans.



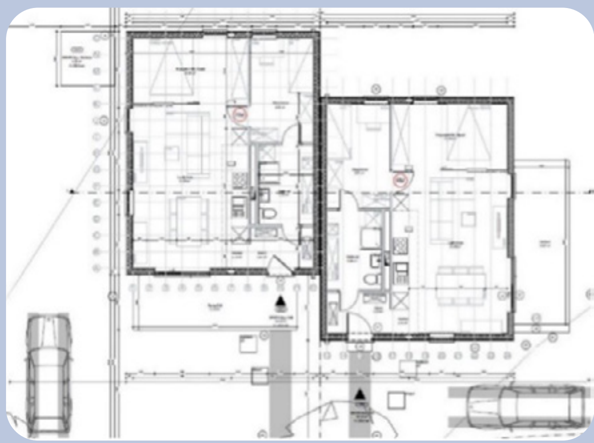


Figure 13: Technical drawings for Huldenberg pilots

• To make a small-scale home comfortable, the surface areas of the rooms must be carefully thought through. It is not enough to scale down or shrink an ordinary house. Designers have to be creative and think differently to create a liveable and comfortable home because every inch counts when you have such a limited floor surface. The reason for opting for a type with a sleeping space that can be part of the living space during the day is that this double use of space is very useful in small-scale living spaces.

• The first sketches were discussed with some future residents and some of their remarks and wishes were integrated into the final design. (see 'the residents' perspective)

• If a house is designed to be circular, it is important that the technical elements can be replaced in due course without having to break down walls. Parts that need maintenance are easy to reach. Moreover, because of the bundling of technical installations, a perforation in the outer shell has to be provided at only one point. To achieve this, the kitchen and bathroom were designed back-to-back.

• The 4 smallest pilots have a smart adaptable module (SAM) from Bao Living. This is a system of modular cabinets that contain various utilities: heating, ventilation, water, and electricity. A kitchen and bathroom are also integrated into this cabinet arrangement, they help to shape the layout of the living environment. Bundling the technologies has the great advantage that only 1 exterior penetration in the floor of the pilot needs to be provided. The prefab SAM module has a shorter lead time, lower failure costs, and provides a more habitable area. The module can be easily assembled according to the space available. For these 4 pilots, the 'basic' version of the module is installed because affordability was an important criterion. You can watch this video to learn more about this concept.

• Because of the limited number of m², there is no separate storage room, but the storage space is spread over (space for) several cupboards. It is very important to think about this when dividing up the rooms.

You can take a virtual tour and visit the pilot houses here: pilot house A and Ak (both 46 m³ with 1 bedroom) and pilot house B with 2 bedrooms.

Techniques and Operational Energy

The six houses are equipped with three different heating techniques: radiant heating panels, accumulation heating, and air/air heat pumps. To assess the impact of these techniques on energy consumption and resulting CO_2 emissions, a monitoring process has been initiated. To provide interpretable measurement data and to keep the energy consumption and costs as low as possible, the residents were advised before they moved in and during the first 6 to 8 months of their staying. This included end-user training, adjustments to the technical equipment, and handing out simplified user manuals.

Figure 14: Flemish Pilot, Huldenberg – Unit Ak

Figure 15: Flemish Pilot, Huldenberg – Unit A&B

Figure 16: Different heating techniques used in the pilot units

To assess the impact of the three different heating techniques- heating panels, accumulation heating, and air/air heat pumps - on the energy consumption and resulting CO_2 emissions, a monitoring process has been initiated. Energy consumption, CO_2 emissions, and some relevant parameters have been monitored over several seasons.

Figure 17: Monitoring Systems

The evaluation will also assess the experiences of residents, who are motivated to save energy as much as possible and to save on their energy bills. The residents are supported to use and maintain these heating systems and other technical equipment and have been assisted by the organisation SAAMO and Volta.

Resident's Perspective

The units are rented out to a social letting agency. This agency lets the homes out to people with a low income that are subscribed on their waiting list. These social tenants will pay a lower rent than the market rental price.

The sketch designs were presented to some potential future residents so that their wishes could be taken into account.

Figure 18: Potential future residents, comment on the first sketch design

An extensive interview with all residents of each of the 6 pilot homes after 5 to 6 months of occupancy, showed a high level of housing satisfaction in the cottages. It brought out the strengths and also points for improvement that is best overcome in new realizations.

Figure 19: Residents' evaluation of the pilot houses by SAAMO and the province of Flemish Brabant

Lahr in Baden-Württemberg, Germany

Thoma started with the world’s first mechanically connected massive wood wall, dowel laminated timber, and DLT. The name of this building system is Holz100. Over 3000 realized projects worldwide serve as a model for a new future of construction. Holz100 is the basis and focus of the prototype in Lahr, Baden-Württemberg, Germany the ethos of Thoma is to build houses that do not burden the inhabitants and environment with construction chemicals. The H4.0E pilot was built at the factory site of Holz100 Schwarzwald (airfield N1, 77933 Lahr, Germany). At this location, it is possible to present the concept of the project holistically. There is a meeting room with a small kitchen and two office workplaces, which can be used by visitors. In the guest room, a visitor can spend the night and experience the timber construction up close. On the 3rd floor, an exhibition is planned. Here, visitors can work out information on the main topics of the project interactively on their own, and in combination with a visit to the prototype, guided tours through the production in the Holz100 factory will be offered to bring the manufacturing process closer.

Figure 20: Holz100 factory in Lahr, Baden-Württemberg

Figure 21: View of the Thoma H4.0E prototype

How This Pilot Is Innovating Housing Construction:

The prototype is a model building for multi-story housing in solid wood construction with a focus on circular economy and innovative building technology. The framework condition for the development of the prototype was the goal of defining a new, faster construction process from planning to implementation of the construction phase via digitalization and the possibilities of industrial prefabrication. All building materials and details were selected and developed in such a way that a reuse rate of over 80 % of all materials used can be realized when the building is dismantled. For heating and cooling the building, Thoma Holz works with a specially developed and patented, prefabricated wooden ceiling with integrated water pipes. Using a central energy management system, the self-consumption rate of the PV system is increased, and the energy peaks are reduced for grid stabilization ("peak shaving"). The building services concept makes heating, cooling, domestic electricity, hot water, and electric mobility highly independent and affordable.

There is a 3D Model of the H4.0E Pilot available online. You can interact with the above 3D model by visiting the following link: https://www.thoma.at/cms/wp-content/uploads/2021/11/3d-turm-lahr.html

During the assembly of the solid wood elements, a film team was on site collecting impressions and interviews with the project participants. Click here to watch the film: https://vimeo.com/manage/videos/723660209.

Figure 22: 3D View of the assembly

The Future of The Thoma Tower in Lahr:

As previously stated, the tower will be available for presentations and even overnight stays. Through this, it is possible to give building owners, planners, and decision-makers the most important basics for project development. In a short time, they gain a deep understanding of solid, glue-less timber construction with its design possibilities, potential and technical limitations. Thoma Holz will keep the building in their possession and will keep it for the next 5 years for presentation, monitoring, and further development of the project priorities. During this time, they will also prepare the deconstruction and reconstruction project of the building. To keep up-to-date visit the website: https://www.thoma.at/wissen/forschungsturm/

Kilkenny and Carlow, Southeast Region of Ireland:

In Ireland, social housing developments are usually provided by the Local Authorities (LA) but funded by the Depart for Housing Local Government and Heritage (DfHLGH). The funding here from the government will only cover houses built with a standardised method. This stunts innovation in the sector as there is a lack of funding for houses outside this standard. Social housing developments are subject to a long approval process enforcing these standards, which could last 2 to 3 years before development even begins. To implement the H4.0E targets around these standards, the Irish partner, South East Energy Agency, added the H4.0E nZEB set of requirements and specifications to the design and construction process, including Passive House (PH) Principles & Techniques and the South East Energy Agency Low Carbon Fabric First Approach. These documents were provided to the Local Authorities who conducted the planning, design, and construction process.

There are three construction sites within the Irish partner's region. One in Carlow (St Mary's Court) and two in Kilkenny (Graignamanagh and Mullinavat). The Carlow pilot is two buildings consisting of 4 social housing units in the form of semi-detached houses. Graignamanagh has two apartment-sized houses in one building, and Mullinavat is two houses in one semi-detached building. These are all located in the southeast of Ireland, where South East Energy Agency primarily operates.

Figure 23: H4.0E Pilot in St Mary's Court in Carlow Town, Graiguennamagh in Kilkenny, and Mullinavat in Kilkenny

The H4.0E nZEB benchmark includes measures to lower embodied and operational CO_2 emissions in house builds and in time reduce the cost of construction by utilising a DfMA model and ensuring the houses are built to nearly Zero Energy Building (nZEB) standards. The Irish pilots sought to achieve this by using prefabricated timber-frame closed panels or low-carbon GGBS cement composites and energy-saving efforts like the installation of Photovoltaic systems and heat pumps.

Figure 24: ICF module & roof truss

How are the Irish Pilots different from 'normal' construction methods:

One main feature of the alternative design of all Irish Pilots is to mitigate the carbon hotspot "cement" which has a high impact on CO_2 emissions within its production process. To achieve this, they used Ground Granulated Blastfurnace Slag (GGBS), a by-product from the manufacture of Iron, which is a by-product of the steel-producing process and consists of the same properties as the commonly used Portland cement. GGBS can be used in all cement composites to a max of 70%. This 70% is allowed in walls, for slaps and foundation it is recommended to use a max ratio of 50%. By using the max allowed ratios in all concrete mixes, screed, render, and concrete blocks, all the embodied CO_2 emissions of the buildings were reduced by 60%.

Figure 25: External wall in ICF

The H4.0E nZEB benchmark includes measures to lower embodied and operational CO_2 emissions in house builds and in time reduce the cost of construction by utilising a DfMA model and ensuring the houses are built to nearly Zero Energy Building (nZEB) standards. The Irish pilots sought to achieve this by using prefabricated timber-frame closed panels or low-carbon GGBS cement composites and energy-saving efforts like the installation of Photovoltaic systems and heat pumps.

Figure 26: External ICF wall, part wall, and roof truss

Another feature of the Irish pilots is the use of Passive House Principles and techniques. Passive House is the improvement of passive effects like building form and orientation. Some of the features of a Passive House used in these pilots include:

- Improving the thermal envelope with a continuous external insulation layer and continuous airtight layer from the inside.
- Using Passive House standard windows and doors.
- Minimising thermal bridges.
- Using (Mechanical Ventilation with Heat Recovery (MVHR).
- Using Air to Water Heat Pumps/Exhaust Air Heat Pumps (EXAHP) techniques for heat and Domestic Hot Water (DHW) supply with a low-temperature distribution.

In Carlow, an underfloor heating system was also applied. The Kilkenny sites used air heating in combination with the EXAHP and Mechanical Ventilation. All Irish Pilots employed PV panels for energy generation.

At the Mullinavat site, South East Energy Agency moved to test a Timber Frame construction type with a closed panel system, which is an innovation for social housing from this County Council. This subsidised the standard concrete brick with a low-carbon construction type and thus, reduced the embodied carbon impact as well as reduced the site duration. The Timber Frame Closed Panel system is an innovation in the offsite timber frame industry. In this process, the timber frame elements are prefabricated and assembled in factory conditions. This allows for more precision, quality, and saving of assembling time.

South East Energy Agency has made a promotional video highlighting the construction and key features of their pilots, which you can view below.

Figure 27: Irish Pilot promotional video

Creation and Future of the Irish Pilots:

The works on site were commissioned on 24.01.2022. A site duration of 9 months was planned. Need new completion and hand over dates

There is time-lapse footage available, showing from the foundations upwards of the Carlow and Mullinavat pilots. You can view this below.

All these houses will go to people waiting for housing on the social housing list. There is a very large number of families waiting for homes through this system, so it is good that these houses will be able to contribute towards this social issue in Ireland. As a result, for operation, renting, and maintenance, the buildings will be handed over to a local social housing agency which will facilitate and rent out the building to applicants for social housing in the area. The house, however, will belong to the county council and will remain with the local authority. Both the County Council and Housing Agency will share the responsibility for the maintenance of the house.

Figure 28: : Carlow timelapse footage

Figure 29: Mullinavat timelapse footage

Replicating the Housing 4.0 Energy Project and What You Can Do.

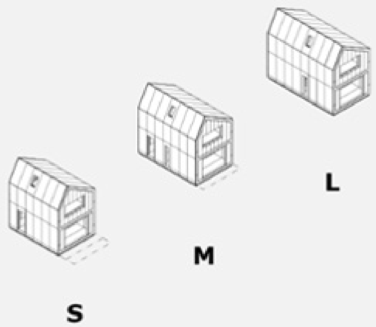
I am a Self-Builder...

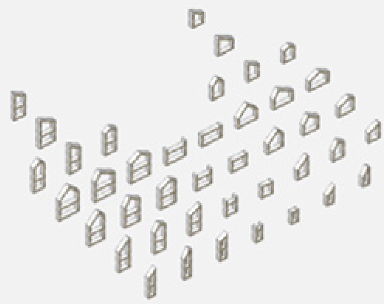
As a WikiHouse self-builder, you have roughly three options:

1. - Use one of the basic types developed by the Dutch WikiHouse Foundation.

2. - Use an existing design that already has been designed and built by another self-builder.

3. - Design your own WikiHouse using the WikiHouse toolbox.





Basic types

Choose from 1 of the 3 basic types, choose or design your own floor plan, then determine facade openings and finishes.

Existing Design

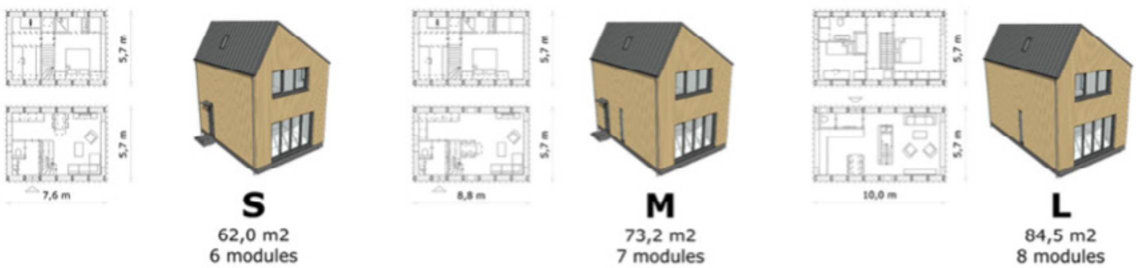
Choose an existing design and download the corresponding files and find out what modifications, if any, are needed.

Own Design

Create a volume with the WikiHouse modules from the toolbox and situate the design on the site. Position the windows to suit the layout of the design and choose finishes as desired.

Basic types

Choose from 1 of 3 basic types, choose a floor plan and production can start through a supplier. Or choose a basic type and design your layout and position the modular facade openings and choose the finishes as desired. Observe the corresponding 'WikiHouse SWIFT' design rules for the various design steps. The design process can also be done with the guidance of a WikiHouse architect. The necessary components are delivered to the construction site by a WikiHouse supplier. It will also be possible in the future to mill the shell on-site and have it built. The first basic types are expected to be available by the end of 2021.

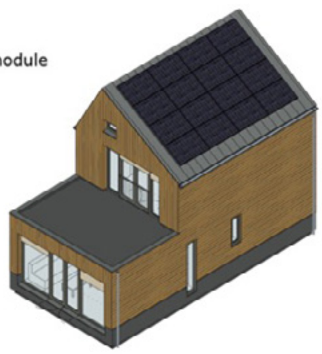


Existing design

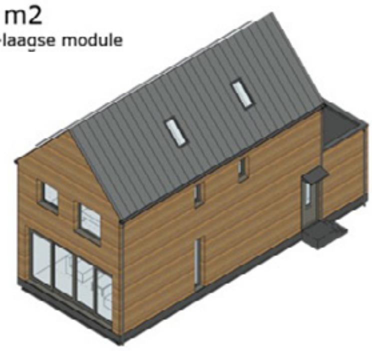
Choose an existing design and download the corresponding files and find out what modifications, if any, are needed. Files such as building application documents, manuals for the WikiHouse SWIFT airframe, and milling drawings. An environmental permit will need to be reapplied for and the documents updated to reflect local conditions and regulations. It is expected that by the end of 2021, the first existing designs will be fully shared online.

voorbeeld 1: 66,1 m2
7 x 2-laagse modules en 1 x dakterrasmodule

voorbeeld 2: 44,6 m2
7 x 1-laagse modules en 1 x halve 1-laagse module



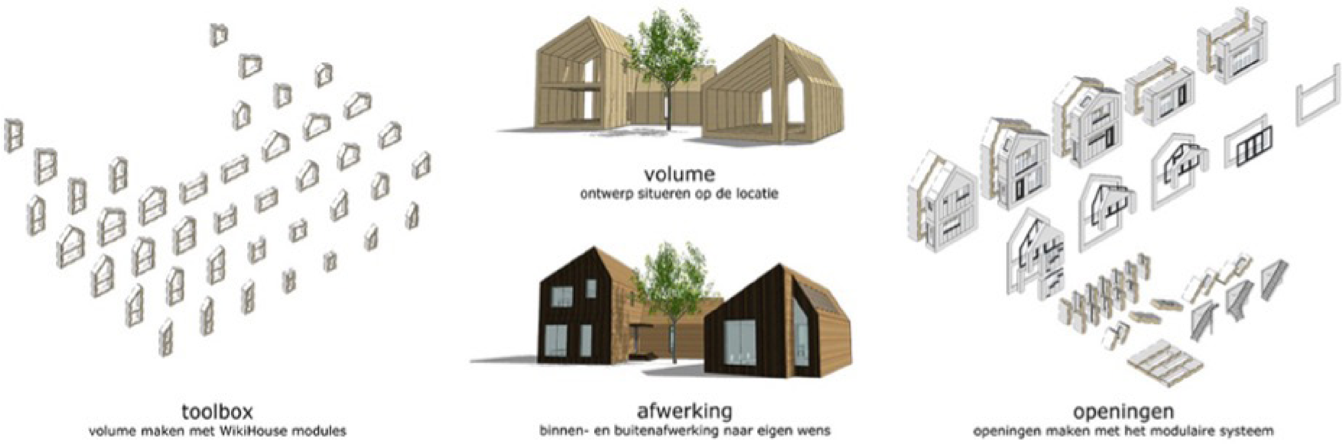
voorbeeld 3: 76,2 m2
5 x 2-laagse modules en 3 x plat dakmodules



voorbeeld 4: 103,6 m2
9 x 2-laagse modules en 2 x plat dakmodules

Own design

Create a volume with the WikiHouse modules from the toolbox and situate the design on the site. Position the modular facade openings to match the floor plan layout of the design and choose the finishes as desired. Observe the corresponding 'WikiHouse Swift' design rules at the various design steps. The design process can also be done with the guidance of an architect with WikiHouse knowledge & experience and there is a VR tool available so that you can view your design in virtual reality. Files and design rules are expected to be available for download by the end of 2021 to create your own design.



I am a Developer...

Thoma Holtz system used in Lahr:

Thoma is a leading company in ecological and chemical-free solid wood construction, with a focus on the circular economy in construction. The Holz100 construction system received the first Cradle to Cradle Gold certification for load-bearing components. In the last 2 years, they developed and built a demountable, 3-story solid wood building in the H4.0E project. With the deconstruction concept of this building, they achieve a reuse rate of all used materials of more than 80%. Thoma stands as an example to developers on how to develop with circularity and low emissions at the core of your process.

Their H4.0E pilot's building services are based on the digital networking of the consumers to achieve a high degree of utilization of the energy generated by the PV system. The outer shell of solid wood elements as well as a specially developed component activation for the wooden ceilings reduces the heating and cooling load peaks in the building. This means that heating, cooling, household electricity, hot water, and electro mobility can be covered to a large extent by the building's local electricity production.

The accompanying development of raw material databases and material exchanges makes an important contribution to the circular economy. A high degree of prefabrication of the components and coordinated planning processes set new standards for Industry 4.0 in construction. Ecological components are produced in such a way that they can be easily removed after use and reinstalled elsewhere. To this end, a stock exchange is currently being set up in which all components are recorded. At the push of a button, it can be determined whether and where a part is installed or whether it is currently becoming available again. In addition, the CO_2 stored in each component is assigned and displayed. This exchange creates a transparent, ecological pool of components and assets with linked CO_2 certificate trading.

The H4.0E pilot in Lahr lays the practical foundations for transferring this concept to other projects. The prototype is located on the factory premises of Holz100 Schwarzwald GmbH and can be visited by appointment. In addition, guided tours of the Holz100 production facility are offered. Investors, builders, and project developers who want to provide a solution for generations and avoid short-term profiteering at the expense of others can gain important impulses from this prototype. For concrete project development, there are possibilities for cooperation. Through cooperation and knowledge exchange, a co-creative space is to be created in which concepts suitable for grandchildren can be implemented.

The independence from oil, gas, coal, and nuclear power for heating and cooling the building structure is an essential part of the necessary energy transition. For our grandchildren, today's building structure must transform from a problematic landfill to a valuable depot. This is what this project stands for.

Developer for social housing units – South East Energy Agency work in Kilkenny and Carlow.

This will give an overview of the situation for the Local authorities in Ireland as a provider of Social Housing. The regulations and guidelines before construction will be reviewed, as Models of acquiring social Housing units, conditions of the relevant institutions, the design process and sites presented, and the tender process explained. The focus here is on the system in Ireland, however, there may be overlap or important lessons to be learned and applied in the social housing system in your region.

Review of existing regulations & guidelines before construction:

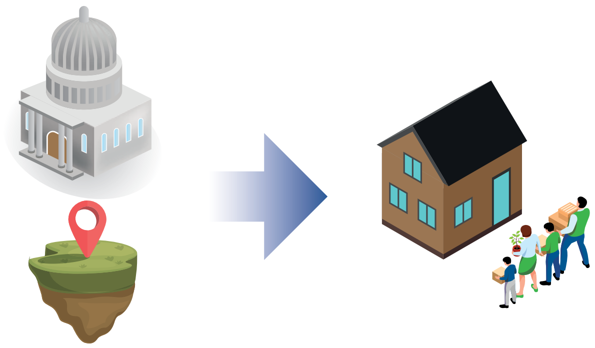
Social Housing developments are usually provided by the Local Authorities (LA's) but funded by the Department for Housing Local Government and Heritage (DfHLGH).
This funding place covers only standard construction methods and systems and binds the Social Housing provider to certain/minimum standards, because of a lack of further financial support. To establish a Social Housing development, the LA's need to go through a DfHLGH approval process, which includes 4 stages and achieving Planning Permission. The DfHLGH procedure refers to following relevant standards to give guidance for planning, design, and costings. The construction standards are described in the TGDs, which are a minimum to be achieved. There are single-stage applications for smaller units like semidetached bungalows, which applied for the Carlow pilot. This procedure consists of a timeline of 2 to 3 years + usually 12 months of site duration until practical completion and another 2 months until handover.

To implement the H4.0E targets requirements and specifications to the design and construction process need to be established, which is the H4.0E Benchmark includes Passive House Requirements, Principles & Techniques, and a Low Carbon Fabric Approach, which are established in documents like a project goal document, a general performance specification and project specification document. These documents were provided by South East Energy Agency to the Sub Project Partner the LA's, who are conducting the planning, design, and construction process.

Models of acquiring social housing unit

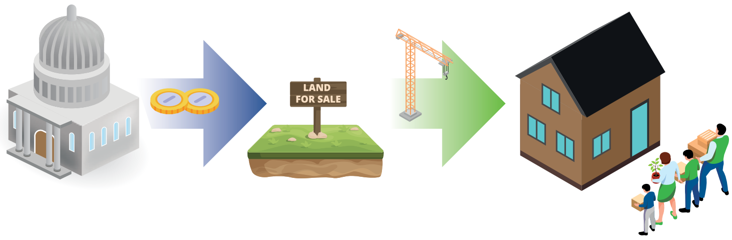
There are several models of how the Local Authorities acquire land and social housing units.

Model 1



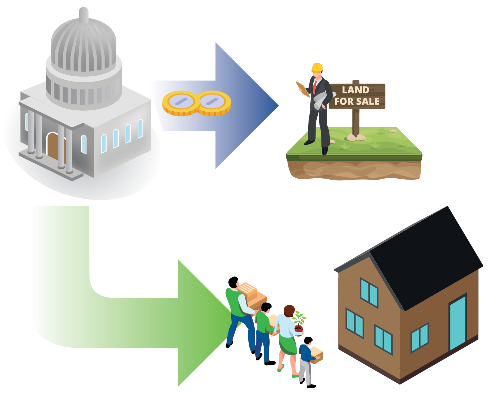
The Local Authorities own the land and the buildings and rent them out to Social Housing Agencies. These agencies are renting out these units to eligible tenants for social housing.

Model 2



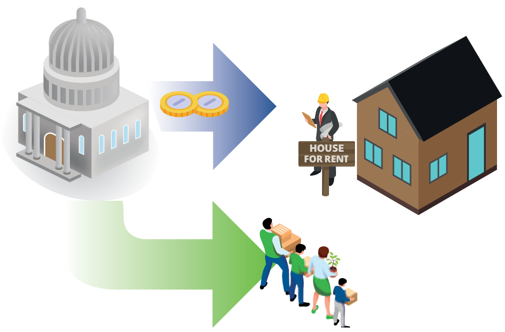
The LAs buying land:
Greenfield or brown sites can be developed (installed service, power, water, wastewater, gas supply, street layout, and street lighting.) and undeveloped land.

Model 3



The LAs buying land and houses from the developer.
Design and build regarding the DfHLGH social Housing standards.

Model 4



The LAs are renting houses fit for Social Housing from the developer and let them to the social Housing Agencies.

Conditions or hurdles in the site conditions.

Site conditions depended firstly on the Spatial planning and land use plan ordinance, ground geology, landscape, and terrain altitudes and as well depend on the type of land like green fields (grassland or fields changed to building land) or brown sites (the site was used for other built constructions), both are possible as developed or undeveloped land, was developed land are building plots where the access to power supply, gas supply, fresh and waste, street layout, and street lighting could be established as well.

Institutional conditions: explained with the example of the Carlow Pilot:

As mentioned before, Social Housing developments are usually provided by the LAs but funded by the Department for Housing Local Government and Heritage (DfHLGH). For new developments, it is required that a certain % of these new houses will be social housing units.

The big-scale public project would be bound to go through a full length of planning process, called Part VIII, including public consultations. A small project like the H4.0E Pilot building except the Wexford one can go through a simplified procedure, the single-stage application. In all cases, objections will likely be raised, which will need to be addressed and may extend the timeline of the project.

Pre-Part VIII commenced in May 2019 and Part VIII was finally issued on 7th September 2020. – issue arose from various parties: Existing residents, Soccer club, Pigeon Club, Community allotments, Irish Water, ESB.

All of the above had to be addressed before commencing Part VIII along with requests from internal departments MD Engineer, environment, Planning, Sanitary, etc.
The single-stage application for funding is usually submitted to the department (DfHLGH) after Part VIII is granted and the designs finalised. For this project, the application was submitted to the department on 25th November 2020 and departmental approval was received on the 23rd April 2021.

Design conditions:

The governmental Technical Guidance Documents (TGA) present a minimum standard, and the DfHLGH is only funding up to this standard. That led to the fact that this minimum standard turned into a benchmark for social housing in Ireland. Because of the high demand for social housing, a rapid-built framework is anticipated. This rapid-built framework includes using data from successfully conducted social housing projects and reusing this data for further new projects. This brings with it the task of convincing the LA that this minimum standard may not be sustainable. Therefore, additional efforts need to be made to convince Local Authorities to adopt the H4.0E nZEB benchmark, which includes reductions in operational and embodied CO_2 emissions and cost savings in the upscaling process.

Tender process:

Irish public sector procurement:

The H4.0E Sub Partner County Council Kilkenny is using for Construction Procurement the Capital Works Management Framework (CWMF):
The Capital Works Management Framework (CWMF) is a structure that is mandated by circular and was developed to provide:

- *an integrated set of contractual provisions*
- *guidance material*
- *technical templates and procedures*

These cover all aspects of the delivery process of a public works project from inception to final project delivery and review to assist contracting authorities in meeting their ongoing procurement requirements. eTenders is the Irish Government's electronic tendering platform administered by the Office of Government Procurement.
The platform is a central facility for all public sector contracting authorities to advertise procurement opportunities and award notices. For procurement news and guidance, legislation, and circulars under the National Public Procurement Policy Framework, please visit ogp.gov.ie

Circular 20/2019: Promoting the use of Environmental and Social Considerations in Public Procurement:

Circular 20/2019 highlights the Government's priority in promoting Green Public Procurement in the context of the wider commitments under the Climate Action Plan. The Circular instructs Departments/Offices to consider the inclusion of green criteria in their procurements. The Department of Communications, Climate Action, and Environment are developing these criteria which will support the effective implementation of this initiative. There will be a phased introduction of green criteria across Government and Public Sectors targeting priority products and services, as well as building appropriate green criteria into the Office of Government Procurement (OGP) frameworks as they arise and providing support and guidance to procurers. The circular can be accessed here.

Dynamic Purchasing System (DPS) on eTenders

The Dynamic Purchasing (DPS) service is now available on eTenders for all contracting authorities. Click HERE for the guidance material.

Dynamic Purchasing is a completely electronic process that may be established by a contracting authority to purchase commonly used goods, works, or services which are generally available on the market. The DPS is a two-stage procurement process. Firstly, the contracting authority can set up a DPS qualification using the electronic ESPD service and create and manage DPS Tenders in the second stage. All economic operators who meet the selection criteria at qualification are admitted to the DPS Tender stage. The dynamic nature of the DPS allows suppliers to apply to join at any point during its lifetime.

I am a Designer...

Note: A Designer can be any person but, to design a building, a certain team of qualified professional designers is needed. Members of a typical design team could be Architects, Geologist Engineers, Structural Engineers, MEP Engineers, Q&S Engineers, and Consultants e.g., for Energy Rating, Airtightness. These team members do not only design a building, but they will also deliver all necessary certificates for planning permission, tender, construction, and documentation.

Design Strategy:

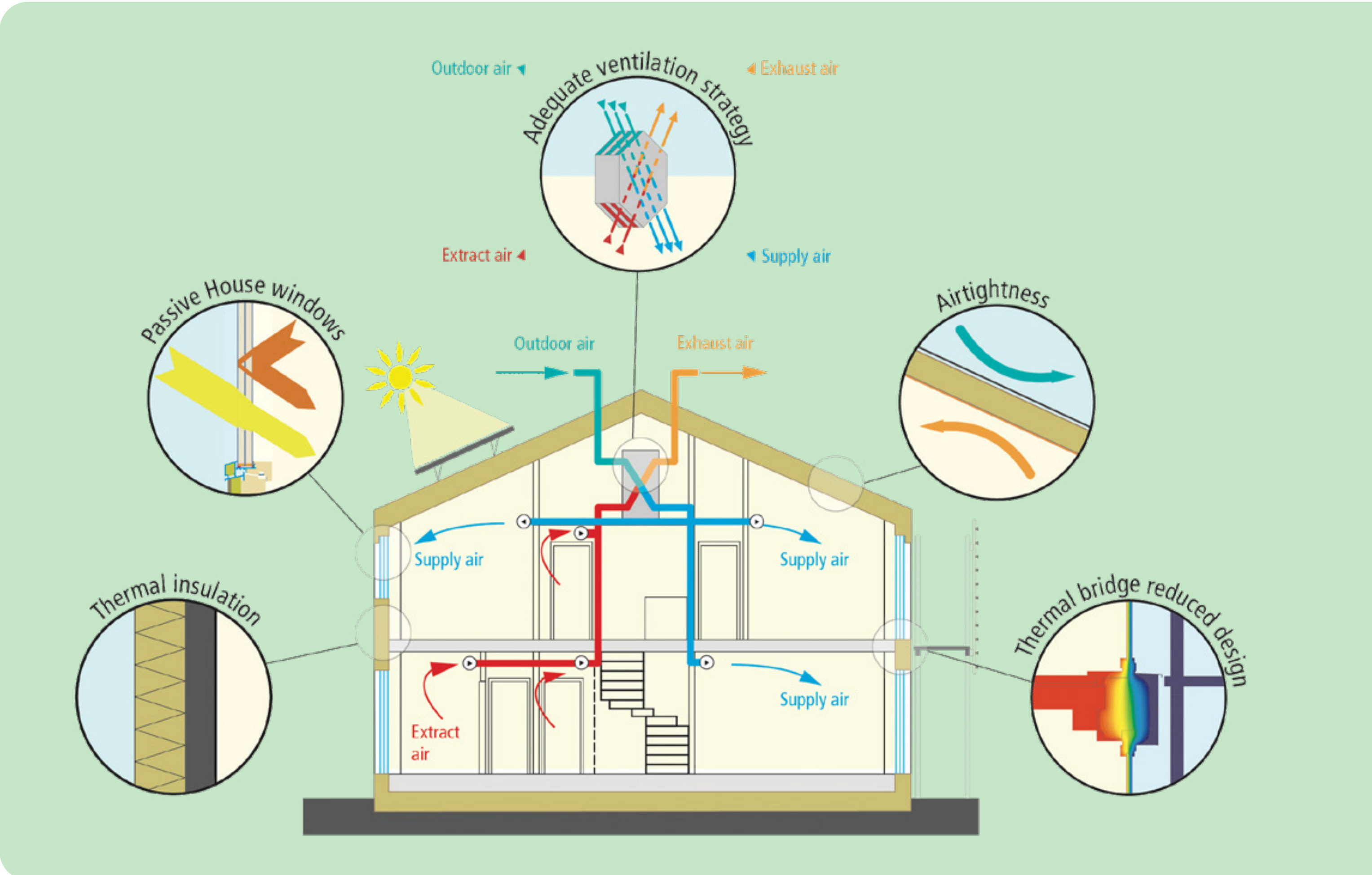
There are lots of factors, conditions, demands, goals, etc. that are shaping every single Building design. A predesign phase usually starts when individuals, willing builders, investors, etc. want to use the H4.0E approach for their building project. This, of course, depends on certain critical factors that influence investors, clients, owners, self-builder, planners, and designers. The main critical factors could be outlined as follows, client demand, construction site conditions, planning conditions, and budget limit. These factors and conditions must first be identified and reviewed to create a sustainable project brief. This will then define the desired goals and conditions that will influence the building design in addition to the specified H4.0E benchmark.

H4.0E Benchmark:

This prespecified H4.0E Benchmark describes a certain strategy to achieve future H4.0E buildings, especially for the initial planning phase. Here the Architects or other Designers need to evaluate early design decisions and find suitable solutions, to mitigate upfront embodied CO_2 emissions and identify and manifest the Gap to Target measures. These design decisions are usually decisive for the whole course of the project. Besides the reduction of operational CO_2 emissions via the Passive House Approach, the main objective and questions are; which construction type and which building material will lead to how much carbon emission? The first step will be to identify Carbon Hotspots and mitigate them. The next step would be a Preliminary Life Cycle Assessment (Pre LCA) for upfront embodied CO_2 emissions in detail. With this assessed and evaluated information, early design decisions could be made to mitigate this upfront embodied CO_2 emission. Carbon Hotspots and the upfront embodied CO_2 emissions can be assessed by a Pre-LCA tool. Needed building material should be sourced regarding the results of the Pre LCA, with a focus on reusing material. This could be delivered by certain material Banks. The H4.0E platform as a design tool will give aid in the design, procurement, and construction of the desired building.

Passive House Approach:

The Passive House Institute achieved to be a worldwide-accepted benchmark for high-performance buildings using passive elements for creating a healthy living environment. It is providing a benchmark including quality requirements, principles, and techniques. The focus is on using energy efficiently and saving necessary operational energy and therefore operational CO_2 emission. By using the Passive House benchmark, it is possible to design a Zero Energy Building or a Plus Energy Building.



Low Carbon Approach:

A passive house can be built entirely from fossil building materials, in contrast, as well as entirely from low-carbon renewable building materials. In order to realise the low carbon approach, here we defined an additional approach, the Low Carbon First Fabric Approach.

With this approach, we are making sure to reduce the embodied CO_2 emission of the building material to be used to a minimum and save this upfront embodied CO_2 emission already in the very early Project stages.

Note: Therefore, savings in embodied CO_2 emissions carbon made during the design and construction stage are achieved during the building stage and have an immediate impact. Savings to operational energy are achieved gradually over time.

Material Banks (Circularity):

Consider used Material: Construction Materials Exchange (CMEx) is a feasible, transparent, fair, user-friendly system for the reuse of construction materials that would otherwise enter the waste stream. It is possible to identify and track resources through the supply chain; identify the potential value of matching materials and apply these insights to steer organisational processes toward supporting a circular economy.

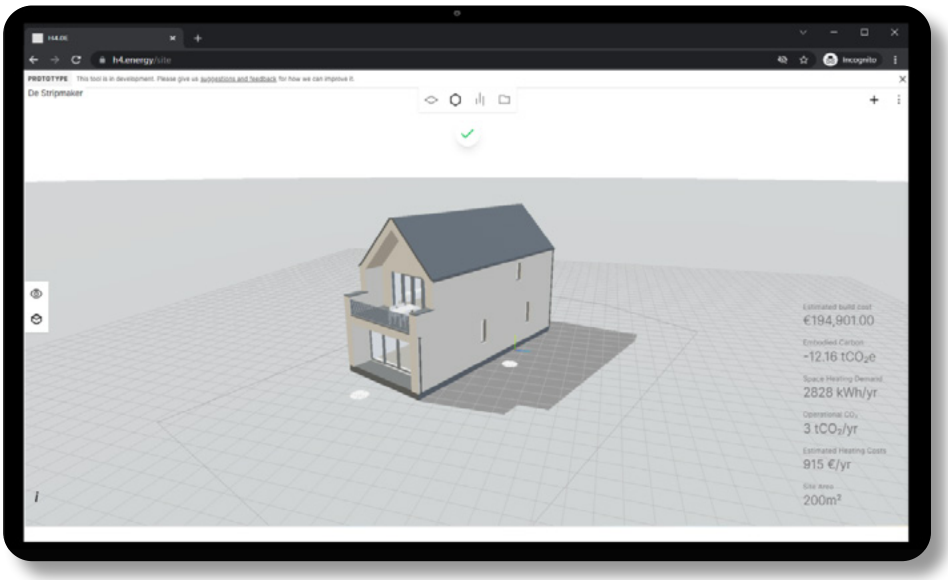
H4.0E Approach benefits:

Using this approach is not only necessary to get benefits for all stakeholders of any housing building project, but is also even more important to contribute to climate change mitigation.

The H4.0E Platform:

As a designer, you are a key stakeholder in Housing 4.0 Energy. We hope that on reading this Guidebook you will be inspired to implement H4.0E standards in your designs. This chapter, therefore, will introduce the H4.0E Platform, which will be an important tool for replicating H4.0E. The platform will mostly cover a surface level on the use of the platform and look at how it was developed and the considerations during its design. Links are provided for more in-depth information for those that would like to try it out. We will also outline the key differences in considerations between a standard build and an H4.0E build during the design phase. We will use a Step-by-Step outline to highlight this.

The H4.0E digital platform aims to explore how we can use the World Wide Web to make it easier for developers, municipalities, and communities to replicate manufactured housing solutions like the ones being piloted by the Housing 4.0E project. It allows future developers and even laypeople to design homes using the H4.0E principles, based on a menu of modules listed by regional manufacturers. It will allow users to instantaneously see the estimated impact of their design decisions on cost, carbon, and energy use. The aim is to give users the information they need to make informed design choices and factor in the long-term cost savings of up-front investment in good energy performance.



The platform was designed with the user in mind. Because it is intended to be a platform that anyone can use regardless of their engineering/construction ability, it had to be intuitive to allow for quick build and design, but also in-depth enough to allow for more experienced users to create more bespoke designs. To achieve this, the platform will allow the user to use the designs already input from the H4.0E pilot testbeds and create a home that is similar to these but matches their own available space and land profile.
Please be aware that the H4.0E platform is a design tool that cannot replace the design team and with this H4.0E Platform you cannot generate necessary design certificates for constructing a building.

It is strongly recommended that anyone looking to replicate this project or wanting to design an H4.0E house should read the further information available at Open Systems Lab notion. This will give much more detail on the platform and how to work it than this Guidebook can. The tool for designing these houses is currently in the Beta stage. You can view and play around with this tool as well as the WikiHouse tool at the Open Systems Lab website.

The Aim of the H4.0E Platform.

One of the most challenging transformations required to change building culture is not technical, but commercial. Today, most buildings are designed as one-off bespoke projects. An architect produces a sketch design, then engineers check the validity of that design, and then a constructor bids to turn up and craft it. The shift towards modern off-site manufacturing requires clients, manufacturers, and installers to reverse this order: so, a product manufacturer first designs, and engineers their solution as a modular 'product' (such as a building system or house type), then allows architects and clients to customise and configure buildings using those modules. In essence, to make the way we build homes much more like the way we make most other products in our lives, such as cars or kitchens. However, this transformation in the way we design and procure is challenging for developers, municipal authorities, and construction businesses.

The Design of the H4.0E Platform.

To be useful beyond this project, the platform had to be able to support not just the modular building solutions being used by the H4.0E pilots, but most types of modular building products. To do this the developer, Open System's Lab, developed a 'universal' grid system that challenges manufacturers to break their products into 'modules'. The design and size of these modules can vary enormously, but they all follow the same basic principles and require product owners to bake in key knowledge, rules, and data into their modules. There was also a focus to begin on those aspects of the user journey that are universal, regardless of whether the user is an architect, a municipal client, or a self-builder, taking into account factors such as what sequence of actions might feel logical to them or what vocabulary they might understand. New systems are expected to be added by the companies that invent them. To make the platform scalable and 'localisable', it puts power (and responsibility) into the hands of the product owner to maintain that data when something about the system changes and to check that their product complies with all codes and regulations in the region where they make their product available.

What types of building systems does the platform support?

The platform has been designed to support any type of building system, that is:

Modular:

That is, it must be made of countable, repeatable units, which can be combined. These countable units might be as large as an entire building or as small as a small cross-sectional slice of a story. They do not need to reflect how the system is made, but rather the scope of design options available to the user.

Manufactured:

The building system must be made to sufficient precision so that estimates of cost, time, and performance are likely to be reasonably accurate. This usually means a product that can be manufactured offsite, in a factory. This includes volumetric, mass timber, open and closed panel systems, or cassette-based systems. As a deliverable of this project, South West College produced a review of innovation, digital technologies, materials, and methods which listed a wide range of manufactured building systems (see H4.0E Online Training UNIT 1 – Construction Industry Guide To NZEB).

Orthogonal plan:

At present, the system can only support 'straight' building layouts comprising 90° angles, not curved or angular plans. However, it will support multiple roof types.

Step by Step – Gap to Target for an H4.0E

By developing their pilots and working on this project, all partners developed and established an H4.0E Benchmark. This Benchmark consists of the Passive House approach to lower the operational CO_2 emissions, the Low Carbon Fabric First approach, to lower the embodied CO_2 emissions, and DfMA models like the H4.0E Platform to support the design and construction team. This will give a lead at the early design stages in evaluating and decision-making as well as supporting the procurement, manufacturing, and construction process. To give guidance to compare to a standard common way, this step-by-step guide will use a gap to target scheme. The gap to the target range is shown for all necessary building project phases. Depending on the design approach these stages will not appear necessarily linear, they could be groped and rearranged, but these 8-10 stages are appearing in each building project and are applicable all over the EU and beyond. The focus will be the early project stages where decisions are made on what type of building is wanted, who are the stakeholders, and what type of design process will be used. These early design stages are the most crucial ones. Once decisions are made, this will be a one-way system in terms of economic reasons. e.g. to change the structural elements in later stages like planning permissions, it is costly to rearrange the design and planning documents. We only can recommend taking on measures to close this gap to target to achieve an H4.0E Building.

e.g.: Common linear project stages of a building as a step-by-step guide through a project:

1 Existing and given Tools and Preconditions.
2 Brief Development:
3 Preliminary Design:
4 Design Planning
5 Planning Permission Application
6 Construction Drawings & Specification
7 Tender Process Preparing
8 Tender Process Awarding
9 Construction Process /Building Control
10 Certification/Building Control/Documentation
11 Hand over

e.g.: Rearranged project stages:

Design

Existing and given Tools and Preconditions.

Brief Development:

Preliminary Design:

Design Planning
Construction Drawings & Specification
Tender Process Preparing

Legal requirements 1:

Pre Certifications
Planning Permission Application

Construction:

Tender Process awarding
Construction Process /Building Control

Legal requirements 1:

Certification/Building Control/Documentation

Hand over

Recommendation for the project stages

In General, build better than prescribed.

There is a need to "build better" than legally required because the current regulations are not adapted to the necessary measures to mitigate climate change. Political framework conditions for energy-efficient and climate-friendly buildings must be stricter. This is also shown by the requirements for Nearly Zero Energy Buildings (NZEB). Often, a building in the passive house standard, using low carbon material and construction types, saves four times more energy and emits fewer CO_2 emissions than the respective national specifications. Builders and renovators are urged to go well beyond the legal requirements in terms of climate protection and healthy living. For the urgently needed energy turnaround in the building sector, training and further education must also be intensified, both in the trades and at universities.

Stage 0 = Given tools and preconditions

The pre-project stage 0 presumes the existence and the intention to use the H4.0E Benchmark, including the Passive House Approach, Low Carbon Fabric First Approach, and the use of a DfMA model like the H4.0e Platform. Using IGBC/CMEx (Construction Materials Exchange).

H4.0E Platform development

A positive example of a Digital Platform is the Wikihouse platform. The Almere Partner with their self-builder teams showcased the Wikihouse (digital) platform to develop and build 18 Wiki Houses so far.

At the time of writing the H4.0E platform is in its Beta stage of development and so has limited usability. As more users come to the platform, it will have the opportunity to grow and develop. The development of The H4.0E platform is continuing and it can be assumed that the platform will facilitate the work through the project stages and that this design tool, including developed construction types and an existing and connected supply chain, will be fit for use upon release of this Guidebook.

Passive House Approach

Provides an essential range of technical values to be achieved and the use of the 5 Passive House Principles and Passive House Techniques. Here is the focus on reducing operational CO_2 emissions.

Low Carbon Fabric First Approach

Describes relevant measures to take on to mitigate carbon Hot spots and further reduce upfront embodied CO_2 emissions by conducting Pre LCA of the intention to use building materials. Here is the focus on reducing embodied CO_2 emissions.

IGBC/Construction Materials Exchange

The Irish Green Building Council (IGBC) is part of an international network that allows the sharing of best practices, by sharing knowledge and projects bilaterally with other Green Building Councils to collaborate on specific projects. IGBC shares at a European level to engage and influence European policy and at a global level as a Global Action Network to enable concerted action on global issues such as climate change. Networks are for example European Regional Network, World Green Building Council, and European Policy Updates.

The IGBC is piloting CMEx (Construction Materials Exchange), a scheme to demonstrate a feasible, transparent, fair, user-friendly system for the reuse of construction materials that would otherwise enter the waste stream. The CMEx project will identify and track resources through the supply chain; identify the potential value of matching materials and apply these insights to steer organisational processes toward supporting a circular economy.

IGBC is teaming up on this project with Excess Materials Exchange (EME). EME runs a highly successful materials exchange platform in the Netherlands.
https://www.igbc.ie/wp-content/uploads/2021/12/CMEx-One-page-Flyer.pdf. If you are working in Ireland or the Netherlands, we recommend you search these programmes to see how your project can work with them. If you are outside these regions, then check with your own national building council or the European Regional Network for advice and information on material exchange programmes.

1-9 stage

The following 1-9 stages present the commonly used and general project development stages in the construction of a building of any kind in the EU, including the Gap to Target (GtT), from a standard Build to an H4.0E Building (highlighted in each stage). The input of gap-to-target measures needs to be largely taken into account in the initial phase and eventually fixed and included in the tender documents to ensure that it is carried out accordingly. The main GtT measures are described in the H4.0E benchmark. The carrying out of the GtT measures must then be controlled and inspected in the subsequent phases to ensure that the recommended measures are implemented as planned.

Pre-project Stage 0:

The pre-project stage 0 presumes the existence and the intention to use the H4.0E technical Benchmark, including the Passive House Approach, Low Carbon Fabric First Approach, and the use of a DfMA model like the H4.0E Platform.

Available land and developed building sites.

There are greenfield developments where the infrastructure needs to be determined or brownfield sites where some demolition and decontamination work needs to be carried out. Some sites are redeveloped and equipped with infrastructure. There are typically sequences of a building project, but every project is unique especially when it comes to the site and its dependencies and conditions, like boundaries to neighbours, existing landscape, geology, orientations, legal issues, ownership, community development plans, and planning issues. There are options and opportunities but as well restrictions.

Brief Development/Basic evaluation Stage 1:

During the Brief Development/Basic evaluation stage, the task is to be clarified and the basic technical and economic questions of the project are presented. This phase of construction planning also includes a site inspection by the client and planner, whereby both the building ground and the immediate surroundings are inspected. The results of the basic investigation are finally processed within the framework of a presentation of results.

1. Stage 1 Sub Criterion:
   - 1.1. Review existing regulations & guidelines.
   - 1.2. Review existing traditional building methods/culture.
   - **1.3. Manifest to:**
     - **1.3. Use the H4.0E benchmark including Passive House principles/technique and Low carbon Fabric First approach.**
     - **1.3. Set wanted construction types.**

1.3. Use Benefits of the H4.0E Platform.

1.3. Define wanted Building supply systems.

1.3. Compare different business model approaches.

1.3. Involve the complete design team at this early stage.

1.4. Compile Brief.

1.5. Conduct a Site survey.

1.6. Set cost frame/budget.

Preliminary Design, Stage 2:

The results of the Brief Development/Basic evaluation stage form the basis for the preliminary planning. In this phase of construction planning, inquiries are made about the type of building ground to create a planning concept and to discuss possible alternative solutions. Preliminary planning also includes an initial cost estimate for the building project regarding relevant standards. The information obtained from the preliminary planning is also recorded through a presentation of the results.

2. Stage 2 Sub Criterion:

2.1. Identify site conditions.

2.2. Evaluate alternative design and construction types.

2.2. Use and consider Stage 1 GtT.

2.2. Conduct Pre-BER.

2.2. Consider the quality of details.

2.2. Consider Carbon Hotspot mitigation.

2.3. Conduct Pre LCA.

2.4. Consider using the benefits of the H4.0E Platform-stage 0.

2.5. Choose construction type and material.

2.6. Evaluate design concepts.

2.7. Prepare design layout.

2.8. Define the design team, roles, and communication channels.

2.9. Prepare cost approximation and comparison with cost frame.

Design planning, Stage 3:

In the design planning stage, a calculation and layout of the system are made. The project is converted into a technical drawing on a scale of 1:100 and described. Here, too, there is a cost calculation under relevant standards, and the results are again recorded in the form of a presentation of results.

3. Stage 3 Sub Criterion:
    - **3.1. Use and consider Stage 1 and 2 GtT.**
    - **3.2. Consider wind and airtightness.**
    - **3.3. Plan in quality of details.**
    - **3.4. Use the benefits of the H4.0E Platform-stage 0.**
    - 3.5. Calculate/define design layout.
    - 3.6. Prepare technical drawing set.
    - 3.7. Prepare cost calculation and comparison with cost approximation.

Planning Permission Application, Stage 4:

In the Planning Permission/Approval stage, the templates for the consent and approvals by the authorities are prepared. A submission plan is prepared, which serves as the basis for negotiations with the authorities. This is followed by the approval of the project by the building authorities.

4. Stage 4 Sub Criterion:
    - **4.1. Check if Stage 1-3 GtT are considered.**
    - 4.2. Obtain necessary certifications.
    - 4.3. Prepare forms for consent/approvals.
    - 4.4. Prepare submission plan.
    - 4.5. Sent out Planning Permission.
    - 4.6. Approval by Planning Authorities.

Construction Drawings/Specification, Stage 5:

In this stage, the execution/construction planning is an instrument used by architects and engineers, in which implementation plans are drawn up, on a scale of 1:50, as well as detailed drawings on a scale of 1:1 to 1:20. The execution planning also includes a detailed project description for the execution. Relating to the constriction drawings, the building and its construction will be described and specified in an extended list.

5. Stage 5 Sub Criterion:
    - **5.1. Use and consider Stage 1-4 GtT.**
    - 5.2. Obtain necessary certifications.
    - 5.3. Prepare execution general alignment drawings.
    - 5.4. Prepare execution of detailed design drawings.
    - 5.5. Prepare MEP Design.
    - 5.6. Prepare execution specifications.
    - 5.7. Prepare a time plan.
    - 5.8. Review cost calculation.

Tender Process: preparing Tender documents, Stage 6:

Following the execution planning stage, bills of quantities are drawn up and comparable offers are obtained for the execution.

6. Stage 6 Sub Criterion:
    - **6.1. Use and consider stages 1-5 GtT.**
    - 6.2. Preparation of the award of the contract.
        - 6.2. Cost pre-estimation.
        - 6.2. Draw up bills of quantities.
        - 6.2. Obtain comparable offers for the execution.

Tender Process – Evaluate Tender returns and award contracts, Stage 7:

The bids received are examined and the bids are evaluated. A price list is drawn up and the contract is awarded.

7. Stage 7 Sub Criterion:
    - 7.1. Involvement in the awarding of contracts.
        - **7.1. Use and consider stages 1-6 GtT.**
        - **7.1. Check if Stage 1-6 GtT are considered.**
        - 7.1. Cost estimation.
        - 7.1. Bids received are examined.
        - 7.1. Bids are evaluated.
        - 7.1. The price list is drawn up.
        - 7.1. Cost audit.
        - 7.1. Define practical completion of site works.
    - 7.2. Contract awarded.
        - **7.2. Use and consider stages 1-,6 GtT.**
        - **7.2. Check if Stage 1-6 GtT are considered.**
        - 7.2. Draw up all necessary legal issues.

Construction process/Certification/Building Control, Stage 8:

After the commission of works on site, the execution of the object is monitored for compliance with the planning and specifications. The supervision of the construction phase also includes the preparation and adherence to a schedule, the checking of measurements and invoices of the executing companies, and the conformity with recognised rules of technology. The services are checked from a technical point of view and any defects are identified and rectified.

8. Stage 8 Sub Criterion:

8.1. Pre-site works.

8.1. Check if Stage 1-7 GtT are considered.

8.1. Procurement.

8.1. Obtain necessary certifications.

8.1. Monitor the planned execution works for compliance with planning and specification documents.

8.1. Review time plan and set Timeline.

8.2. Site works.

8.2. Check if Stage 1-7 GtT are considered.

8.2. The commission works on site.

8.2. Supervise/inspect the construction phase regarding planning and specification documents, timeline, and costs audit. Identify any misaligning, or defects and rectify them.

8.2. Check Certification/Building control.

8.2. Acceptance and defect removal.

8.2. Snag list and Elimination.

8.2. Practical completion on site.

8.2. Cost assessment.

Documentation /Handover/Object handling, Stage 9 (sign off):

This service phase includes an inspection of the property after the completion of the building to identify defects. The central tasks here are the observance of limitation periods, the monitoring of the elimination of defects, and the cooperation in the release of security deposits.

9. Stage 9 Sub Criterion:

9.1. Compile all necessary documents and certificates.

9.2. Hand over.

9.2. Preparation of equipment and inventory lists.

9.2. Preparation of maintenance and care instructions.

9.2. Preparation of a maintenance concept.

9.2. Object observation.

I am a Policy Driver...

The Policy and Cultural Barriers Preventing Housing 4.0 Energy Propagation

As a policy driver, H4.0E needs you to create an environment where such housing designs can flourish. For this project, TU Delft investigated the political, technical, financial, and cultural barriers that prevent H4.0E designs and designs like this from becoming mainstream. It may not be possible to make wholesale changes and some issues, such as culture, may be out of your hands. We hope that identifying the problems in the partner regions may assist you in identifying like-issues in your region. Policy changes can have a domino effect. A policy change could allow for a more favourable financial landscape, which could lead to a larger uptake, and ultimately a change in housing culture. We see policy drivers as essential stakeholders in bringing change to Northwest Europe and beyond.

Despite past efforts to promote and accelerate the adoption of innovative, affordable, and zero-energy dwelling solutions, the number of dwellings complying with standards such as the EPBD (Energy Performance of Buildings Directive) remained relatively low by the year 2020. Studies have already explored potential challenges and opportunities for the uptake of such designs. However, despite previous findings and recommendations, the market's response remains slow. Building on existing knowledge, the Housing 4.0 Energy project investigated current financial, cultural, legislative, and technical barriers. It also looked at the drivers of implementation and uptake of small, innovative, affordable, zero-energy dwellings in small towns in Almere in the Netherlands, Huldenberg in Belgium, and Carlow and Kilkenny in Ireland. Focus groups gathering different housing professionals were conducted in Almere, Leuven, and Kilkenny.

This focus group was conducted to:

- Explore the challenges to a successful implementation of the innovative H4.0E dwelling designs.
- Explore the potential financial, legislative, cultural, and technical barriers to upscaling.
- Explore the take of focus group participants on the use of the digital platform.

The focus groups included a balanced composition of people representing all potential parties involved in the field of housing (social housing associations, housing agencies, local authorities, policymakers, private developers, local banks, contractors, engineers, architects, etc.). The focus group discussions were guided by explorative and engaging questions about housing policy, planning and land use policy, energy policy, financial schemes, tax reductions, subsidies, cultural habits and preferences, technical building regulations, and building and energy-saving standards. These were divided into three rounds. While the first round focused on the current situation within each pilot country, the second and third rounds explored the uptake of the housing designs to a wider scale, taking into account the individualities of each location.

Outcomes revealed that participants' general perceptions around barriers and drivers are similar between the three pilots and are validated by previous research findings. However, a closer look at context-specific barriers reveals considerable differences. The identification of these contextual differences enabled a better apprehension of the current situation in every location, leading to the formulation of context-specific recommendations and a better allocation of precedence. Thus, this demonstrates the importance of context-specific investigations not only in the identification of challenges to energy efficiency innovations but also in establishing more effective implementations.

Summary of Focus Group Outcomes

On the one hand, a comparison of focus group outcomes between the different pilot countries reveals a significant number of barriers that appear to be similar to each other. Examples are the general lack of public awareness and knowledge when it comes to the urgency of an energy-neutral built environment, the perception of higher initial costs associated with new designs and constructions, the absence of mandatory strict building regulations, and the general shortage of skills. Common outcomes also include a general lack of industry investments interrelated with the risk of innovation and lack of financial investments, as well as the absence of a clear policy framework promoting energy efficiency measures and innovations. A considerable number of these barriers are also similar to outcomes reached by previous literature. This occurs despite different research scopes, times, and methods which indicate that the stated challenges are perceived by most professionals involved in the housing sector and that they apply to different types of innovative energy efficiency measures. This can be interpreted as a validation of research outcomes indicating the generalizability of results and providing a holistic view of challenges to a successful implementation and uptake of innovations (Tables 1, 2, and 3).

On the other hand, adopting a qualitative methodological approach through the conduction of focus groups allowed an in-depth investigation of context-specific challenges, revealing differences in precedence within each country. The most significant contextual differences were found within planning and land-use policies. When it comes to land prices, the most significant challenge in the Netherlands is the market-value-based land price determination; whereas in Flanders it is the inaccessibility caused by a traditional buying/selling system. Within land use and allocation, the inefficiency of the established allocation regulations consists of a significant barrier in Flanders, whereas in Ireland and the Netherlands, the scarcity of land is perceived as obstructive, and in the Dutch context, in particular, the insufficient allocations for self-building. Additional contextual differences are found within the planning process where third-party's objections, individual certification scheme systems, application costs, and a lengthy process are challenges particular to the Irish context. Within building regulations, an outdated standard aiming for the universality of designs is a particularly hindering aspect of the Flemish social housing sector. The limited level of influence obstructs building innovations within the Irish context; whereas the testing of new designs and technologies can become a lengthy process within the Dutch context. The identification of these contextual differences enabled a better apprehension of the current situation in every country and allows comparison and distinction of variations between them (Table 4).

This led to a better allocation of precedence when formulating context-specific recommendations. These recommendations include; the adoption of non-traditional subdivisions of land that looks into the development of an area rather than a parcel, the establishment of long-term leases to increase land accessibility specifically in Flanders, and the establishment of workshops, training, and demonstrations to change social perceptions and potentially reduce third party objections specifically in Ireland, and collect more information on household characteristics and needs during the application to social housing process to potentially promote less universal and more updated housing designs among others (Table 5).

Category	Barrier	Quote
Financial	Insufficient allocation of funds promoting a zero-energy performance. Precedence is given to the provision of more dwellings over an improved energy performance. Discrepancies between green financing benchmarks. Loan against security schemes. Mortgage requirements for innovative designs and construction. Lack of knowledge.	"You do not get funding for exceeding building regulations." "You have to meet building regulations but it will always come down to finalising your actual costs because ultimately [...] there is a housing crisis at the moment so if [...] somebody does an analysis and says actually if we had funding we could build 4 or 2 extra properties with no technologies or a few technologies the answer will always be well if we could house 6 families instead of 4 families if that makes economic sense then that's what they will go with." "Lack of knowledge about how the system works makes people frustrated and pushes them to play around with switches not knowing how it affects the performance of the house."
Cultural	The negative perception of timber-framed dwellings. Habits linked to traditional heating systems. Reluctance to change fuel sources. Third-party objections. Limited access to land.	"As a society, we decide if the room is warm enough by touching the radiator. If it's boiling then the house is warm, but the house might be too warm..." "In winter [...] they are actually paying 50 to 60 euros a week of fuel because they buy coal during the cold periods [...] but for some reason, they don't see that spend." "The department of housing in the government is more focused on traditional construction."
Legislative	Precedence is given to refurbishments and the provision of traditional housing. Design restrictions. Lengthy planning process. Individual certification scheme. Lenient building regulations.	"Social houses should be more innovative and try new technologies because it will eventually lower the costs but it does not seem to be the priority at all." "There is not international training when it comes to operating heat pumps. Everybody is so focused on when heat pumps break down or fail but it is actually before that happens that should be looked into."
Technical	Lack of standards for innovative designs and construction. Fire and accessibility requirements. Shortage of skills and lack of experience. Risk of higher maintenance costs. Turnkey projects. Procurement and turnaround speed.	

Table 1: Summary of barriers in the Irish pilot

Category	Barrier	Quote
Financial	Established an economic model based on profit maximization. A constant trade-off between affordability and innovation specifically higher initial costs. Insufficient data and uncertainty around lifecycle analysis and costs. Lack of incentive for social lessors. Perception of higher maintenance costs from innovative building materials.	"It is established that there is a constant trade-off between economy and energy efficiency. This trade-off is traditionally made at the level of the initial investment." "To be able to make a good investment a client should not only have insight into the initial investment, but also the lifecycle costs. A lot of data is needed for this and unfortunately, it is not always available." "In the (social) rental sector it is generally the case that the landlord invests and the tenants have lower energy costs."
Cultural	A negative perception of small dwellings. Habits linked to traditional heating and ventilation systems. Reluctance to move dwellings.	"Traditional buildings with gas combustion and radiators are much more manageable for the tenant." "Society has to make the switch. The new techniques must be socially accepted." "New technologies (such as underfloor heating) are no longer much more expensive, but the residents must be able and willing to deal with them." "Many elderly do not want to live in an apartment (yet)."
Legislative	Lack of implementation of framework around housing and mobility. The slow progress of spatial development plans. Limited access to land. Restrictions on compact construction. Design guidelines (social housing) and housing quality requirements are restrictive for small-scale living. Precedence to the provision of traditional housing.	"There is still no clear framework within which to work. If this framework exists and it is incorporated into spatial implementation plans, developments can proceed quickly." "The realization of affordable housing [...] could be a reason for municipalities to make semi-public and public land available in the form of long-term leases instead of selling the land to project developers." "The social rental sector in Flanders has traditionally focused on spacious traditionally built homes."
Technical	Loose building regulations. Lack of standards for innovative designs and constructions. Traditional, outdated, and prescriptive design requirements. Shortage of skills and lack of experience. Risk of higher maintenance costs.	"Modular and circular construction requires standardization." "There are no specific guidelines for the use of materials." "For example, the new techniques (ventilation) ensure that it is not necessary to have interior walls everywhere, but current standards demand that." "If the tender is specifically aimed at prefab construction there is a risk that there will not be enough tenders, few companies specialize in this."

Table 2: Summary of barriers in the Belgium pilot

Category	Barrier	Quote
Financial	Perception of higher initial costs and the constant trade-off between innovation and energy efficiency and affordability. Perception of higher maintenance costs from innovative building materials. Land price determination based on residual counting. Collateral/security is needed to obtain support from financial institutions.	"When scaling up you must take into account the fact that Wikihouse is a timber frame type, corporations are still building with concrete. That is in culture and because the maintenance concept is easier." "Land price was one of the obstacles. There were difficult negotiations." "You need to show that you have enough income, you need to show that the house will have enough values [...] so your loan to value is valid. Now [...] the bank (is) saying [...] we want a guarantee that the house will be finished so what happens if someone [...] breaks his arm [...] the actual costs if you use a professional for this are higher because then you will have to pay these and then suddenly someone doesn't have enough income anymore. "
Cultural	The negative perception of timber-framed dwellings: robustness and resistance to water over time. Habits linked to traditional building versus self-building. Business as usual mindset amongst housing professionals: precedence given to traditional building process.	"90% of the houses in Holland are built with concrete and bricks and that's what we are used to so suddenly starting to use wood is a bit different. (People) have got questions and worries about it." "Within the council generally, if you want to do an innovative project that does things a bit differently let's say 10% of the organization absolutely loves that and the other 90% thinks [...] this is different and far away from the standards."
Legislative	Organization of land policies around self-building.	"There is no land and it is not organized enough by national or local government to make available plots for self-build.
Technical	National building regulations requirements: long periods of testing and development. Municipalities design restrictions through their land use plans. Uncertainty and insufficient information around risks associated with self-building.	"A land use plan [...] determines what you are allowed to build i.e. how high you are allowed to build, how high the pitch on the roof is allowed to be, how high the gutter should be, how many layers, where you are allowed to build on the plot [...] what you want to build has to fit in the land use plan and then the actual build and what you're designing has to fit the [...] national law which determines what the quality has to be."

Table 3: Summary of barriers in the Dutch pilot

Category	Ireland	Flanders	Netherlands
Financial	Mortgage loan requirements for individuals in the private sector. Loan to security scheme. Green financing benchmarks.	Inaccessible land prices. Split incentive between social housing company/social letting agency and tenant. An economic model based on profit maximization.	Residual counting: market value vs. land price. Project completion guarantee: collateral for financial institutions.
Cultural	The negative perception around the durability and quality of timber-framed houses. Reluctance to change energy sources. “Not in my backyard” mindset toward innovations.	The negative perception of small houses. Preference for traditional heating systems. Reluctance to move.	The negative perception around timber-framed houses’ resistance against water. Reluctance towards self-building. Business as usual mindset among housing professionals.
Legislative	Individual certification scheme system.	The allowable number of dwellings per plot/ densification and efficient land occupation. Need for low embodied carbon/circular building standards.	Land policies give precedence to projects other than self-build.
Technical	Restrictive accessibility and fire requirements. Limited level of involvement of housing providers in dwelling designs. Adoption of turnkey projects system.	Restrictive building regulations for the H4.0E concept. Outdated social housing design requirements concerning minimal living space. Preservation of the universality of social housing designs.	Uncertainty and insufficient information around long-term risks of innovation and self-building. Long periods of testing and development for national building regulations for future concepts and upscaling (only applicable if different modules are chosen for implementation). Restrictive land use plan design requirements for upscaling (only applicable if different modules are chosen for implementation).

Table 4: Comparative summary table of context-specific differences

Category	Policy recommendation
Financial	• Redirect established financial schemes to encourage the implementation of energy efficiency measures that exceed basic building regulations. • Ensure consistency between the different financial institutions by establishing a common benchmark for the financing of green engineering. • Provide financial institutions with information on innovations with a focus on lifecycle cost analysis. • Reduce investment costs within the rental sector through energy cost savings (Energiesprong). • Reduce investment costs within the rental sector by establishing rents dependent on energy labels (TRIME).
Cultural	• Increase publicity campaigns promoting H4.0E dwellings with a focus on promoting timber-framed dwellings in Ireland and the Netherlands and small dwellings in Flanders. • Organize workshops and training to increase tenants' level of knowledge and prevent the misuse of new technologies. • Organize workshops on a neighbourhood level to ensure people's involvement and decrease third-party objections in Ireland. • Assign super-tenants; volunteers interested and motivated to provide constant support to their neighbours by being more accessible and available. • Provide and obtain constant feedback. • Revisit the tenancy selection process in social housing to attract active people willing to cooperate and provide feedback.
Legislative	• Inform and update housing providers on design progress, performance, and outcomes. • Ensure collaboration and good communication between housing providers with designers, contractors, and builders. • Organize energy performance-based tenders promoting innovation and requiring energy efficiency and energy quality. • Ensure modularity and flexibility of dwelling design to satisfy household needs despite demographic differences. • Revisit the tenancy selection process to obtain more information on household requirements before allocation and attract people open to behavioural change. • Revisit the individual scheme of certification for H4.0E dwellings in the Irish context. • Promote clustered construction by giving precedence to area development rather than parcel-based land subdivisions in the Flemish context. • Increase land accessibility to low to middle-income homeowners wanting to self-build in the policy of the land organization in the Dutch context.
Technical	• Promote zero-energy performance and low embodied carbon through tenders while waiting for building regulations to make it mandatory. • Organize training and workshops for contractors, builders, and facility managers to decrease the shortage of skills. • Standardize building systems, building materials, and construction methods of H4.0E dwellings. • Install user-friendly technologies and building systems. • Document and demonstrate the performance of H4.0E dwellings and distribute results to housing professionals.

Table 5: Summary of general recommendations

Monitoring the H4.0E Pilot Performance

One of the aims of the Housing 4.0 Energy project is to construct low-carbon houses. This means that the target for CO_2 emissions of the houses is 60% lower than that of regular houses. That means that two indicators are needed to estimate the total CO_2 emission over the whole life cycle of the house: The CO_2 emissions as a result of the operational energy consumption (for heating, cooling, and ventilation) in the houses, and the embodied CO_2 of the building materials of the houses.

Operational energy consumption:

The main source of CO_2 is the emission from the combustion of carbon-containing fuels such as oil, natural gas, and wood. With dwellings, this combustion can take place directly, in a boiler for heating the house, in a heater for warm tap water, or for cooking on a gas stove. But CO_2 can also be indirectly emitted by the use of electricity that is generated using fossil fuels. Therefore, to estimate the CO_2 emission related to operational energy consumption, both gas and electricity consumption need to be considered.

There are energy models for houses, ranging in detail from generic energy models using only a few parameters such as floor area, insulation thickness, type of installations, and location of the house (often used in relation to the EPBD) to detailed models such as TRNSYS with detailed models that require many details such as air leakage areas and are difficult to use by non-experts. Simple energy models only indicate the operational energy consumption of a house, and modelled energy consumption often differs from the real operational energy consumption because of differences in the actual parameters of the house and because of the energy behaviour of the residents. Therefore, to determine the actual energy performance of Housing 4.0 Energy houses, the operational energy consumption needs to be monitored.

Monitoring of operational energy consumption is not mandatory for all Housing 4.0 Energy houses. It can be decided to only use the energy models for the estimation of operational energy consumption, or only look at total energy consumption at the central gas and electricity meters of the house (that includes the tenant-related energy consumption as well). This avoids the extra effort and costs for the installation and operation of the monitoring equipment, but the results of the operational energy consumption are less accurate.

General set-up of monitoring:

Operational energy consumption of a dwelling is defined as the energy consumption related to the dwelling and its installations, and not to appliances of the residents such as lighting, cooking equipment, or televisions. This means that energy for heating, cooling, ventilation, and preparation of hot tap water (HVAC) is considered part of operational energy consumption. Also, electricity production with photovoltaic panels is considered a (negative) part of the net operational energy consumption.

The individual HVAC installations (for heating, ventilation, etcetera) can be monitored individually, but as an alternative, groups of HVAC installations (or all dwelling installations) can be monitored together. Most important is that the operational energy consumption related to the house is separated from the energy consumption of the residents' appliances such as lighting, cooking appliances, or televisions.

All energy sources are to be emitted. In the case of all-electric houses, only electricity is used for the HVAC installations. But if natural gas, oil, wood, or other fuels are used for heating, then the fuel consumption of these fuels also needs to be monitored.

The CO_2 emission per kWh of electricity consumed is dependent on the electricity mix of the grid to which the house is connected. The electricity on the grid is produced with a mix of fuels or renewable sources, which is different per country. Data on the CO_2 emission per kWh of electricity are available from national institutes that monitor the CO_2 emissions of the country. The CO_2 emissions of natural gas, oil, or other fuels depend on the composition of the fuel and are also provided by the same national institutes. The CO_2 emission of wood is often considered as 0 g/MJ because of the CO_2 adsorption during the growth of the wood, but the CO_2 emissions of harvesting, processing, and transport should be considered if possible.

Additionally, the indoor climate of the house can also be monitored. This helps to assess the comfort of the residents in the house, but it also helps to interpret the operational energy consumption. Indoor temperature is related to the energy consumption for heating and cooling, and indoor CO_2 concentration is related to the amount of ventilation in the house. Furthermore, the outdoor temperature can be monitored to compare the operational energy consumption between different periods with different outdoor temperatures, but using temperature data from nearby weather stations is also possible.

In Table 6, an overview of the installations and indoor climate parameters to be monitored are given.

Energy consumption	
Total energy consumption of the dwelling.	Related to the energy bill, used for the calculation of energy consumption of resident appliances.
HVAC installations.	Operational energy consumption of the dwelling.
PV panels (if present).	Production of electricity in the house decreases net operational energy consumption.
Energy storage (e.g. batteries).	Used for determination of actual energy consumption at a given moment.
Indoor climate	
Indoor air temperature.	Related to energy consumption for heating.
Relative humidity.	Related to ventilation.
CO_2 concentration.	Related to ventilation.

Table 6: Overview of the installations and indoor climate parameters to be monitored.

Practical guidelines:

Many monitoring systems on the market are suitable to measure energy consumption and indoor climate parameters in dwellings. The choice for a monitoring system can depend on the data needs for the project, the technical possibilities in the house, and practical considerations such as purchase price, ease of installation and maintenance, and impact/benefits for the residents. In this section, a few considerations and possibilities for monitoring systems are given.

Monitoring of energy consumption:

System	Advantages	Disadvantages
Directly in fuse board in line with electrical wiring.	• Low risk of malfunctioning or data loss. • Can be used for all types of electricity meters or dwelling set-ups.	Installation of fuse board by a professional technician. • Only suitable for electricity meters.
Energy clamps attached to wires.	• Easy to install if wiring is accessible. • Can be used for all types of electricity meters or dwelling set-ups.	• Less accurate measurements (but still usable for general purposes). • Only suitable for electricity meters.
Smart meter local read-out port.	• Low risk of malfunctioning or data loss. • Easy to install. • Can measure gas and electricity consumption.	• Depending on the type of smart meter, small differences between smart meters within a country, and large differences between countries. • Smart meters are not always present.
The pulse counter is attached to the energy meter.	• Works with all meters with an optical or galvanic pulse counter. • Can measure gas and electricity consumption.	• Installation takes more time due to tuning. • Larger risk of malfunctioning. • No data means data loss (no historical data).

Table 7: Monitoring of energy consumption

Indoor climate:

The relevant indoor climate parameters to measure are temperature, relative humidity, and CO_2 concentration. The temperature and relative humidity are parameters reflecting indoor comfort, and the CO_2 concentration is a measure of the ventilation and air quality (background concentration is 450 ppm; concentrations above 800 ppm indicate too little ventilation; concentrations above 1200 ppm indicate bad indoor air quality).

There are several indoor air monitoring systems on the market. Some of these only show the measured values. Other systems allow for local storage of the data, so it can later be read out manually. The disadvantage of such as system is that the data cannot be accessed remotely and that remote management is not possible.

Other systems allow for data collection and transfer either to a local logging system or a data server on the internet. The connection between the sensor and the data logger or internet hub can be wired or wireless. A wired connection is more robust (wireless connections can sometimes suffer from a bad connection), but needs wiring to be installed. Data access and flexibility of data use depend on the system; many systems use a proprietary data collection and presentation system, but other systems allow for more flexible use of data.

Data storage and transport:

Energy and indoor climate data can be stored in several ways. Local storage is often used as a buffer, also when the data is collected remotely, to avoid data loss when the internet connection is down. Local storage can also be used when no internet connection is available in the house, but this makes remote management impossible, and data can then only be collected locally.

Another possibility is to store data remotely on a data server via the internet. This can be done via a proprietary system of the provider of the monitoring system, by a general database server, or both. This provides the possibility to access the data during the monitoring period, allows for the flexible presentation of the data, and provides a means to check for malfunctioning of the monitoring system when no data come in.

Data can be visualized to the residents by using direct meter readings, but also by using visualisation systems such as (local or remote) websites presenting tables and graphs. This way, the residents can see their energy consumption and indoor climate and can adapt their habits and behaviour to reduce their energy consumption and improve their indoor climate. It can be useful to also provide a reference for an average house of a similar type to gauge the performance of the residents of the project house to an average household.

Privacy:

In general, energy consumption data are considered as personal data of the residents. From the energy consumption patterns, habits, preferences and actions of the residents can be deducted, such as presence in the house during the day, holidays, showering habits, or indoor temperature preferences. Therefore, the privacy of the residents needs to be respected and the project needs to comply with privacy regulations such as the European General Data Protection Regulation (GDPR).

The best way to comply with these regulations is to inform the residents about the purpose and method of the monitoring, have written informed consent from them, and have a data processing agreement with third parties such as the provider of the monitoring system, especially if they store the data on their servers as well. Furthermore, measures need to be taken to avoid data losses, such as secure data connections over the internet and adequate security measures for data servers and data presentation systems.

Embodied carbon:

Embodied carbon is the amount of CO_2 that is emitted because of the production of a material. This includes emission during the winning of raw materials, the production of intermediates, the production of the material itself, transport, and the construction phase. To be precise, not only the emissions of CO_2, but all compounds that have an impact on climate change are considered, but CO_2 generally has the highest contribution. And usually, most CO_2 originates from the combustion of fossil fuels, but other processes can generate CO_2 as well, such as the production of cement.

Traditionally, in countries with cold winters, the CO_2 emissions for heating the house had the highest contribution because often the energy performance of houses was low. However, when the energy performance of houses increases and more renewable energy sources are used, the relative impact of the embodied carbon of the building materials becomes more important. Therefore, it is important to pay attention to the reduction of the embodied carbon of new houses as well.

The embodied carbon can be calculated using life cycle assessment (LCA) tools. These tools assess the environmental impacts of a product or service during the whole life cycle (cradle-to-grave). The impacts of the use phase and waste treatment are also included in an LCA. Furthermore, in an LCA a broad range of environmental impacts are assessed, such as climate change, toxicity for humans and ecosystems, depletion of resources, and acidification. For the embodied carbon calculations, only the impacts of climate change are of interest.

There are several LCA tools specifically for buildings on the market, often directed to the building practice in a single country. A few examples are given in Table 8. The background data for production processes, transport, industrial processes, and waste treatment are taken from generic LCA databases such as Ecoinvent and supplemented with additional data for specific building materials and regionalized data for energy production, transport distances, and waste disposal. Most building LCA tools comply with the EN 15978 standard for determining the sustainability of construction works.

To determine the embodied carbon of a Housing 4.0 Energy house, the amounts of building materials used need to be collected. These data can then be entered into a building LCA tool that is the best suitable for the specific country. The building LCA tool then calculates the environmental impacts of the life cycle of the house. For the embodied carbon, the specific impact on climate change (in kg CO_2 equivalents) can then be taken as the embodied carbon value. Take care that no normalized or weighted impact scores are used.

Name	Country	Remarks
TOTEM	Belgium	No data on installations
GPR Gebouw	Netherlands	Complies with the Dutch harmonized calculation method
BREAAM BREAAM NL BREAAM ES BREAAM NOR BREAAM SE BREAAM DE	United Kingdom Netherlands Spain Norway Sweden Germany	
One Click LCA	Several European countries	
ÖKOBAUDAT	Germany	

Table 8: Examples of building LCA tools usable for embodied carbon calculations

CO_2 reduction in the Housing 4.0 Energy project

The operational CO_2 emission reduction was calculated by subtracting the annual electricity consumption for installation minus the electricity produced by the PV panels from the reference CO_2 emission for operational energy consumption of 850 kg CO_2/yr. This value was then multiplied by 1.2 to account for the avoided rebound effect that applies to the household-related energy consumption (not applied for negative reductions).

	Dwelling	Embodied carbon	Operational CO_2 emissions (10 years)	Operational CO_2 emissions (10 years) including 20% avoided rebound effect	Total (10 years)
BELGIUM	Dwelling B1	59,100	-750	-750	58,350
	Dwelling B2	58,400	4,600	5,500	63,900
	Dwelling B3	59,100	740	890	59,990
	Dwelling B4	59,100	1,100	1,300	60,400
	Dwelling B5	59,100	4,300	5,200	64,300
	Dwelling B6	58,400	5,200	6,200	64,600
	Average Belgium	58,900	2,500	3,100	61,900
	Total Belgium (6 dwellings)	353,200	15,200	18,400	371,500
NETHERLANDS	Dwelling N1	29,300	28,800	34,600	63,900
	Dwelling N2	29,300	-	-	29,300
	Dwelling N3	29,300	9,400	11,300	40,600
	Dwelling N4	29,300	35,500	42,600	71,900
	Dwelling N5	29,300	25,700	30,800	60,100
	Dwelling N6	29,300	16,700	20,000	49,300
	Dwelling N7	29,300	26,800	32,200	61,500
	Dwelling N8	29,300	10,300	12,400	41,700
	Dwelling N9	29,300	15,700	18,800	48,100
	Average Netherlands	29,300	21,100	25,300	51,800
	Total Netherlands (27 dwellings)	791,100	168,900	202,700	1,398,600
IRELAND	Dwelling I1	34,000	-8,400	-8,400	25,600
	Dwelling I2	34,000	15,300	18,400	52,400
	Dwelling I3	34,000	-7,300	-7,300	26,700
	Dwelling I4	34,000	-1,200	-1,400	32,600
	Dwelling I5	28,900	-	-	28,900
	Dwelling I6	28,900	-	-	28,900
	Dwelling I7	32,800	-	-	32,800
	Dwelling I8	35,200	-	-	35,200
	Average Ireland	32,700	-400	330	32,900
	Total Ireland (8 dwellings)	261,800	-1,600	1,300	263,100
	Average Housing 4.0 Energy	38,200	10,100	12,352	47,900
	Total Housing 4.0 Energy (41 dwellings)	1,406,100	182,500	222,400	2,033,200
	Negative values are negative CO_2 reductions, i.e., having a higher CO_2 emission than the baseline				

Table 9: Reduction in CO_2 emissions of the Housing 4.0 Energy dwellings for a period of 10 years (in kg CO_2 eq.)

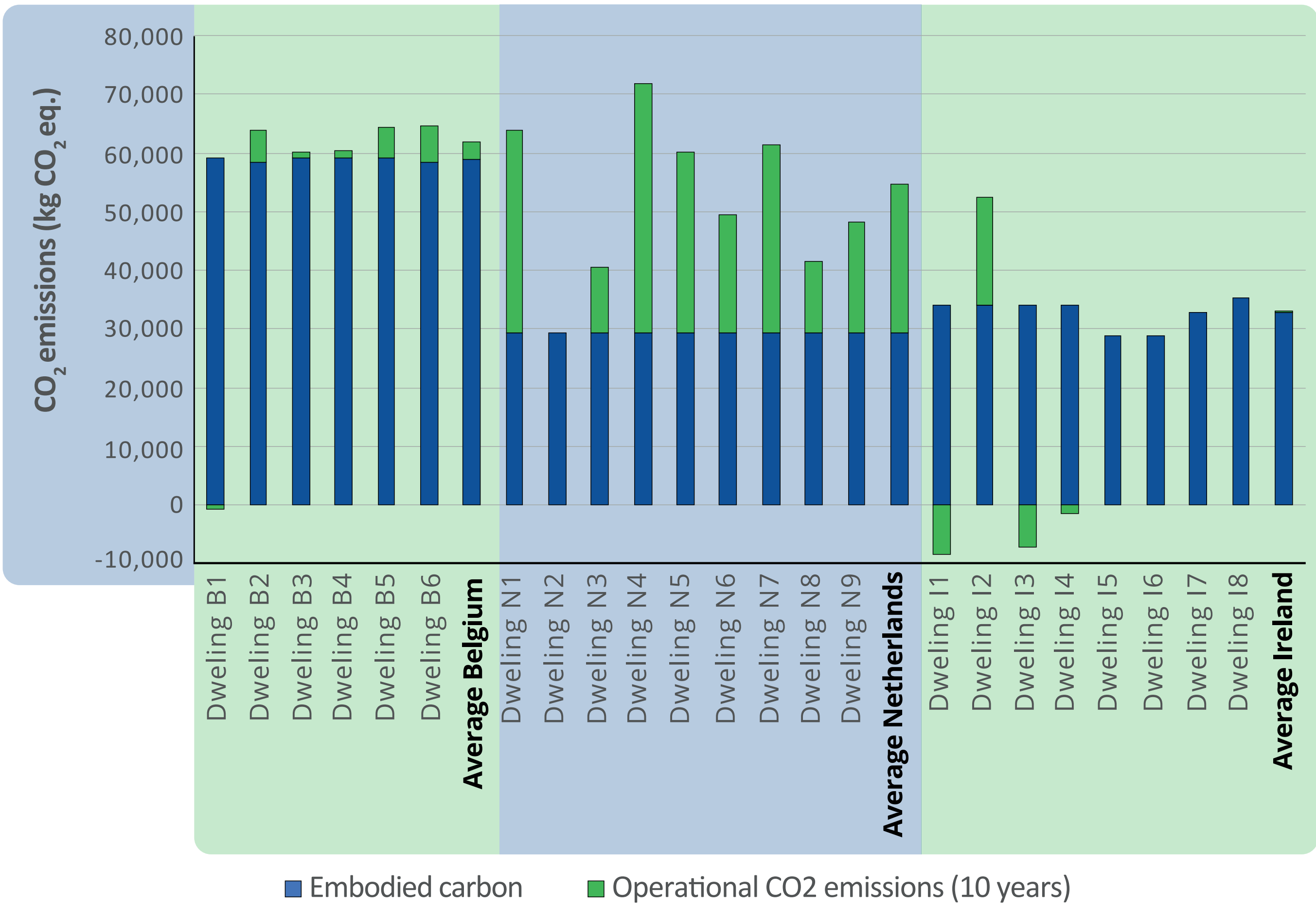


Figure 30: CO_2 emissions of the Housing 4.0 Energy project for a period of 10 years.

Moving Forward After Housing 4.0 Energy (Helpful Links)

Having now read this Guidebook, what comes next is up to you. There are further resources available online for you to learn more technical information about Housing 4.0 Energy and Passive House, and the H4.0E Platform is also available in a Beta stage (at the time of writing) to be explored. You can also see the partner's websites for updates on their pilots, as these will continue to be delivered beyond the project. Below is a list of potentially useful links for you to use as you continue your Housing 4.0 Energy journey.

Whatever you do, we wish you the best and hope you take with you the principles of Housing 4.0 Energy. There is a clear need in Northwest Europe and beyond to start changing how we approach housing construction and construction in general, as our current system is too costly, too time-consuming, and altogether too harmful to the environment. This starts with the individual and so we thank you for taking the time to learn about what we have done and hope it has inspired you to replicate it.

The kindest regards from all the Housing 4.0 Energy Team.

Helpful links

- Housing 4.0 Energy Interreg Website
- Housing 4.0 Energy Website
- Provincie Vlaams-Brabant
- Europäisches Institut für Innovation – Technologie e. V
- Gemeente Almere
- TU Delft
- South East Energy Agency
- South West College
- Open Systems Lab
- Kamp C
- Thoma Holz GmbH

South West College Training Material

- Unit 1: Construction Guide to NZEB
- Unit 2: Constructor's Guide to Housing 4.0 Energy User Platform
- Unit 3: Occupant's Guide to Near Zero Energy
- Unit 4: Housing 4.0 Energy Case Studies