4M process roadmap and implementation guidelines

Deliverable Report D2.1

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P2ENDURE
Plug-and-Play product and process innovation for Energy-efficient building deep renovation

This research project has received funding from the European Union's Programme H2020-EE-2016-PPP under Grant Agreement no 7723391.

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Colophon

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Publishable executive summary

The objectives of P2ENDURE ***WP2 'Process innovation'***, is to crystallize the P2ENDURE 4M modular process for deep renovation by integrating all required methods as well as the e-Marketplace, BIM and software instruments that will support decision-making based on a life-cycle assessment and life-cycle information.

This report summarizes the first step towards reaching this goal, the detailed development of the P2ENDURE 4M process. The report provides detailed process guidelines for a deep renovation process that makes optimized use of PnP prefab solutions and that aims at completing deep renovation cycles within weeks instead of months. P2ENDURE plans to reach this significant reduction in time through developing a number of process innovations, including advanced BIM modelling methods and an e-Marketplace.

The report also outlines how these different process innovations can be aligned throughout the renovation effort from early planning phases to the final monitoring of the energetic performance of the building. To provide readers with ideas of how the process guidelines can be implemented on projects, the report also maps the 4M process to two specific P2ENDURE demonstration cases and one P2ENDURE ***Innovative Deep Renovation Product*** (IDRP). Because of the predominance for BIM models for supporting the energy assessment of buildings the report also introduces the P2ENDURE BIM modelling standard that is to be followed by all P2ENDURE demonstration projects.

List of acronyms and abbreviations

4M processes: Mapping, modelling, Making and Monitoring

BIM: Building Information Model

PnP: Plug and Play

IDRP: innovative deep renovation product

HVAC: Heating, Ventilation, and Air Conditioning

UML: Unified Modelling Language

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1. Introduction

P2ENDURE proposes the 4M process, a step-wise approach for preparing and implementing the deep renovation, followed by real monitoring of the resulting performance improvements. The 4M stand for mapping, modelling, making, and monitoring and aims at significantly reducing the time required executing deep renovations. One main feature of the 4M process is that it makes use of advanced process innovations, such as web-platforms, laser scanning, 3D printing, robotics, as well as, data sensing and monitoring. The 4M process is also designed to allow for staged renovations. Through the iterative nature of the 4M process – the last stage monitoring directly provides the input for the first stage mapping – renovation activities can be spread out over a longer period (10-15 years) and a continuous energetic performance can be guaranteed. This report D2.1 will specify the P2ENDURE processes in detail providing a guideline to be followed by all the P2ENDURE demonstration cases. The report will also highlight the differences to the traditional deep renovation process and explain where in the process advanced technologies and P2ENDURE products should be ideally implemented. Within the appendix the report will provide a check list to support projects with tracking their specific process.

To further support the implementation of the specified guidelines, D2.1 will not only provide a detailed description of the 4M process, discussing the steps to be taken within each of the 4Ms. Making use of three different P2ENDURE demonstration projects, D2.1 will also illustrate three application examples of the 4M process with different deep renovation focuses: A renovation using smart HVAC innovations, a renovation focusing mainly facade upgrade, and a renovation applying advanced robotic techniques.

Within the 4M process, Building Information Modelling (BIM) will play an important role, supporting a large number of process activities. Because of the requirement for these BIM models to allow for predicting and monitoring the energetic behaviour of the building before and after renovation, BIM models need to fulfil very specific requirements. Therefore, D2.1 also proposes a detailed BIM modelling standard accounting for these specific requirements.

The report is structured as follow: The next section discusses and explains the 4M process in detail. Afterward the report illustrates the process on the three specific examples. The next section introduces the BIM modelling standard for the 4M process. The report closes with a short conclusion.

2. The 4M Process

The P2ENDURE 4M modular process is a stepwise approach for preparing and implementing the deep renovation of buildings making use of PnP based IDRPs, followed by real monitoring of the resulting performance improvements. The main stages of the modular process are

- Mapping with the purpose to develop a detailed technical plan and economic feasibility report for deep renovation, as a starting point for the renovation design –including conversion of building function or typology when relevant.
- Modelling with the purpose to develop the deep renovation design ready for execution. This step will result in advanced BIM models of the existing buildings and deep renovation designs with energetic properties, including architectural, structural and MEP systems and parametric BIM's of the prefab renovation components for manufacturing, local factories (3D printing), and to enrich the digital solution library in e-Marketplace
- Making with the purpose to execute deep on- and off-site renovation activities. This step will result in improved, tested and implemented innovative PnP based IDRPs to be installed ensuring that the P2ENDURE goal of 60% in energy improvement, .15% improvement in first cost, and an overall time reduction needed for completing a deep renovation by a factor of two.
- Monitoring with the purpose to monitor and guarantee the high quality execution of the construction works, and to monitor the Indoor Environmental Quality and Energy performance after deep renovation. This step will result in "as-built" BIM models integrated with sensory systems and software tools for continuous performance monitoring and long-term maintenance and optimization.

The following figure 1 shows the described 4M processes. The rest of this section will provide detailed guidelines for conducting each of the four above stages.

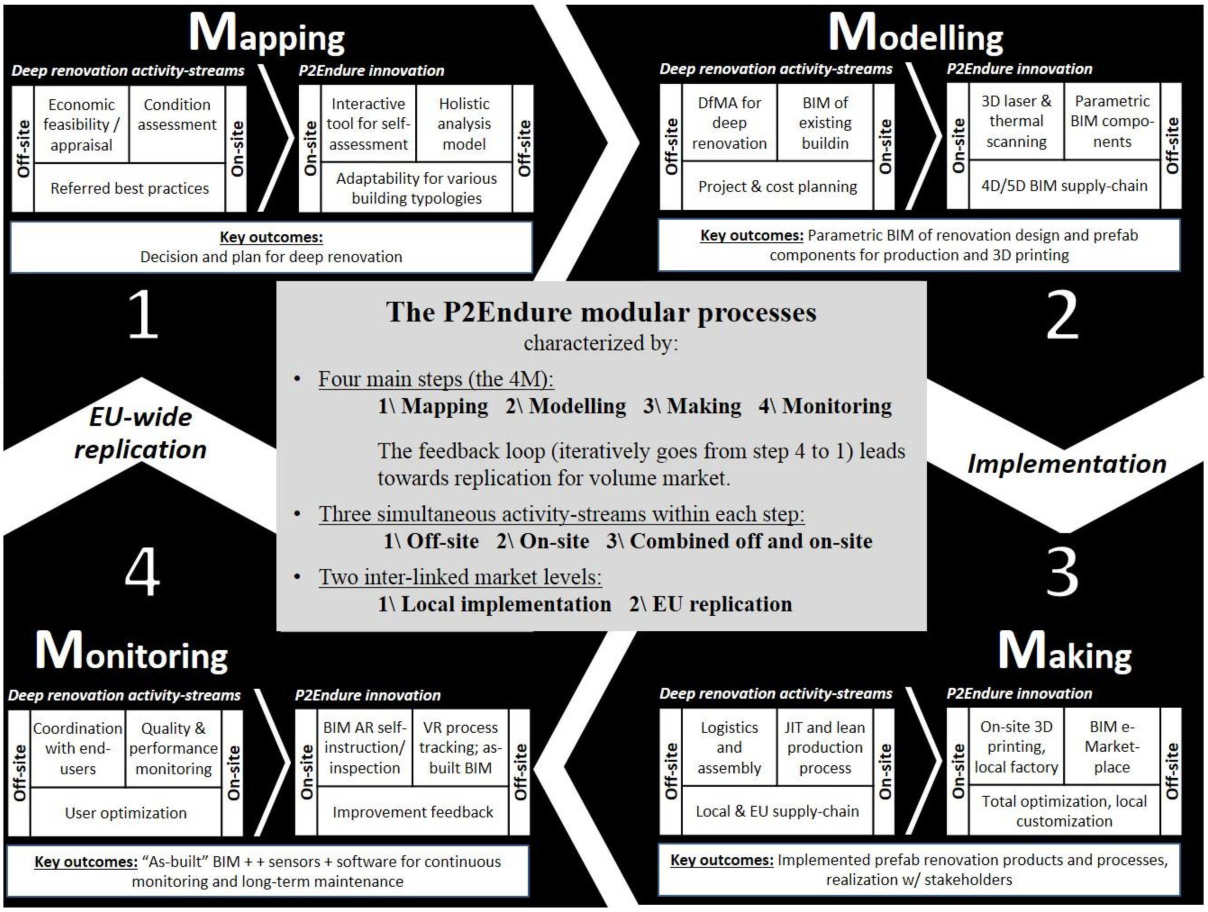

Figure 1: The 4M process Model

2.1 Mapping

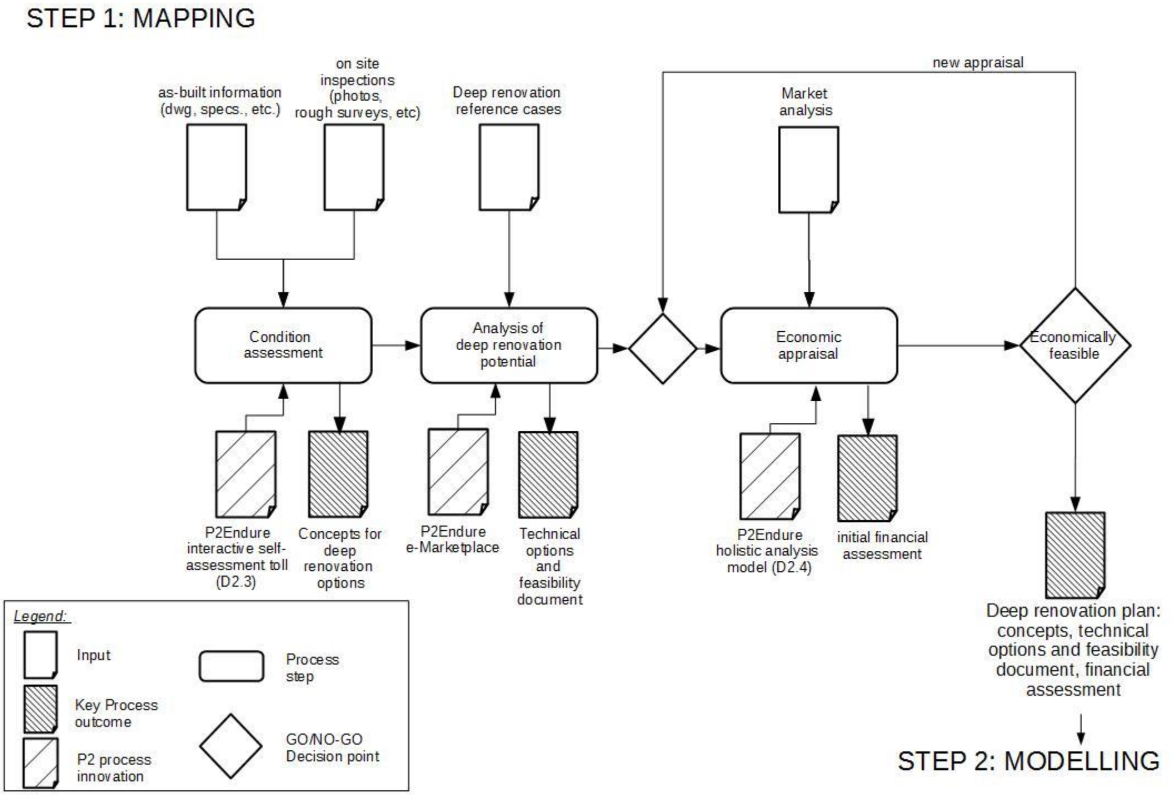

Figure 2. Mapping stage of the 4M process.

The first stage within the P2ENDURE 4M process – mapping - is concerned with screening particular objects to understand the financial and technical feasibility for undertaking a deep renovation. The purpose of this step is not to design or plan a deep renovation in detail, but to conduct a first reality check The mapping stage starts with a general assessment of the object's condition. To this end, planners need to collect existing as-built information about the building that is usually available in the form of paper-based or digitized sets of drawings and written specifications. Helpful within the mapping stage is also a physical site visit to inspect the building and to document additional information in the forms of photos and selected detailed measurements of important details. The outcomes of the mapping process are a first summary of deep renovations building upon available PnP IDRPs describing initial ideas for deep renovation options.

For the next step within the mapping process we suggest to analyze the potential for deep renovation based on the initially screened information. Preliminary possibilities for implementing IDRPs, such as new windows, façade elements, or HVAC components, should be assessed in relation to the current status of the building. For identifying good practice options, planners should evaluate a number of reference cases. An initial technical options and feasibility document should be drafted based on the outcomes of this step.

Within the third step of the mapping process, the financial viability of the most promising solutions identified while analyzing the deep renovation potential should be assessed. To this end, current analyses of the local real estate market should be taken into account and an initial cost benefit study should be conducted. The outcomes of this step should result in an initial financial assessment plan for a number of deep renovation options for the project.

The mapping stage should close with making a decision about the financial and technical viability for deep renovations. If the project seems to be financial viable, the outcomes of the mapping stage should be formulated in a deep renovation plan that summarizes the most promising of the analyzed deep renovation concepts together with the concepts technical and financial viability. In case, it has to be decided that the project is not financially feasible, the planner needs to make a decision to intensify the mapping process to find better deep renovation options, or to abandon the project.

To improve and streamline the mapping process, P2ENDURE will develop and demonstrate a number of innovative process improvements. Within WP 2 it is planned to develop a tool to allow for the self-assessment of the condition of a building which intends to streamline the initial condition assessment task. The tool, to be delivered with D 2.3 will allow tenants and building owners to collect a large part of the information required to assess the condition of the building themselves. Hence, D 2.3 has the potential to significantly reduce the effort that is required for planners to collect all the initial data required within the mapping stage. During the selection of possible deep renovation concepts, the P2ENDURE e-Marketplace (D 2.4) can provide an important support for browsing and finding a large number of possible deep renovation options. Finally, P2ENDURE will develop a holistic analysis model that will be published together with D 2.4.

After completion of the mapping stage with the proposition of a financial and technically viable financing plan, planners can then continue with the next stage of the 4M process: Modelling.

2.2 Modelling

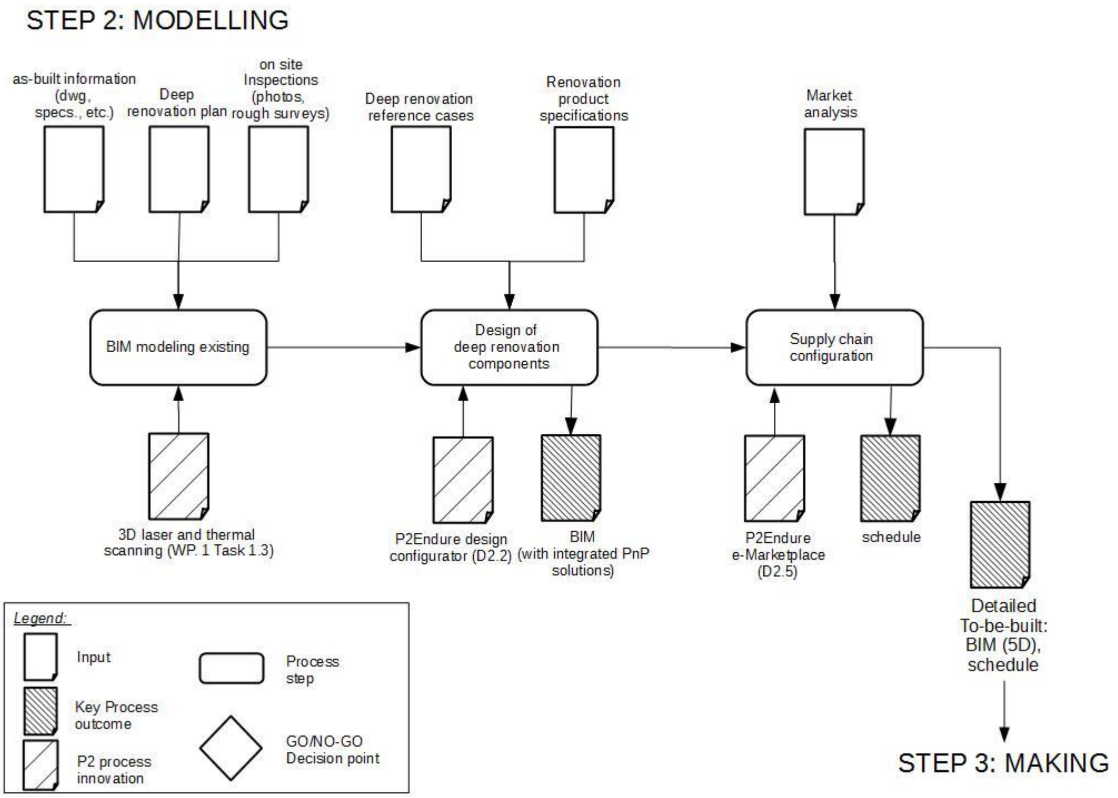

Figure 3. Modelling stage of the 4M process.

The second stage of the P2ENDURE 4M process – modelling - is concerned with developing all the details that are required to start with the renovation related production and installation work. The goal of the stage is it to create a fully developed BIM model, describing all the required details for the production. P2ENDURE plans to achieve a duration for this step of one to two weeks for modelling the to-be-built BIM for a typical residential building (e.g. single family house or low high rise apartment).

As first step of the modelling stage, the P2ENDURE 4M process prescribes a detailed modelling effort to establish a precise BIM model of the existing conditions that follows the P2ENDURE BIM for energy modelling standard introduced in section 4 of this report. As input for the modelling process, planners need to refer to the existing documentation of the building (drawings and specifications), information collected during a detailed inspection of the building, and the initial renovation plan developed in the mapping phase.

Once a detailed existing BIM model is generated, the planner can then proceed with the detailed design of the deep renovation effort. To complete this step, the P2ENDURE process suggests to model IDRPs and to integrate these models with the previously created BIM model of the existing situation. This integrated model should then be used to provide a detailed energetic calculation of the effects of different specific deep renovation solutions. By iteratively simulating different options, the final details of a close to optimal deep renovation effort can be designed. Planners should also use the integrated BIM model to detail the interfaces and required connections of the innovative deep renovation components. Tolerances should be adjusted and checked and any required connection details, for example, between facade elements and the existing structure of the building or between new HVAC components and the existing building systems. The result of this step should be a final BIM model integrating the existing building with the chosen deep renovation components that maximize the energetic savings behaviour of the building as indicated by the energy simulations.
To accomplish this task detailed information about IDRPs is required. Again the design work can be supported by various deep renovation reference cases to provide ideas and suggestions for working solutions that have been implemented elsewhere.

As a final step in the mapping process, planners should develop a plan for the required supply chain for realizing the chosen option. This step should specify where the deep renovation components can be purchased. An important decision during this step is to decide whether the components can be produced within a local factory or whether it is better to order them from a specific European product suppler. The supply chain configuration step should also include a selection of the required contractors for installation of the components on site.
Closing the mapping stage, all information about the chosen deep renovation configuration, its detailed integration within the existing building, and the supply chain configuration plan should be represented within a 5D BIM model providing all details required for the next stage of the 4M process- making.

Throughout the P2ENDURE project, we will develop a number of innovations to support and streamline the modelling stage. Within Task 1.3, P2ENDURE will develop detailed guidelines of how to apply laser scanning and thermal scanning technology to support the generation of a detailed BIM model within the first step of the stage. To support the design step, P2ENDURE will deliver a design configurator (D2.2) that utilizes the BIM model from the first step in relation with detailed models of possible IDRP. The configurator will allow designers to quickly generate energy saving predictions for a combination of different IDRPs. These predictions, in turn, will support the designer to quickly understand what combination of solutions will provide a close to optimal overall deep renovation of the building.

The last step in the modelling process, the configuration of the supply chain, will then again be supported by the P2ENDURE e-Marketplace (D2.5) that will already provide detailed information about specific process related indicators, such as time required for production, delivery, or installation, but also about specific costs.

2.3 Making

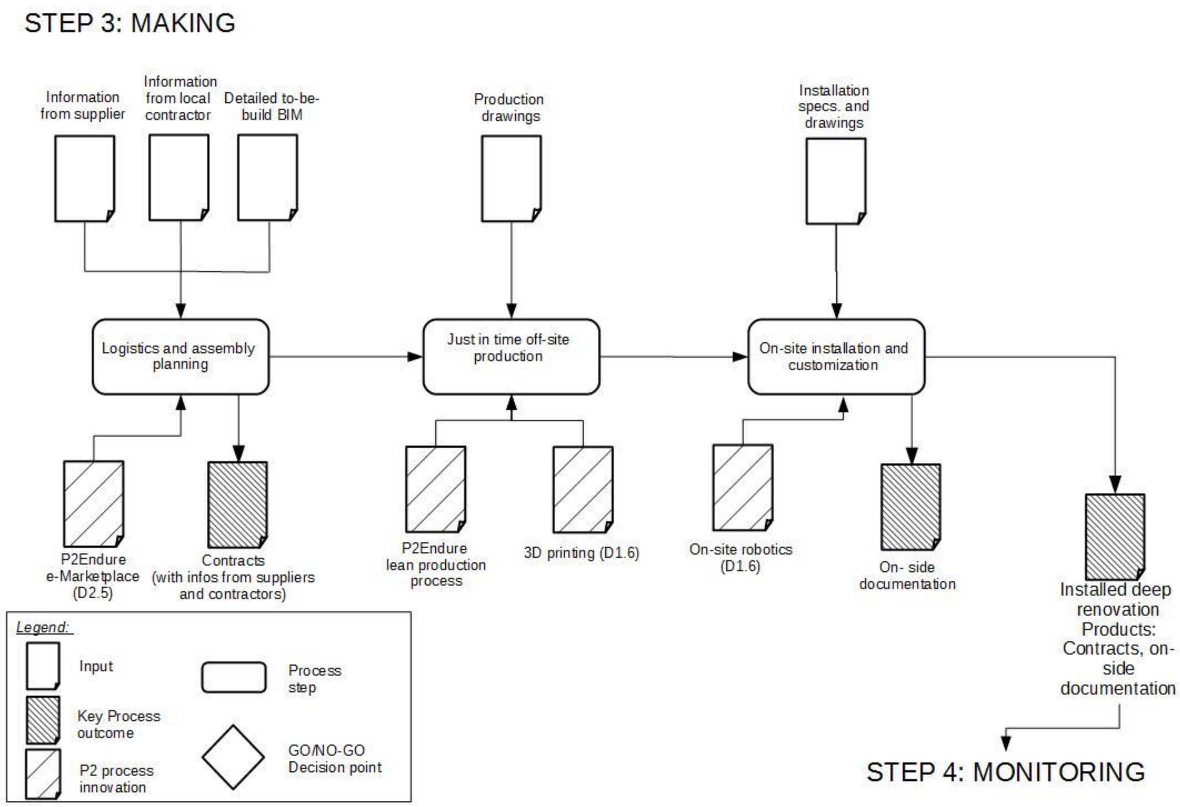

Figure 4. Making stage of the 4M process.

The next stage in the P2ENDURE 4M process – making – is concerned with the actual production and installation work required for the physical transformation of the building. The goal of this stage is to complete all the fabrication and on-site work in the quality required for ensuring a successful deep renovation of the building that achieves a minimum of 60% energy savings compared with the previous situation.

The first step in the making stage should be concerned to transform the supply chain management plan developed within the mapping phase. To this end, detailed information from possible suppliers and local contractors needs to be collected. Further contractual discussions with all supply chain parties should be started taking the detailed 5D BIM model from the mapping phase as a baseline for price negotiations. The results of this first step should be agreed upon and signed contractual relationships between all required supply chain partners.

The next step in the making process, is to organize and execute the required off-site fabrication work as specified in the 5D BIM model plan. To support this task, production drawings can be extracted from the 5D model for each of the contractors. IDRPs should be produced and delivered to ensure that they arrive on the physical building site so that they can be directly installed (just-in-time). By extracting detailed installation specifications and drawings from the 5D BIM, the final step within the making phase is concerned with the onsite installation and construction of the chosen IDRPs.

The P2Ednure 4M process is designed to ensure that the existing occupants of the building are disrupted as little as possible during the installation process. The 4M process also prescribes that each completed installation is thoroughly documented. The detailed document of the final installation then serves as input for the last stage of the P2ENDURE 4M process- monitoring.

To support the making process P2ENDURE will develop the following process related innovations. For the first step in the making process, the P2ENDURE e-Marketplace (2.5) can again support finalization of the logistic and assembly planning. On the e-Marketplace IDRP providers can post real time information about production, delivery, and installation times.

The e-Marketplace platform is also meant for entering contractual relations by placing binding product orders. The off-site production of IDRPs will be support by guidelines for how to set up lean production processes that will be developed across WP1. WP1 will also suggest methods for off-site production of IDRPs using 3D printing technologies (D 1.6). Deliverable 1.6 will also develop methods for the application of existing on-site robotic technology.

2.4 Monitoring

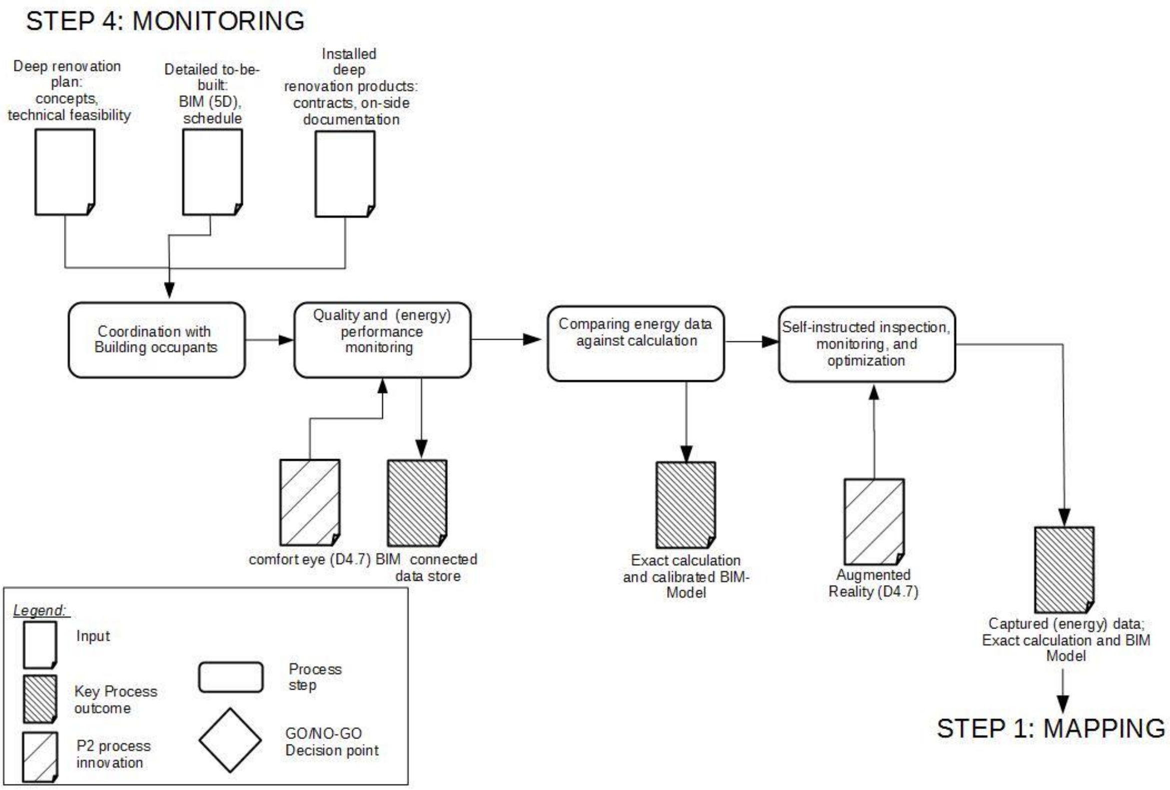

Figure 5. Monitoring stage of the 4M process.

The final stage of the P2ENDURE 4M process – monitoring – is concerned with establishing the necessary means to allow for a continuous monitoring of the deeply renovated building. Continuous monitoring should allow for a direct evidence based validation of the expected energy savings for the just completed deep renovation. Monitoring should also allow for a continuous improvement of the building. Finally, the monitoring results should provide the required information to allow for starting another 4M process of deep renovations. In this way, deep renovation activities can become a continuous effort of improvement spread out over periods of 10-15 years.

The first step to start the monitoring stage is to coordinate the monitoring effort with the building occupants. To this end, all occupants should be informed about the taken measures as documented in the deep renovation plans, 5D and as-built BIM models, and the IDRP specifications. Once informed, sensors and feedback mechanisms should be installed to monitor indoor

environment quality indicators and the energetic behavior of the building. Mechanisms need to be established that allow capturing all this monitoring data within adequate information stores that are connected to BIM models of the existing building. As a next step, the monitored data should be compared with the simulated and calculated predictions from the mapping phase.
To this end, an as-built and as-operated BIM model should be developed that calibrates all the required variables for an exact energy prediction according to the 4M BIM modelling standard (section 4 of this report). Finally, during the monitoring step the building occupants should be empowered to self-maintain the newly installed IDRP solutions and if necessary to adjust their set-up and settings to achieve an optimal operation of the deeply renovated building.
Finally, the captured energy data and the calibrated BIM model according to the 4M BIM modelling standard can serve as input for another iteration of the P2ENDURE 4M process starting again with the mapping phase.

The P2ENDUREs R&D efforts will develop new innovations to support the monitoring effort. As a first innovation, P2ENDURE will improve the existing comfort eye technology (see WP 4, and D 4.7) to allow for the streamlined monitoring of indoor environments to support the second step of the monitoring stage. To provide occupants with instructions for how to best self-inspect, self-monitor, and self-optimize their indoor environment D 4.7 will also suggest innovative applications for the use of augmented reality technologies.

3. Illustrative Demonstrations

This section describes three illustrative demonstrations of how two of the P2ENDURE demonstration projects plan to implement the 4M process. These illustrations should provide readers with a clearer understanding how the 4M process can be conducted on their projects. An additional illustration shows how the 4M process can be used for one of the P2ENDURE IDRP. This last illustration should provide detailed information for IDRP providers.

For each of the three cases, we developed process diagrams that are based on a detailed interview with the specific P2ENDURE partner representing the case or IDRP. During the interviews we asked the representatives about the activities and steps they plan to conduct for each of the 4M steps. The interview lasted roughly 60 minutes and was conducted via the phone.

3.1 Tilburg

The goal of this project is the renovation of a school building close to the centre of the Dutch city of Tilburg. The building will be transformed into six apartment units based on a collective self-organised housing principle. An owner-occupied development in collaboration with a housing association.

Currently, the building is owned by the municipality and has the energy label F. The goal of the deep renovation will be a transformation towards zero energy consumption. The building consists of brick walls, concrete uninsulated floors and a wooden roof. The single storey building is well-suited for a prefabricated rooftop extension. IDRP considered for the renovation are prefabricated facade elements, a prefabricated lightweight rooftop extension, prefabricated integrated installation, and a smart flexible insulating floor with accessible ducts. The responsible project partner for this project is Dutch partner PAN+.

PAN+ started the renovation process of the project in Tilburg in the mapping phase with an initial assessment of the object from the outside. To this end, PAN+ collected first impressions about the state of the building. Subsequently, PAN+ also retrieved additional information about the object by re-viewing existing drawings of the buildings.

Because of the location of the building close to a main road within Tilburg, the mapping phase also included a noise study based on detailed measurements conducted by an external expert to ensure that the building can be transformed to a dwelling. This expert also developed initial suggestions for noise reduction measures. The mapping step on this project also included a detailed study of the building's foundations. Following the 4M process this initial mapping phase was closed with developing a feasibility study report about the status and potential for the building.

Starting with the modeling phase, PAN+ created an initial BIM model to conduct some preliminary energy calculations. Based on the calculation results, PAN+ initiated a distribution plan of the future rental space together with an energy plan with the future tenants of the apartments. At the time of writing the report, PAN+ is finalizing the modelling stage by developing a preliminary BIM model. As a future step, PAN+ plans to initiate the making process with the creation of detailed 2D and 3D models of the building for production and on-site installation. Based in this model, the renovation of the existing building can commence, followed by the retrofitting of the rooftop.

PAN+ will not take over the monitoring processes, but is looking for a partner for this task.

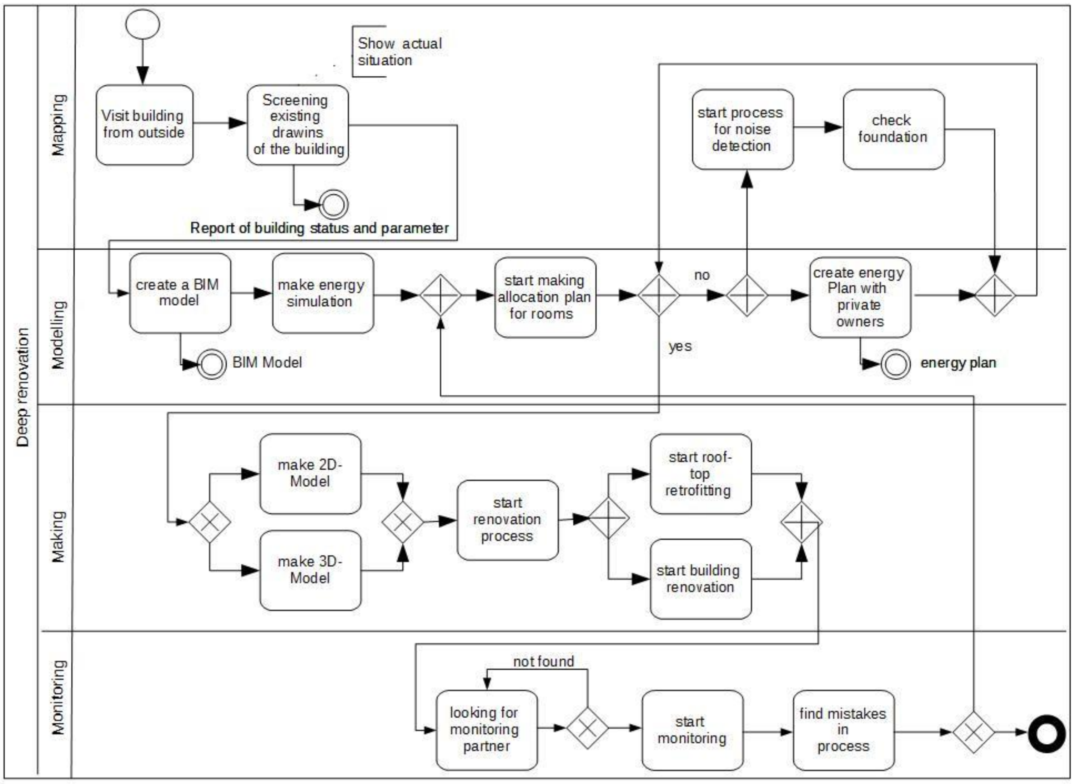

Figure 6: Planned 4M process implementation for the renovation for the demonstration case in Tilburg.

3.2 Soest

This renovation project in the German city of Soest includes the refurbishment of three nearly identical high rise apartment buildings. The buildings were erected in 1970 and have a Gross Floor Area of 3 x 3,358 m^2 = 10,074 m^2 over six storeys. The Gross Volume is 3 x 9,314 m^3 = 27,942 m^3. Each regular floor has 4 apartments with sizes from 65 to 90 m^2. The outside and bearing walls are concrete or masonry walls. The floor slabs, the roof and the balconies consist of reinforced concrete. The non-bearing interior walls are masonry walls. The energy performance of the current buildings is substandard to actual demands (German Energieeffizienzklasse G). Possible options for a deep renovation are, among others, the addition of a prefabricated facade, prefabricated lightweight rooftop extensions, and prefabricated integrated insulation. After the deep renovation, the building is targeted to have zero energy consumption. Because of the special ownership (almost all the apartments of the buildings are owned by different owners), the renovation process is difficult. The individual parties of the house have partly very different interests. The responsible project partner for this demonstration project is 3L.

As prescribed by the 4M process, 3L started the renovation process with the mapping stage. In a first step, 3L collected information about the building via the building's facility manager. 3L also sighted existing drawings and conducted an on-site inspection of the objects. Based on the collected information, 3L compiled a first assessment report. In this initial feasibility study, 3L started to investigate how to best improve the energy performance of the building. 3L prepared and submitted a German ENEV application. 3L also examined whether changes in the use of the building can be made to further improve its energy efficiency. At the time of writing this report, 3L is checking into possibilities for project funding using an initially established cost estimate.

As soon as financing is found, 3L plans to immediately start with the modelling stage. 3L plans to apply laser scanning to check the initial assumptions made in the mapping process. 3L will then evaluate possible energy improvement products (façade elements) for their tolerance values.
Based on these tolerance values, 3L will create BIM model detailed enough to support all production and installation tasks. 3L plans to start the making process with deciding how to best purchase the respective façade components. The options are to purchase the parts from a local factory or via the e-Marketplace. Once the elements are ordered and arrived at the construction site, a building contractor can install them. A separate contractor needs to install new HVAC elements. Subsequently, 3L will monitor the proper functionality of the components and control the assumptions in the existing BIM models from the modelling and making stages. If errors are detected, 3L will correct different steps of the modelling stage. If 3L detects no errors, they will initialize a remote maintenance service.

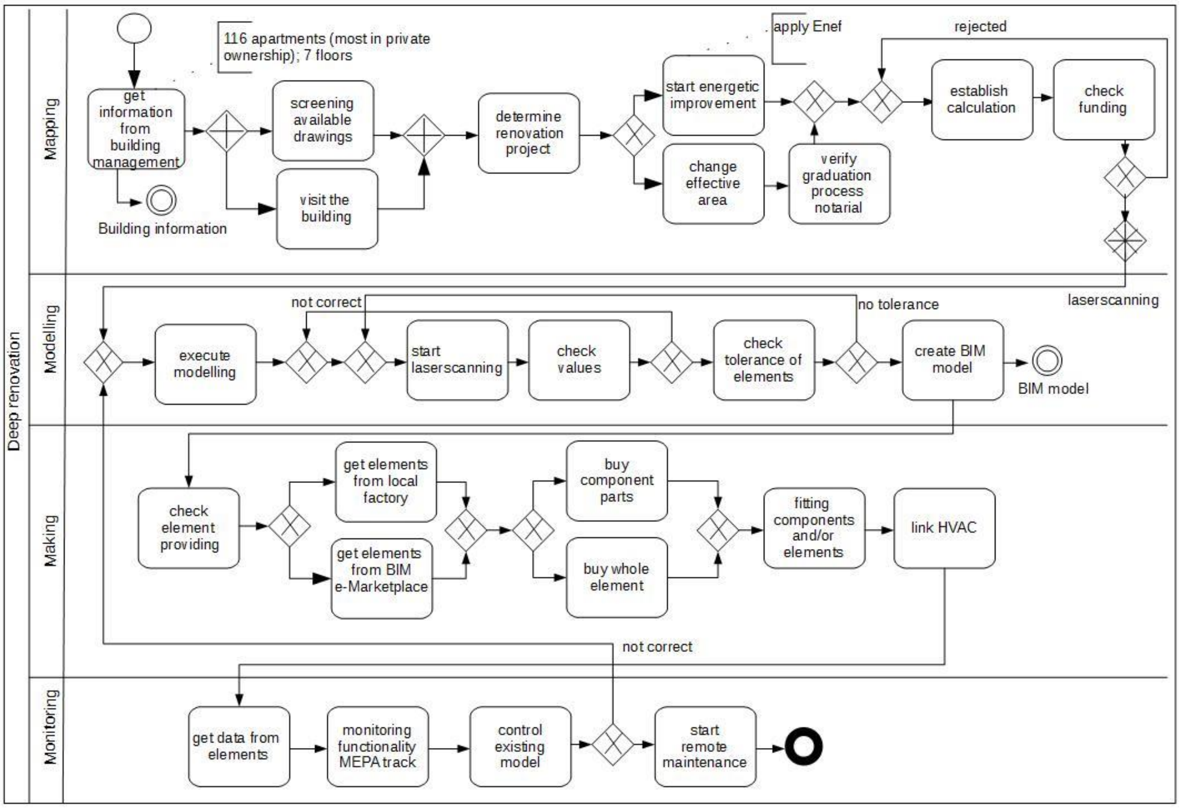

Figure 7: Planned 4M process renovation for the demonstration case in Soest

3.3 Robot at Work

This last example aims at illustrating the 4M process from the perspective of building product providers. As an example of such an innovative product we chose the application of on-site robots to spray custom tailored insulated facades. This advanced installation product is developed by project partner INV. The solution works with various sorts of materials, but INV prefers a mix of Thermosilit and limestone to create effective layers of insulation. INV applies state-of-the-art 3D printing technologies to create plastering with special limestone material on concrete walls, ventilation ducts, or water pipes. In this way, INV solution can deliver a complex 3D design of the exterior finishing in combination with painting. The solution controls robots using on-site laser scanned information. INV uses 3D BIM models (currently based on Revit software) to pre-programme the robots and the on-site processes. A 4M based renovating process from INV's perspective is illustrated in the below figure.

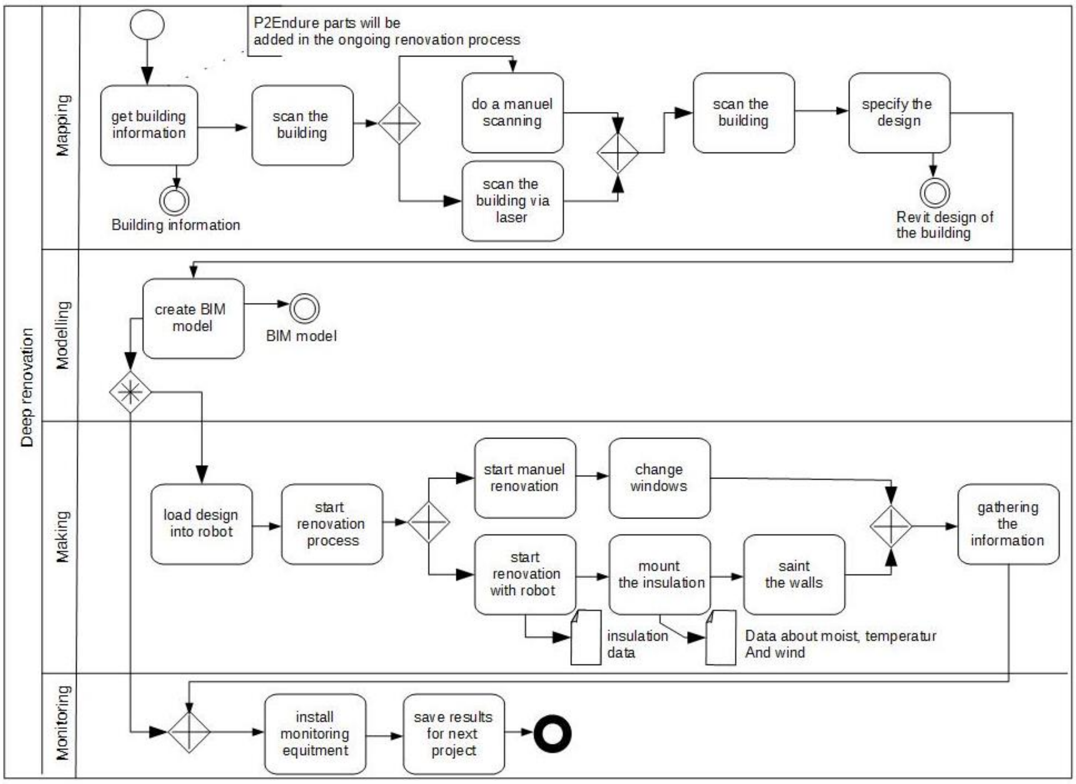

Figure 8: Planned 4M process renovation from the perspective of a deep renovation product provider

According to INV, the renovation process starts in the mapping step with the recording of information of the building. As a first result, a possible client interested in using INV's solution should collect all existing building information. Next to collecting and displaying the information in the mapping phase it is important that clients also have a detailed laser scan of the building at hand in the modelling phase. Laser scanning also needs to be accompanied by some additional manual measurements. INV might plan an additional service to support possible clients with this detailed scanning work. After the scanning process is finished, the client can order the external façade design from an architect. INV then checks this design against the specification of the robot, completing the modeling stage. As a result the project partners receive a Revit design of the building.

The making process at INV consists of creating the BIM model that can be used as input for the robot. Only if this is finished, INV envisions being directly able to start with the making and monitoring process in parallel. In the making stage, INV carries out the renovation both manually by replacing the windows, as well as by the robot. The Robot brings the insulation material to the facade and then sprayed the facade with color. During production, INV can already start recording control data for monitoring.

4. 4M BIM Modelling Standard

The previous two sections show that the 4M process heavily depends on the application of advanced BIM models as information containers to support various activities. Modelling these containers should ensure that all information required for calculating advanced energy analyses are provided and that the information fulfil the requirements of the specific energy calculation software tools used. We conducted a general literature review to develop a BIM model guideline to be used during the P2ENDURE project. The reviewed literature is listed in the appendix.

It is important to note that the 4M process also describes some specific BIM models that are not related to conducting an energy assessment. The here proposed BIM modelling standard does not support such specific applications. Separate standards need to be developed in the course of the project for supporting the supply chain management, on- and off-site fabrication, and monitoring. For conducting energy assessments based on BIM, the here proposed standard is applicable. Figure 9 illustrates a generic process of conducting energy assessments using BIM models generated according to the standard.

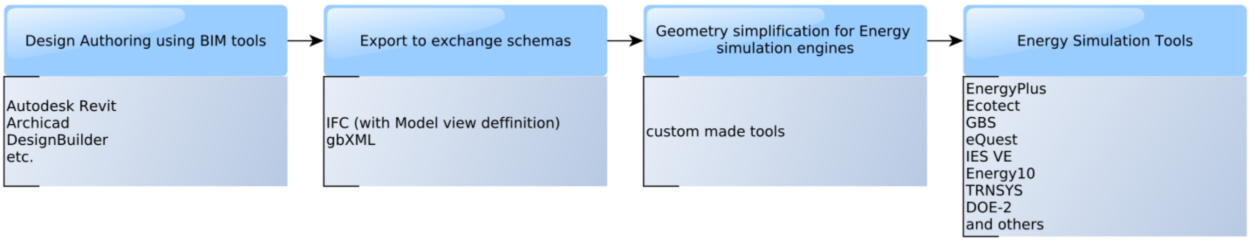

Figure 9: Energy assessment using BIM models

The main categories identified during review are represented by Geometry, Material Properties, Building Systems, Site Conditions and Building Operation Information (Figure 10).

According to the standard, BIM models need to provide information about the climate and location of the building on site. The standard also specifies the physical components that need to be modelled. Ideally, modelling of the physical components should be based on up to-date information, best if collected by a laser scan of the existing building. All physical elements have to be labelled as either architecture or structural elements and whether they are external elements or internal elements. External elements represent the envelope of the building, therefore embedded elements such as windows and doors have to be included with their specific characteristics. For embedded elements, the height and width also plays an important role defining the window to wall ratio. Additionally, information about glazing plays an important role for precise energy calculations. Moreover, the materials characteristics are specific to each material layer of the element.

Internal elements can be classified into vertical elements (walls) and horizontal elements (such as floors, ceilings, etc.). Vertical internal elements and/or external elements can contain doors which have to be taken into account for internal air flow and considered when defining the infiltration rates. The HVAC and lighting systems have to be modelled as well taking into account the exact location of the elements in the building's rooms. The model also need to contain non-geometric information used to identify performance level of the elements (e.g. heating level, cooling level, lighting level, etc.). In the end, the information is connected to room elements for which the external and internal elements define the boundaries. For these rooms energy system related information is required specifying the requirements for temperature, cooling, ventilation, and lighting. Additional information required for rooms are operational details, such as, Operation schedules or use schedules. Based on all these information it is finally decided if a single room forms a specific heat zone within the building or whether multiple rooms can be combined to a heat zone based on similar behaviour.

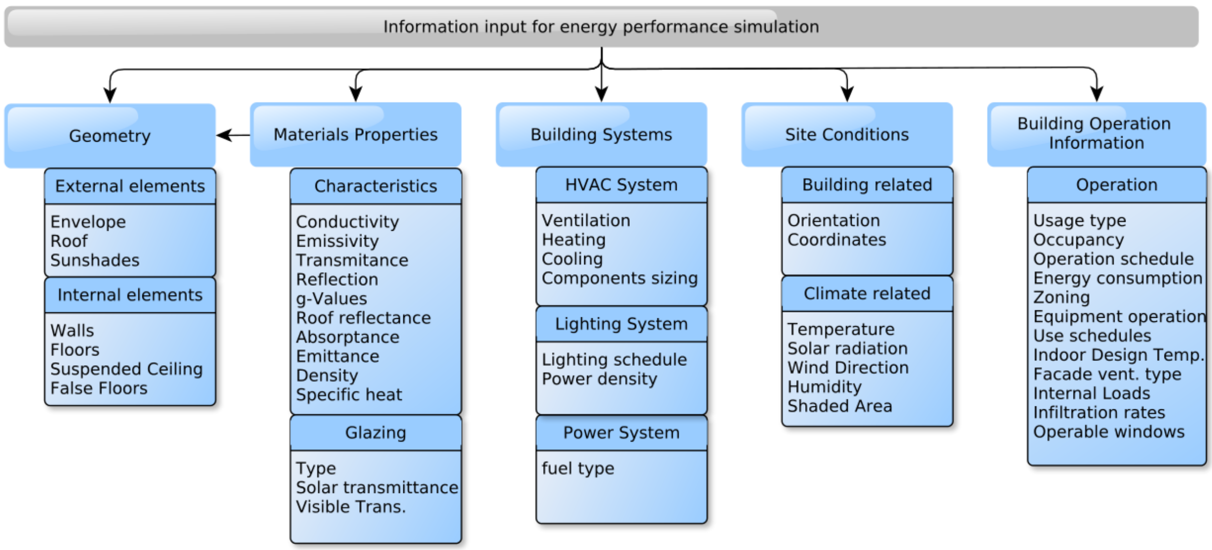

Figure 10: Overview of the BIM model standard's main information categories.

Usually, no zone should exceed the limits of a floor level. The expansion of the zones in order to contain multiple levels is commonly used in practice for elevators cores as well for stair cases which basically do not have elements to define horizontal boundaries at each level. Additional information related to occupancy, energy consummation, and infiltration rates plays an important role to obtain accurate energy simulations, and inaccurate input related to these leads will lead to unrealistic energy prediction and substantial errors. The appendix presents a more detailed static configuration of the whole system within the UML modelling language, showing the inter-dependencies between categories and information.

Conclusions

This deliverable proposed the 4M process for the P2ENDURE project. This document will function as a guide for the consortium's demonstration projects providing detailed guidelines for planning and conducted renovation activities and implementing a monitoring strategy.

The project also shows where the process innovations that will be developed in P2ENDURE can be directly applied within the 4M process. Detailed guidelines for BIM modelling are also provided.

During the course of the project, all demonstration projects will conduct their renovation according to the here specified process.

Where required the process, however, will be adjusted according to specific findings on the demonstration projects. At the same time, specific requirements or findings during the development of the different P2ENDURE process innovations might lead to changes in the here proposed guide.

APPENDIX 1– 4M Project checklist

	Required Input	Outcome
Mapping	as built information (dwg, specs, etc.) on-site inspection (photos, rough surveys, etc.) market analysis	Deep renovation plan: concepts, technical feasibility, monetary plan
Modelling	as built information (dwg, specs, etc.) Deep renovation plan on-site inspection (photos, rough surveys, etc.) Deep renovation reference cases Renovation product specification market analysis	Detailed To-be-built: BIM (5D), schedule
Making	Information from supplier Information from local contracter Detailed to-be-BIM Product drawings Installation specs and drawings	Installed deep renovation Products: Contracts, on-side documentation
Monitoring	Deep renovation Plan: Concepts, technical feasibility Detailed to-be-built:BIM (5D), schedule Installed deep renovation products: contracts, on-side documentation	Captured (energy) data; Exact calculation and BIM Model

APPENDIX 2– Literature used for developing the BIM model standard

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APPENDIX 3– UML diagram of the proposed BIM model standard