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Report on process/workflow management tools for renovation support

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0.9	BOC	20.01.2020	Final Version prepared
1.0	BOC	30.01.2020	Finalisation

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Abbreviations

AI	Artificial Intelligence
AEC	Architecture, Engineering, and Construction
API	Application Programming Interface
AWMA	Adaptive Workflow Management and Automation
BIM	Building Information Modelling
BIMERR	BIM-based holistic tools for Energy-driven Renovation of existing Residences
BPEL	Business Process Execution Language
BPMN	Business Process Model and Notation
BPMN DI	BPMN Diagram Interchange
BPMS	Business Process Management System
DX.Y	Deliverable X.Y
IBPM	Industrial Business Process Management
ICT	Information and Communication Technology
NVA	Non Value-adding Activities
OMG	Object Management Group
OWL	Web Ontology Language
PWMA	Process and Workflow Modelling and Automation
RenoDSS	Renovation Decision Support System
SLA	Service Level Agreement

SWOT	Strengths Weaknesses Opportunities Threats
TRL	Technical Readiness Level
TX.Y	Task X.Y
UML	Unified Modeling Language
VSM	Value Stream Mapping
WPX	Work Package X
XML	Extensible Markup Language
XPDL	XML Process Definition Language

Executive Summary

The scope of this deliverable is to report on how the overall renovation process can be supported by a Process and Workflow Management and Automation (PWMA) Toolkit in the context of WP6 **Process Management Tools & End-User Apps for On-Site Stakeholders** that aims to:

- Understand requirements of the entire renovation process from beginning to end
- Develop a digital twin for the renovation designer/planner and link it into the real-world
- Deliver process automation and workflow management tools
- Develop simulation and verification capabilities
- Optimally schedule renovation actions and resources
- Provide a monitoring framework for multi-layer decision support

The analysis task T6.1 focusses on **Renovation Process Analysis & Tool Specification Definition**. During the reporting period (M5-M13), the activities performed targeted the analysis of renovation activities from a process perspective including the analysis of various tasks, work items and stakeholders involved, the identification of information exchanged in the BIMERR context, and the specification of tools required for process & workflow modelling and automation. Therefore, an extension is made to T3.1 *Elicitation of Stakeholder Requirements* and T3.5 *BIMERR System Architecture Design & Elaboration* to identify more detailed requirements for the PWMA Toolkit. Corresponding to T6.1, this deliverable D6.1 titled **Report on process/workflow management tools for renovation support** reports on renovation activities from a process perspective, identifies the corresponding information exchange, and specifies details of tools and components in the PWMA Toolkit.

The approach taken for this report covers five topics. (1) Solution framing of requirements identified in T3.1 is performed. As the solutions under scrutiny are ultimately comprised by the PWMA Toolkit, this requires a refinement of requirements with respect to their relevance from a tooling perspective. (2) Based on the initial solution-framing of requirements, a design thinking approach for storytelling further frames the specification of PWMA Toolkit by telling the stories of the renovation stakeholders using the PWMA Toolkit. Furthermore, this deliverable reports on (3) reference processes and workflows to be modelled and automated by the PWMA Toolkit as a guiding instrument for T6.2 *Adaptive Process/Workflow Modelling and Mapping to the Interoperability framework*, based on the results of a value stream mapping approach. (4) The deliverable also specifies the system architecture for tools/components of the PWMA Toolkit as a guiding instrument for and T6.3 *Renovation Process Simulation and Formal Verification* and T6.4 *Adaptive Workflow Management and Automation Module Configuration*, and augments successive BIMERR system architecture design iterations in T3.5. (5) For the validation of this deliverable, a SWOT analysis is performed.

1. INTRODUCTION

Collecting, analyzing, and digesting the full set of requirements from all stakeholders involved in the different steps of the renovation process allows for the specification of tools supporting the renovation process. The PWMA Toolkit comprises of one such class of tools as a part of the BIMERR system, focusing on modelling renovation measures from a process and workflow perspective and model execution. Therefore, the specification of the PWMA Toolkit implies a specialization of the requirements elicitation and system architecture design process employed for the overall BIMERR system.

The general approach is to obtain a thorough understanding of the renovation process from the initial phase of the process to the end to identify requirements for tooling support that can facilitate KPI improvements by supporting different renovation measures. Thereby, renovation measures and KPIs considered from a process and workflow perspective in the PWMA Toolkit will be correlated with the results from WP7 *Renovation Decision Support System* (RenoDSS). The result possibly is a more efficient, faster, cheaper and less disruptive renovation process. Based on an understanding of these requirements, it is possible to specify (1) the PWMA Toolkit that comprises different tools/components and (2) the outcomes that can be achieved by using them. With this general approach in mind, further details on the objective of this report and its structure can be found in the remainder of Section 1.

1.1 OBJECTIVE OF THE DELIVERABLE

The objective of the deliverable is to harmonize, structure, and present a process perspective on the energy-driven renovation of existing residences, to identify requirements for the PWMA Toolkit as part of a holistic and integrated BIMERR system, and to specify details of the PWMA Toolkit fulfilling these requirements.

Figure 1 shows graphically the structure of the work package, aligned with the BIMERR WP6 innovation methodology introduced in Section 2. In the initial 13-months of the BIMERR project, an observation and an identification phase take place. The results of other work packages are observed. In particular, D3.1 *Elicitation of Stakeholder Requirements* and D3.5 *BIMERR system architecture 1st version* are considered. Simultaneously, the process perspective on the energy-driven renovation of existing residences is defined. At the end of this period, it should be clear (1) what steps in the renovation process and corresponding users are the ones that should be supported by the PWMA Toolkit, (2) what the user stories for the PWMA Toolkit look like considering in particular the potentials of knowledge-based decision support, (3) how best practice models and workflows are designed and reused in practice as digital twins (the digital process and workflow models) of actual renovation projects, (4) what the

architecture of the PWMA Toolkit and its interfaces look like, and (5) which specifications the components of the PWMA Toolkit have. This deliverable reports on these five items.

In the next period of the BIMERR project (M14-M30), this deliverable is a guiding instrument for the innovation and deployment phase resulting in the delivery of the PWMA Toolkit. After that follows an application phase in which the PWMA Toolkit is integrated with the overall BIMERR system to be applied in real renovation projects. This finally results in an exploitation phase in which the BIMERR system is brought to market. Alignment synchronization points are agreed upon after the listening and identification phase, corresponding to the general assembly meeting schedule.

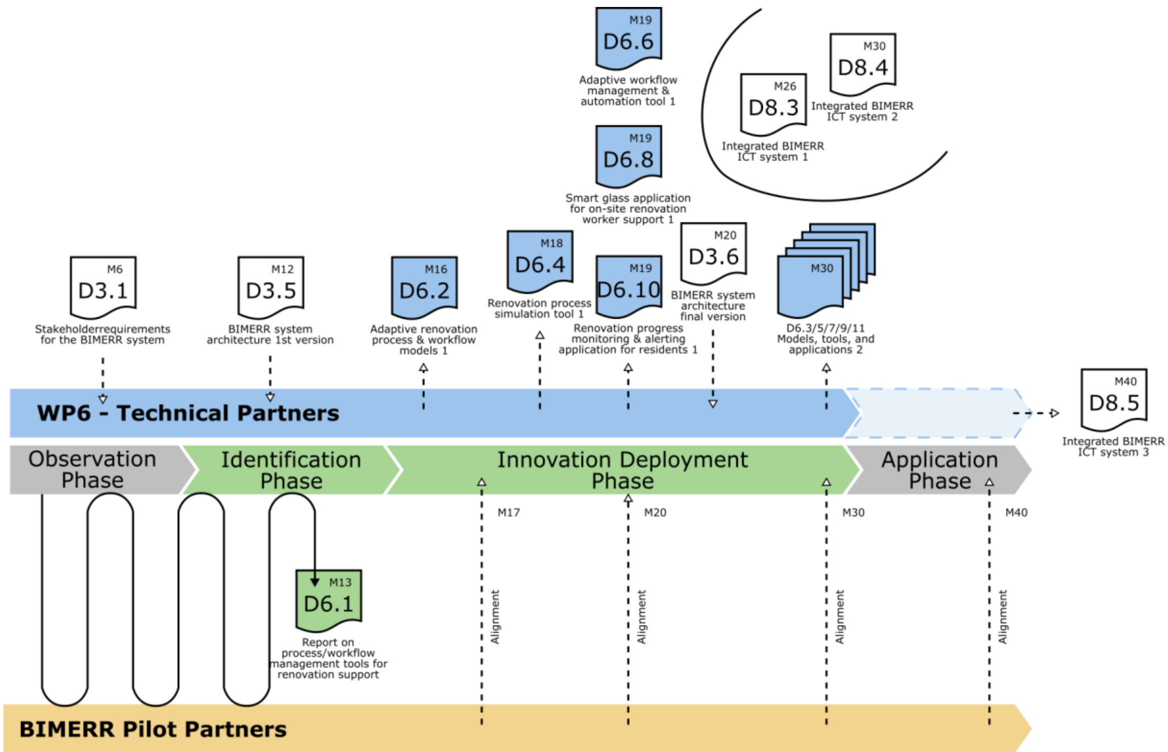


Figure 1 Innovation Methodology for BIMERR WP6

The results of the initial 13-months cumulate in D6.1 containing the findings of technical partners and pilot partners. The results target the topics of T6.1 at three levels:

- A classification of renovation steps supports the analysis of renovation activities from a process perspective. User storytelling combines the process perspective with a tooling perspective. Both perspectives together illustrate application cases of the PWMA Toolkit for descriptive modelling of the renovation process and its automation.
- The survey of best practice reference models through value stream mapping for selected steps in the renovation process helps to understand what information is exchanged in the BIMERR

context. It acts as a binding glue between the observation and identification phase and the innovation deployment and application phase in which a repository of reference models is provided for adaptation in actual projects.

- The specification of the PWMA Toolkit architecture and PWMA tools/components is the foundation that allows the development of the PWMA Toolkit to fully support the stakeholders during the renovation process. This is supported by a survey of existing tools already in use, which allows the technical partners to understand what type of tools the pilot partners themselves believe are useful.

1.2 Structure of the Deliverable

This report is structured according to the methodology introduced in Section 2. The methodology aims to construct a common innovation vision as an input for decisions to be made with respect the development of PWMA Toolkit. This vision and strategy formulated in Section 2 is continuously adapted and evaluated throughout the initial 13-month period and beyond.

Realizing a part of this innovation vision, Section 3 reports on activities performed on framing the requirements for energy-driven renovation as identified by other work packages in the BIMERR project. The goal for this framing activity is to identify attributes of the PWMA Toolkit as a solution to the requirements.

One part for the solution-framing of requirements is the identification of best practice reference models and a survey on what tools should look like from the pilot partners perspective, which is presented in Section 4. While the identification of existing tools influences the design of the PWMA Toolkit, best practice reference models can be employed by the users of the PWMA Toolkit to compare their projects against.

Section 5 takes the previous considerations into account and defines an abstract architecture of the PWMA Toolkit and the responsibilities of all the tools/components it comprises. This architecture is also essential to facilitate the integration of the PWMA Toolkit in the overall BIMERR system, for which an overall architecture is produced in T3.5.

The architecture definition is then refined through the specification of the tools/components that make up the PWMA Toolkit. The specification is also guided by the identified reference models from Section 4 which provide an understanding about what kind of models a user must be able to create and automate according to the user stories from Section 3. Additionally, a development plan is sketched for the PWMA Toolkit in Section 4.

2. METHODOLOGY

This section provides an account and justification of the methods employed for different activities performed during T6.1. Reports on the achievements from these activities can be found in the later sections of this report. Likewise, this section provides information about:

- The innovation methodology employed in WP6 as a guiding instrument for further refinement in the tasks of WP6.
- Design thinking approaches to frame the requirements identified in D3.1 from a process perspective useful for the developers of the PWMA Toolkit.
- Methods to gather best practice reference models (processes and workflows) for a representative selection of steps in the renovation process.
- The instruments employed for defining the architecture of the PWMA Toolkit.
- Tool specification approaches employed to create a foundation for tool development.

2.1 BIMERR WP6 INNOVATION METHODOLOGY

Figure 2 provides a diagrammatic overview of the methodology employed in WP6. On an abstract level, instruments and achievements are introduced. In each task of the work package, they are refined with further details. This enables to organize the activities in a task and to produce the corresponding deliverables.

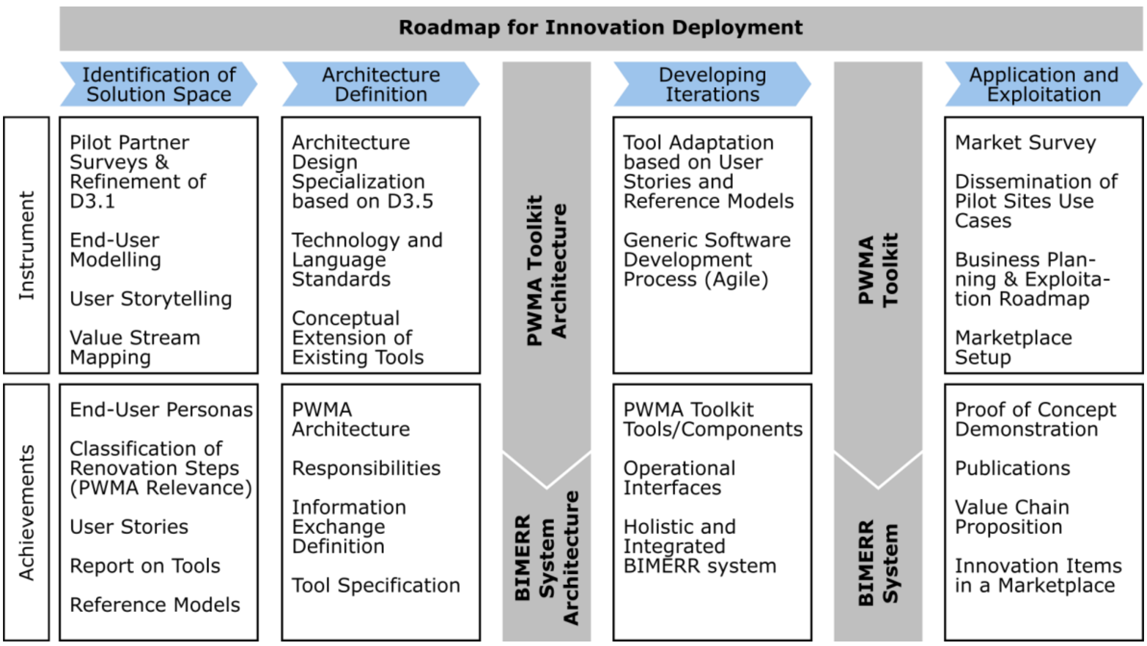


Figure 2 Roadmap for Innovation Deployment

2.1.1 *Identification of Solution Space*

Rationale: establish a view on BIMERR requirements from a process perspective and identify steps in the renovation process relevant for the PWMA Toolkit. Identify the benefits of the PWMA Toolkit for BIMERR stakeholders.

Instruments:

- Observation of T3.1; collection of pilot partner experience to identify end-user personas
- Classification of renovation steps from the perspective of users of the PWMA Toolkit
- Narrating user stories of the PWMA Toolkit, which is supported by the BOC S2M tool
- Survey on reference models through Value Stream Mapping; survey on existing tooling support

Achievements:

- Classification of steps in the renovation process from the perspective of PWMA Toolkit (available in Section 3.1)
- User stories of stakeholder personas using the PWMA Toolkit (available in Section 3.2)
- Report on reference models and existing tools (available in Section 4)

2.1.2 *Architecture Definition*

Rationale: provide information on the PWMA Toolkit from a technical point of view that is useful for developing solutions.

Instruments

- Observation of T3.5
- Collaborative PWMA Toolkit architecture design method
- Reuse of technology and language standards
- Extension, configuration, and integration patterns for existing tools.

Achievements

- Architecture of PWMA Toolkit and its relation to the BIMERR architecture (available in Section 5.1)
- Definition of Information exchange among the PWMA tools/components embedded in the BIMERR system (available in Section 5.2)
- Responsibilities of technical partners (available in Section 0)

- Technical specification of PWMA tools/components (available in Section 6)

2.1.3 *Developing Iterations and Application & Exploitation*

Based on the previous two phases of the roadmap, the technical partners in WP6 adapt existing solutions and develop new tools/components to realize the PWMA Toolkit. Continuous integration is performed among the tools/components, the PWMA Toolkit, and in the BIMERR system. As part of the BIMERR system, the PWMA Toolkit is applied in pilot site projects. For corresponding tasks in WP6, this deliverable is a foundation.

2.2 Solution Framing of Requirements

During the first phase of the innovation roadmap, the requirements identified in D3.1 are refined. This includes a classification of the renovation steps with regards to their relevance for the PWMA Toolkit. Furthermore, user stories of the PWMA Toolkit refine the BIMERR overarching story. These user stories illustrate how the PWMA Toolkit is applied to support stakeholders in the renovation steps of the overall renovation process. Section 2.2 provides details on how solution-framing is performed.

A continuation of the solution-framing method is performed in Section 2.3, which covers a method to collect best-practice reference models for a representative selection of relevant steps in the renovation process. The results from applying the methods from Section 2.2 and 2.3 are combined with D3.5 *BIMERR system architecture* to define requirements for the PWMA Toolkit as shown in Figure 3.

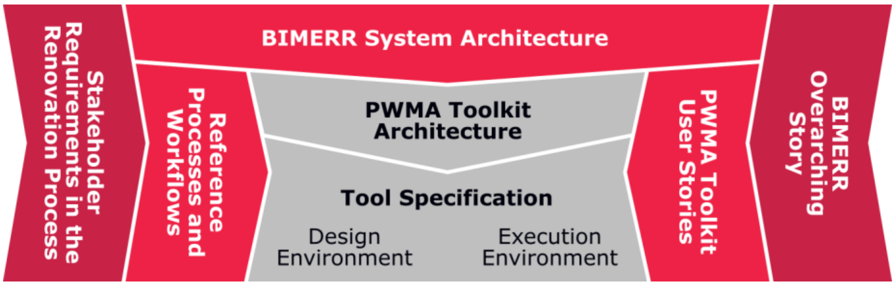


Figure 3 Solution Framing Influences

2.2.1 *Classification of D3.1 from the PWMA Toolkit perspective*

D3.1 *Stakeholder requirements for the BIMERR system* (in particular D3.1, Table 1) provides an account of the high-level renovation process and the more finely grained steps it consists of. As focused support from the PWMA Toolkit is not required in all of those steps, a classification is applied to them from a user perspective. Each pilot partner classifies the renovation steps based on a previously agreed upon classification scheme. The process and result of applying this method is described in more detail in

Section 3.1. The classification can be used to determine for each step in the renovation process its relevance when defining the requirements of the PWMA Toolkit (especially regarding process automation), which is a foundation for the collection of reference processes and workflows.

2.2.2 PWMA Toolkit User Storytelling

The BIMERR Overarching Story has been formulated by the BIMERR consortium to better understand the stories of stakeholders that benefit from the BIMERR system. These stories are refined in this deliverable using a design thinking method called storytelling with scenes which is introduced in this section.

To define the requirements for the functionalities of the PWMA Toolkit based on the BIMERR overarching story, understanding the detailed stories of end-users applying the PWMA tools/components becomes important. Design thinking – and in particular storytelling with scenes - is a human-centered activity applied during the reporting period to understanding user stories (Muck, Miron, Karagiannis, & Lee, 2018). The results from applying the method described in this section can be found in Section 3.2.

2.2.2.1 STORYTELLING WITH SCENES: THE SCENE2MODEL TOOL

Tool support for selected design thinking methods is provided by the Design2Model toolkit by BOC (a free-to-use variant is available at https://austria.omilab.org/psm/content/scene2model/info). Likewise, tooling support is provided for a design thinking method called *Storytelling with Scenes*. The corresponding tool is called Scene2Model. The idea of this tool is shown in Figure 4. In detail, the tool supports designing storyboards that describe scenarios in form of illustrative user stories. Thereby, haptic figures support a human-focused design process by providing pre-defined illustrations. The figures are combined to create visual user stories in different scenes, which make up a storyboard. The digitalization of these storyboards is enabled by the Scene2Model tool.

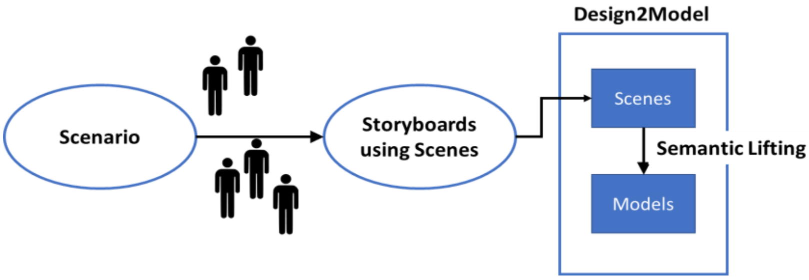


Figure 4 Tooling support for scene-based storytelling

Among other elements, the Scene2Model tool includes recognition hardware and software, middleware utilizing semantic technologies, and a web frontend. By recognizing the figures in the different scenes automatically, the tool is able to create digital twins of the scenes. Semantic lifting of the scenes is possible, e.g., by including ontologies to reason about design alternatives. A web frontend allows easy access to the scenes worldwide, querying, report generation, and many more features.

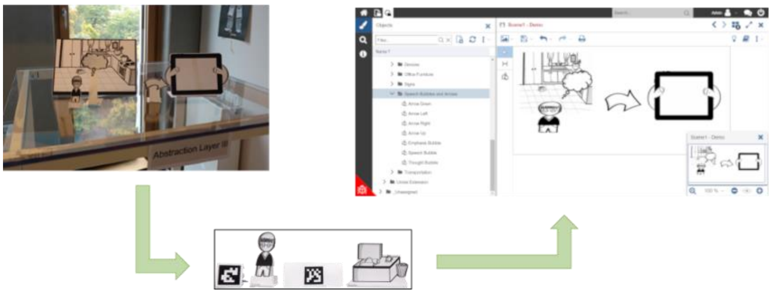


Figure 5 Digital Transformation of Scenes using the Scene2Model tool

Figure 5 shows the application of the Scene2Model tool on a proof-of-concept basis. On the left side of the figure, a scene can be seen consisting of different haptic figures. Many such scenes would originate in a workshop setting from the collaboration of different participants. Together, these scenes capture the user stories of a particular scenario, when arranged into storyboards. Thereby, each scene consists of different elements represented by haptic figures. On the right side of Figure 5, the result of digitalization can be seen for one scene in the web frontend of the Scene2Model tool, which can be used to manage many such scenes and storyboards.

2.2.2.2 APPLYING THE SCENE2MODEL TOOL TO UNDERSTAND PWMA TOOLKIT USER STORIES

The method of the workshops has been discussed with all WP6 partners in a telephone conference. Agreement has been reached also on conducting a hands-on workshop involving all partners of the BIMERR consortium. In this consortium wide workshop, a 60-minute timeslot has been arranged at the meeting in Kosice on 12.08.2019. At the workshop, participants were separated into two groups. One group was made up from partners representing end-users of the PWMA Toolkit while the other group was made up from partners representing developers of the PWMA Toolkit. Leaders were assigned to each group. As an input for each of the two groups, questions were prepared. The task for each group was then to prioritize the questions in 5 minutes time. Afterwards, each group had to design user stories in response to the questions, for which a time slot of 30 minutes was given. To accomplish the task, figures for a scene-based storytelling approach were prepared for each group. Furthermore, an introduction to the approach was given prior to the start of the workshop. After finishing the representation of user stories by building scenes, the members of each group switched places while the group leaders remained. The group leaders then explained the user stories to the opposite groups and

improved the scenes. For this phase, 15 minutes were allocated. The next 15 minutes were used to consolidate the results and to build an integrated user story for the BIMERR PWMA toolkit. During the workshop, the Scene2Model tool is applied to digitalize the scenes and storyboards. These digital scenes are then at a later step refined in the Scene2Model tool which can be accessed in a web browser.

2.3 Collection of Reference Processes, Workflows, and existing Tools

The methods from Section 2.2 are a first step towards turning requirements into solutions. Section 2.3 extends on this notion, by collecting information on best practice renovation processes and workflows that can be used as a reference for different renovation measures. This is an important input considering that the PWMA Toolkit must be able to model such reference processes and workflows, and to instantiate and automate them in concrete renovation projects. Furthermore, Section 2.3 illustrates how information is collected on already existing tools that could be superseded by or interfaced with the PWMA Toolkit. The initial results of applying these methods can be found in Section 4. Further refinement is expected during T6.2.

2.3.1 Value Stream Mapping

Mapping the construction process to reference models is an activity that is tackled in T6.2. As a foundation for this activity, the approach of Value Stream Mapping is introduced. Value Stream Mapping provides a common language for process owners to identify the current process and process deficiencies as well as to improve it. The goal is to model the renovation process while reducing non value-adding activities and time wastes.

2.3.2 Survey on Existing Tools

A list of tools for construction management was composed based on the domain knowledge of experts in the AEC field. Tools were selected based on their relevance regarding construction site management. The functionalities which were listed are the most important with regards to process and workflow management on the construction site. The tool list proposed by the experts was augmented by up to date research on relevant tools. Information was searched for on the web. In particular, the websites of tool providers where analyzed to extract explanations of a tool's most common features.

2.4 Definition of PWMA Toolkit Architecture and Responsibilities

The architecture definition extends the reference architecture for Model-driven Decision Support Systems developed in DISRUPT (Falcioni, et al., 2016), which supports modelling, optimization, and formalization based on IBPM. Further capabilities of the architecture are simulation & prediction to assess potential future states of processes as well as monitoring & analytics to assess their current status.

A twofold extension of the architecture is intended: On the one hand, the aim is to connect knowledge products – either provided from humans or provided by machines – into the architecture, which aims to enable (semi-)automated execution of the designed models and learning based on execution results. On the other hand, the re-emergence of AI manifests itself distributed over the whole architecture. Rather, the aim is to facilitate AI reuse among tools/components of the PWMA Toolkit by extending the capabilities of the architecture, where a dedicated space for knowledge and AI assets is intended. The results of applying the reference architecture and the extension method in BIMERR can be found in Section 5.

2.5 PWMA Toolkit Specification

The architecture definition of the PWMA Toolkit enables the assignment of engineering responsibilities. Furthermore, it provides a structure of the PWMA Toolkit, upon which tools/components can be specified in detail. Corresponding results can be found in Section 6. In particular, a template is created for specifying the tools/components and filled out by the partners responsible for engineering them. The template describes PWMA Toolkit functionality in terms of

- what core component and sub-component realizes the functionality
- into which tool family the components can be categorized
- the use cases, for which the functionality is required
- what capabilities are provided
- how users can access the capabilities
- what interactions among components and sub-components exist
- dependencies on other functionalities
- the license that the functionality is provided under
- how functionality is deployed
- the expected technology readiness level
- who is responsible

2.6 Validation of this Deliverable

To facilitate understanding about decisions taken in writing this deliverable, the methods chosen, and other factors, a SWOT analysis is included in the conclusion section. The analysis identifies strengths, weaknesses, opportunities, and threats of this report.

3. SOLUTION-FRAMING OF REQUIREMENTS

The BIMERR system is described by different stories and other resources, from which initial requirements for the PWMA Toolkit can be derived. These stories and other resources are sometimes not perfectly aligned and lack the specificity of actual requirements for the PWMA Toolkit. Therefore, this section introduces the PWMA Toolkit in the BIMERR system based on the inputs from the BIMERR overarching story and D3.1. Further inquiries and commitments are made to understand what the developers of the PWMA Toolkit should focus on. The resulting story frames a possible solution and is a source for architecture requirements.

Consequently, this section acts as a foundation for the architecture of the PWMA Toolkit described in Section 5 and the specification of its tools/components in Section 6. Together with best practice examples of representative aspects of the renovation process as described in Section 4, a foundation is laid for latter tool development and process & workflow modelling & automation tasks as introduced by the methodology in Section 2.

3.1 REQUIREMENTS, USERS, AND RENOVATION PROCESS

D3.1 specifies the overall renovation process from the beginning to the end. Accordingly, the renovation process comes in many steps in which different stakeholders employ different tools of the BIMERR system. The requirement is that the PWMA Toolkit supports the renovation process from the beginning to the end. This requirement is reflected in the BIMERR overarching story formulated by the BIMERR consortium. The overarching story provides a vision about possible focus points in the BIMERR project. Additionally, the story includes a BIMERR scenario which illustrates in an intuitive way an application case of the BIMERR system. In the BIMERR scenario, the focus of the PWMA Toolkit is on the processes of construction and renovation companies that perform renovation actions.

Based on the BIMERR overarching story, a possible scenario is that ACE Engineering Ltd. is renovating a residential apartment complex in the area of London. A high-level 7-phase renovation process frames such an activity not only for the given example but also in general. Specifically, the PWMA Toolkit must be able to support renovation and construction companies during the high-level 7-phase renovation process. Detailed steps of this process are listed in D3.1, Table 1. However, individual construction and renovation companies are not concerned in detail with all processes and workflows as some of them are not essential to their value proposition or are owned by different stakeholders. For example, Figure 6 depicts a possible configuration of relevant steps in a renovation process from the point of view of renovation and construction companies that potentially would use the PWMA Toolkit.

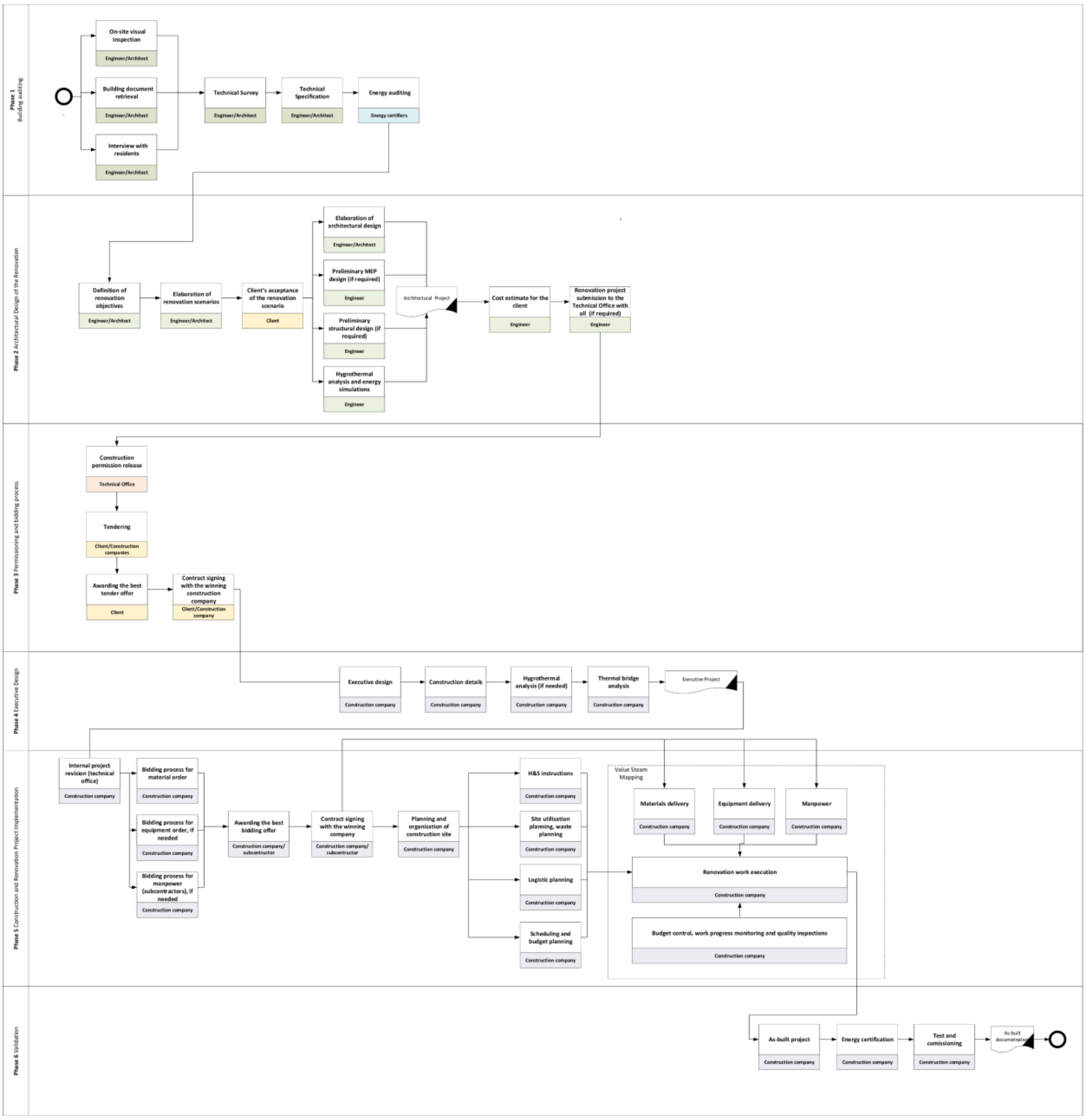


Figure 6 A best practice example of steps in the renovation process relevant for renovation and construction companies

As a consequence from the BIMERR overarching story, the PWMA Toolkit should provide capabilities at different levels of granularity: for the overall renovation process and for specific steps in the renovation process. Likewise, it is required that the PWMA Toolkit (1) is able to facilitate the overall renovation process including the coordination of stakeholders and tools and (2) supports specific stakeholders in specific steps of the renovation process with specific functionality, e.g., the (semi-)automated execution of renovation actions.

This section provides further details on the renovation process to describe in which steps which tools/components of the PWMA Toolkit are employed by which type of user. Additionally, it tells the stories of the users interacting with the PWMA Toolkit.

3.1.1 Stakeholder Identification

To provide a PWMA Toolkit, it is important that the tool vendor knows which steps in the renovation process should be supported for which users. Therefore, the main stakeholders are listed in Table 1. The stakeholders are then classified to reason potential users of the PWMA Toolkit from all the involved parties and the information flow between them.

Table 1 The main parties involved in the renovation process

Phase of the renovation process	Owner of the phase	Involved parties
Phase 1 Building auditing	Architectural firm (Architect/Engineer responsible for performing building survey)	Client Residents Technical office (to obtain existing documentation of the building) Energy certifier (to perform energy auditing of the building before renovation)
Phase 2 Architectural Design of the Renovation	Architectural firm (Architect/Engineer responsible for performing the architectural project)	Client Energy expert MEP engineer Civil engineer Technical Office (if the renovation project needs the official permission)
Phase 3 Permissioning and bidding process	Client	Technical Office Companies that send tender offers for renovation works
Phase 4 Executive Design	It depends on the project. If it is a simple renovation, the executive design is not always required. If it is a complex renovation, the executive design can be done by Engineering or Architectural firm or by construction company.	Client Energy expert MEP engineer Civil engineer Construction company

Phase 5 Construction and Renovation Project Implementation	Construction company	Suppliers Client Architect/engineer H&S Expert Site Manager Forman Workers Project Manager (from client side)
Phase 6 Validation	Client	Construction company Auditing experts Energy certifier

3.1.2 Classification of the Renovation Process from the Perspective of Potential PWMA Toolkit Users

To further understand the requirements for the PWMA Toolkit, the following classification is proposed. The classification provides information about potential users of the PWMA Toolkit in each step the renovation process.

RD) Responsible delivery - this party is responsible for the delivery of information - non-automated workflow

RD+) Responsible delivery - this party is responsible for the delivery of information - automated workflow

C) This party is consuming/requesting the deliverable - non-automated workflow

C+) This party is consuming/requesting the deliverable - automated workflow

IA) Information author - someone who need to supply or create information for a certain deliverable.

I) Informed - this party is just informed; no action required.

The following tables show the typical personas of PWMA Toolkit users working together on one renovation project. It further shows the information flow between them. However, new users and information flows can become relevant while listed ones might disappear, depending on the project that the PWMA Toolkit is applied in. Nevertheless, the tables illustrate a reasonable user group that might want to employ a BIMERR standard facilitated by the PWMA Toolkit. The information flow between these users creates an initial foundation for a repository of reference models to be created in T6.2.

Table 2 Building Auditing (Technical and legislation survey)

Phase of the renovation process	STEP ID		Architect-ural firm	Client	Residents	Technical Office	Energy Certifier	Civil engineer		
1 Building Auditing (Technical and legislation survey)	1.1	On-site Inspection of the building and surrounding context:	**RD**	**C**	**I**	**I**	**IA/C**	**IA/C**		
	1.2	Legislation and Public Offices	**RD+**	**IA**	**-**	**C+**	**IA**	**IA**		
	1.3	Technical survey	**RD**	**C**	**-**	**-**	**-**	**IA**		
	1.3a	Technical survey (BIM-based renovation process):	**RD+**	**C+**	**-**	**-**	**-**	**IA**		
	1.4	Technical specification	**RD**	**C**	**-**	**-**	**-**	**IA**		
	1.4a	BIM Model Refinement and Finalization (BIM-based renovation process)	**RD+**	**C+**	**-**	**-**	**-**	**I/IA**		
	1.5	Energy certifications and auditing of the building	**IA**	**C+**	**-**	**-**	**RD+**	**-**		
	1.6	user surveys (identify what the users need or want)	**C+**	**RD+**	**IA**	**-**	**-**	**-**		

Table 3 Architectural Design of the Renovation

Phase of the renovation process	STEP ID		Architect-ural firm	Client	Energy expert	MEP engineer	Civil engineer	Technical Office		
2 Architectural Design of the Renovation	2.1	Define objectives for the energy efficiency and strategy for the renovation (different scenarios); budget planning and ROI for each scenario. Define with the owner the renovation strategy + validation of the client	**RD+**	**IA/C+**	**IA**	**IA**	**IA**	**-**		
	2.2	Architectural Design (with CAD tools)	**RD**	**C**	**IA**	**IA**	**IA**	**-**		
	2.2a	Architectural Design (BIM-based renovation process)	**RD**	**C**	**IA**	**IA**	**IA**	**-**		
	2.3	Rehabilitation of existing building structure (if required)	**IA**	**C**	**-**	**IA**	**RD**	**-**		

	2.3a	Rehabilitation of existing building structure (if required)								
	2.3b	Rehabilitation of existing building structure (if required)(BIM-based renovation process)	**IA**	**C**	**-**	**IA**	**RD**	**-**		
	2.4	Preliminary Mechanical, Electrical and plumbing (MEP) Design (if changed)	**IA**	**C**	**IA**	**RD**	**IA**	**-**		
	2.5	Integration of renewable energy solutions	**IA**	**C**	**RD**	**IA**	**IA**	**-**		
	2.6	Hygrothermal analysis	**IA/C**	**C+**	**RD+**	**IA**	**-**	**-**		
	2.7	Thermal bridge analysis	**RD+**	**C+**	**IA**	**-**	**-**	**-**		
	2.8	Energy Simulation with renovation solution	**I**	**C+**	**RD+**	**I**	**-**	**-**		
	2.9	Integration of the design into the BIM model	**RD+**	**C+**	**IA**	**IA**	**IA**	**-**		

Table 4 Permissioning

Phase of the renovation process	STEP ID		Technical Office	Companies that send tender offers for renovation works			
3 Permissioning	Different processes depending on the pilot country		**C**	**RD**			

Table 5 Executive Design of the Renovation

Phase of the renovation process	STEP ID		Client	Energy expert	MEP engineer	Civil engineer	Construction company	Architectural company		
4 Executive Design of the Renovation	4.1	Executive design of the project in CAD	**C**	**-**	**IA**	**IA**	**I/IA**	**RD**		
	4.1a	Executive design of the project in CAD/BIM (BIM-based renovation process)	**C**	**-**	**IA**	**IA**	**I/IA**	**RD**		
	4.2	Elaboration of construction details in CAD	**C**	**-**	**-**	**IA**	**I/IA**	**RD**		

	4.2a	Elaboration of construction details (BIM-based renovation process)	**C**	**-**	**-**	**IA**	**I/IA**	**RD**		
	4.3	Cost estimation of the renovation	**C**	**-**	**-**	**-**	**I/IA**	**RD**		
	4.4	BIM execution plan	**C+**	**-**	**-**	**IA**	**I/IA**	**RD+**		

Table 6 Architectural Design of the Renovation

Phase of the renovation process	STEP ID		Construction company	Suppliers	Client	Architect/ engineer	H&S Expert	Site Manager	Forman	Workers	*Project Manager*
5 Architectural Design of the Renovation	5.1	Site utilization planning	**RD**	**-**	**I**	**I**	**IA**		**I**	**C**	***C***
	5.2	Schedule and budget planning	**RD+**	**IA**	**C+**	**IA**	**-**		**-**	**I/C**	***(RD+)***
	5.3	Health and safety planning and assessment	**IA**	**IA**	**-**	**-**	**RD+**		**I**	**-**	***C+***
	5.4	Maintenance planning of the construction site	**IA**	**IA**	**C**	**RD+**	**IA/I**		**I**	**-**	***C+***
	5.5	Waste management	**C+**	**IA**	**-**	**RD+**	**IA/I**		**I/C+**	**I**	***C+***
	5.6	Logistic planning	**RD+**	**I/C+**	**-**	**-**	**IA/I**		**I/C+**	**I**	***C+***
	5.7	Materials and components orders	**RD+**	**IA/ C+/ I**	**-**	**IA/I**	**-**		**I/C+**	**I**	***C+***
	5.8	Manufacturing of renovation components	**RD+**	**IA/ C+/ I**	**-**	**IA/I**	**-**		**I/C+**	**I**	***C+***
	5.9	Components delivery and storage	**RD**	**IA/ C/I**	**-**	**-**	**I**		**I/C**	**I**	***C***
	5.10	Cost control, choice of the subcontractors	**RD+**	**I**	**C+**	**IA/I**	**-**		**-**	**-**	***I/C+***
	5.11	Planning of construction works	**RD**	**IA**	**C**	**I**	**I**		**I/C**	**I**	***C***
	5.12	Construction work execution according to the renovation project	**RD+**	**I/C/ IA**	**C**	**I**	**I**		**IA/ C+**	**IA**	***C+***

	5.13	Inspection during the construction (quality control, audits, monitoring of construction progress, etc.)	**IA/ C+**	**-**	**IA**	**RD +**	**IA**		**I**	**I**	***I/C+***
	5.13a	Independent Inspection	**I**	**-**	**R D**	**-**	**-**	**I A**	**I**	**I**	***IA***
	5.14	Additional Equipment installation (e.g. sensors, IoT equipment, etc.)	**RD**	**I**	**I**	**-**	**I**		**-**	**-**	***C***
	5.15	Preparatory activities for renovation solution installation	**RD**	**IA**		**IA**					***IA***
	5.16	BIM execution plan monitoring and updating	**IA**	**-**	**C+**	**IA**	**IA**		**-**	**-**	***RD+***
	5.17	As-built project	**IA**	**-**		**RD +**	**IA**		**-**	**-**	***I/C***

Table 7 Executive Design of the Renovation

Phase of the renovation process	STEP ID		Client	Construction company	Auditing	Energy certifier				
6 Executive Design of the Renovation	6.1	1a) Testing and commissioning (by the construction company)	**C**	**RD**	**IA**	**IA**				
	6.1a	1b)Testing and commissioning (by independent company)	**C**	**RD**	**IA**	**IA**				
	6.2	Energy Certification	**C+**	**I**	**IA**	**RD+**				
	6.3	Testing with Thermal imaging and Blower - Door Test (in case of deep renovation)	**C**	**IA/I**	**-**	**RD**				

Table 8 Building Operation and Maintenance

Phase of the renovation process	STEP ID		O&M company	Residents	Client	Suppliers	Maintenance personell			
7 Building Operation and Maintenance	7.1	**BIM Model- O&M**	**RD+**	**IA**	**C+/I**	**IA**	**IA**			

3.2 User Stories

The storyboards shown in Figure 7 and Figure 8 illustrate a collection of stories about users interacting with the PWMA Toolkit. They result from workshops that were conducted internally at BOC and together with the whole consortium based on the methodology introduces in Section 2.2.2. Their digital counterparts and a corresponding description can be seen in Table 9.

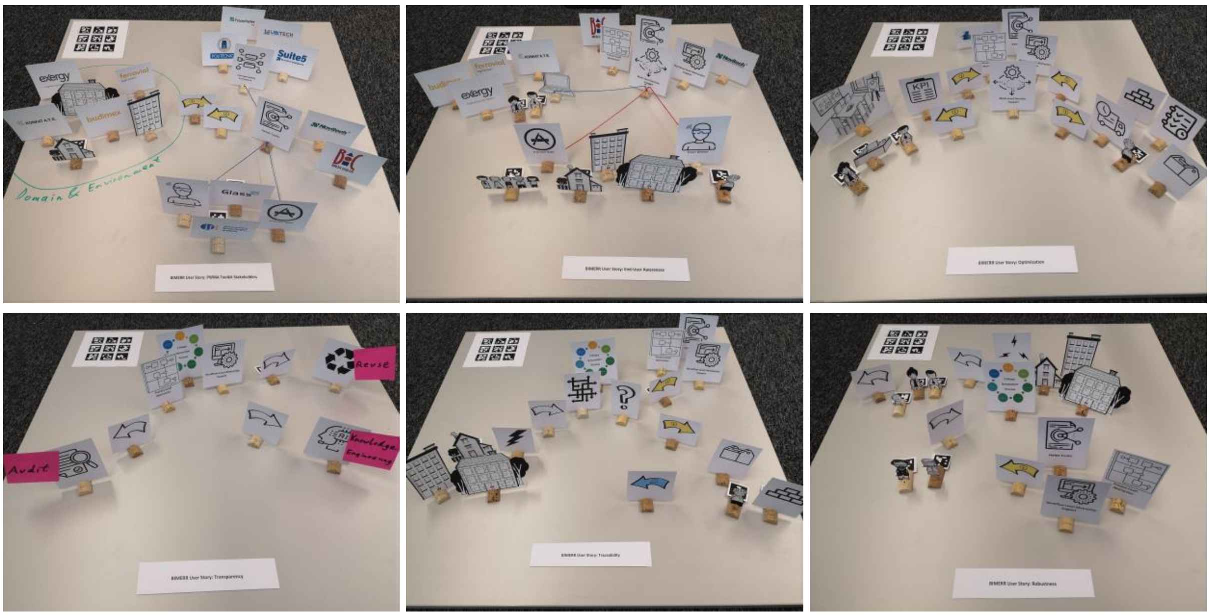


Figure 7 User Stories for the PWMA Toolkit - Results from the first Design Thinking workshop

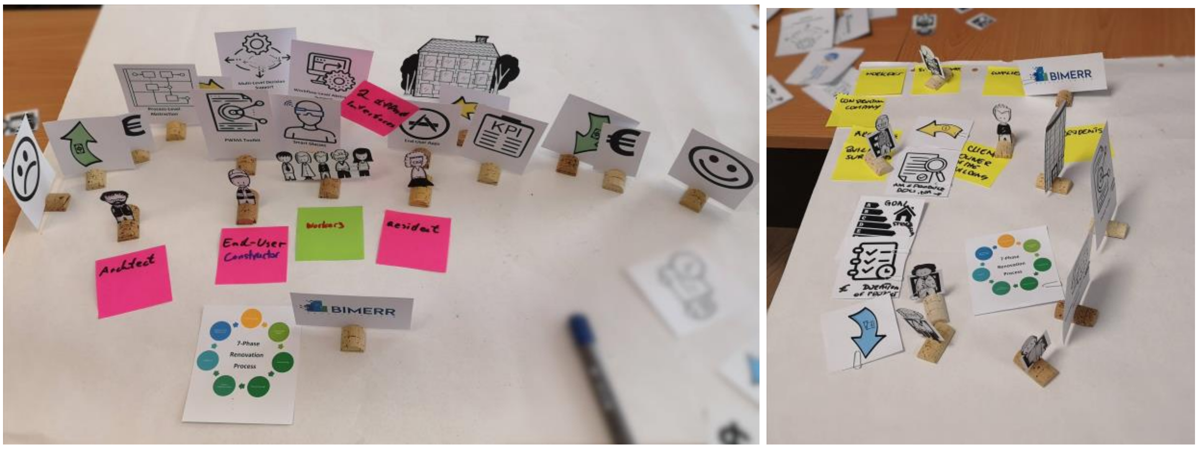
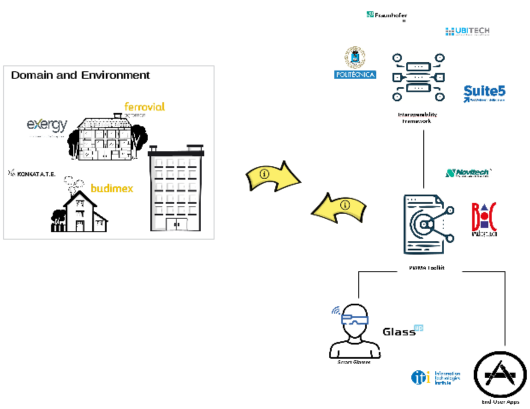
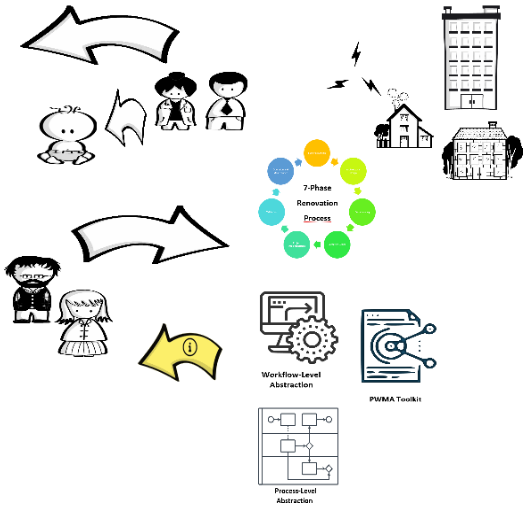
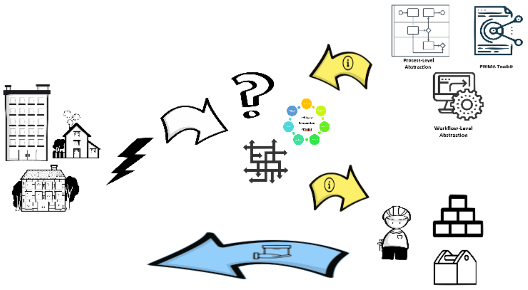
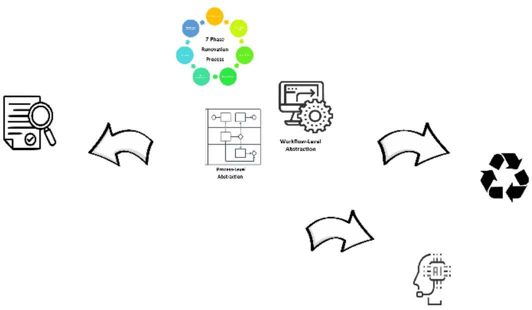


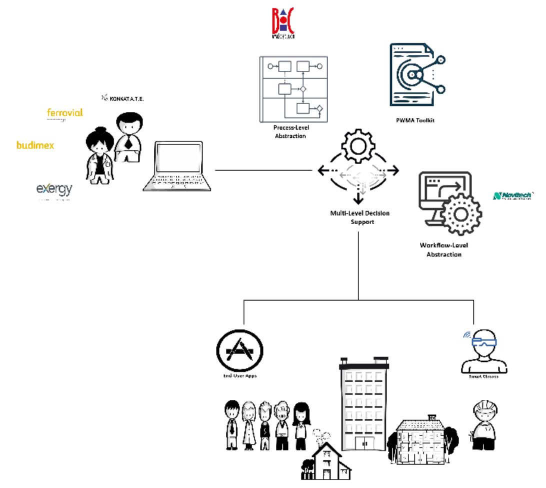
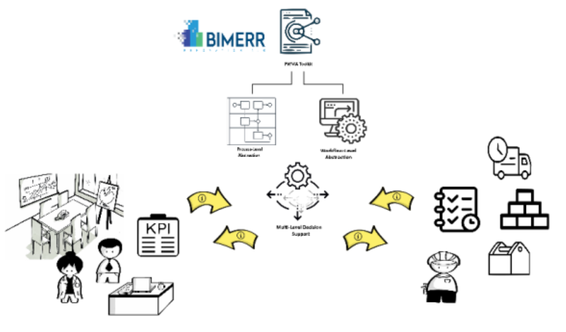
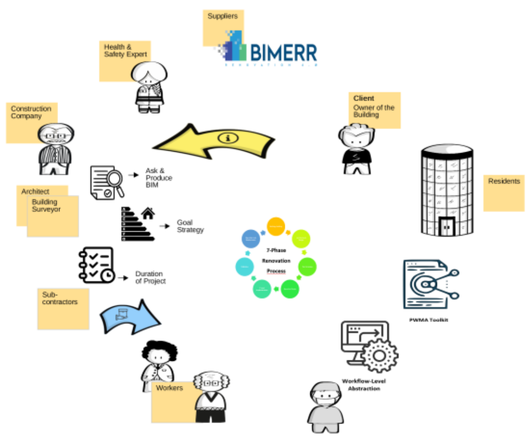
Figure 8 User Stories for the PWMA Toolkit - Results from the second Design Thinking workshop

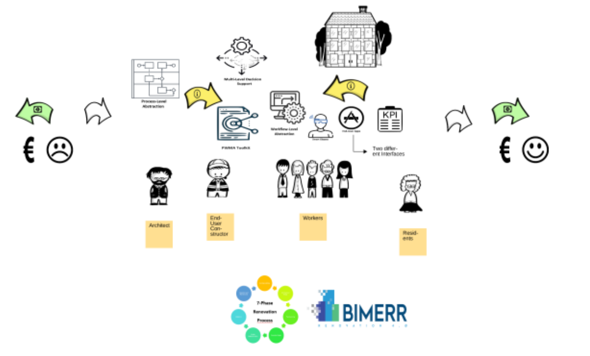
The Workshop results have been digitalized and refined in an effort to further crystalize the user stories of the PWMA Toolkit. However, while the Design Thinking workshops proved to be powerful tools to ideate these user stories, the artifacts resulting from these workshops on their own do not adequately capture all the topics and concepts discussed. Therefore, Table 9 provides additional information on these artifacts based on the discussions in the workshops.

Table 9 User Stories for the PWMA Toolkit

Digitalized PWMA User Stories	Description
	As the initial application of the PWMA Toolkit will be within the BIMERR consortium, it is important to identify the stakeholders involved in this special use case. One can see the partners providing pilot sites and data on the left. These partners and their subcontractors interact with the PWMA Toolkit, Smart Glasses, and End-user Applications. On the right, the suppliers for these technical solutions can be seen. Here, the focus is on facilitating the high-level renovation process.

	Depicted by this artifact, is the user story of an employee leaving a company involved in the management of the renovation process. To alleviate potential disruptions and to speed up initial training of new employees, it is beneficial to rely on a model of the renovation process. Likewise, modelling the renovation process in the PWMA Toolkit provides robustness against unexpected disruptions.
	The story depicted here shows a use case of the PWMA Toolkit. In this use case, a problem is identified during or after the renovation process. As the relevant aspects of the renovation process related to this problem can be traced in the PWMA Toolkit, it becomes easier to identify the responsible subcontractor, to purchase required materials, and to schedule corrective actions. Furthermore, it should be possible to foresee such problems during process planning through simulation. Simulation data should be learned based on past experiences.
	A potential of using the PWMA Toolkit is that it turns the renovation process into a digital artifact. A first property of this digital artifact is that the renovation process becomes highly transparent, which enables, e.g., easy report generation for audits. A second property is the agility of the digital artifact, which implies that it becomes easier to reuse or change parts of a renovation process. A third property of the digital artifact is its semi-formal nature, which means that it can be understood by humans but that it can also be processed by machines like intelligent process automation systems.

	The PWMA Toolkit provides capabilities for end-user decision support. Such end-users can be the residents using apps, workers using smart glasses, or the owners, managers, and planners of a renovation project. The corresponding user story is that end-users log in to the PWMA Toolkit, where they find information and knowledge on multiple levels of detail. Examples are dashboards that abstract information to allow KPI monitoring, interfaces showing concrete work instructions and notifications, or simulation runs that rank process alternatives.
	Users can employ the PWMA Toolkit for optimization tasks. Examples are the scheduling of on-site workers, materials, and tools in the renovation process; and the agile design of the renovation process based on the performance of KPIs. This is enabled by multi-level decision support bridging the process and workflow abstraction of the PWMA Toolkit.
	Different stakeholders in the renovation process can be motivated to employ the BIMERR system either by a central authority or because it makes their life easier. Process- and workflow-based collaboration patterns for subcontracting and for interfaces among stakeholders enable a more efficient renovation process. Furthermore, such patterns can be the foundation for automated tendering features.

	A central user story in the renovation process is the interplay between architects, construction companies, workers, and residents. By organizing this interplay and associated in an efficient manner, the owner of a building can save time and money during its renovation. The processes and information exchange between architects and the construction company has to be optimized, the results have to be decomposed and related to workers, and residents have to be involved next to KPI monitoring.

3.3 Requirements from a Process and Workflow Tooling Perspective

In this section, end-user requirements are placed under scrutiny from the point of view of the technology provider, which can make the actual requirements more concrete. The extended and focused end-user requirements illustrated previously in Section 3 call for the PWMA Toolkit supporting the renovation process. Properties of this toolkit are:

- The high-level renovation process can be modelled in the PWMA Toolkit including tools used in each step and information exchanged among stakeholders. The resulting process models can be decomposed into finer granularity. A repository of best-practice process models at different levels of granularity is to be provided to be instantiated and customized in actual renovation projects. Likewise, it is possible that a client models the whole renovation process, but a focus is on the process interaction between architecture and construction companies, as well as on the workflow interaction between construction companies and workers. However, multiple repositories of reference models might be necessary for a user to choose from corresponding to different renovation measures proposed in RenoDSS.
- The tool can be used to plan, validate, and simulate activity flows and information exchange among different stakeholders and tools in the renovation process. Decision support is offered to optimize the collaboration of stakeholders in a virtual enterprise which can be linked to a real enterprise representing renovation project stakeholders, their tools, and information. KPIs specified in RenoDSS are correlated with KPIs on the process level which are optimized through simulation and monitored on different levels.
- Adaptive rescheduling of materials and tools, workforce, and activities is supported during a renovation project. Simulation and optimization during the planning phase minimizes negative impacts of rescheduling like increased costs and longer project durations. The result of

simulation during the planning phase is an initial schedule of the renovation process which can be further refined to support (semi-)automated execution of renovation actions.

- Workers and residents are connected to the renovation process in a feedback loop via the PWMA Toolkit. They receive instructions and other information but also report on the status of the renovation. Automated systems also receive information and produce logs from which process feedback can be mined. The feedback is aggregated and abstracted to higher levels of granularity so that different stakeholders like the foreman and the project manager can make use of it.

Thus, what the interpreted requirements call for is an innovative multi-level decision support system that supports planning of a renovation project, execution, monitoring & analysis, and long- & short-term improvements & adaptations. However, fulfilling the vision of multi-level decision cannot come at the cost of fundamental functionality required from the PWMA Toolkit. That is to enable process simulation for optimization across project phases in order to identify and leverage opportunities for fine-tuning process steps and their attributes while considering quality requirements, eliminate undesired documentation for project delivery, and on-site tools for on-the-fly progress reporting and guidance of workers via innovative AR-enabled smart glasses for improved productivity and re-work elimination.

The PWMA Toolkit aims to deliver all the benefits of process and workflow management to the energy efficient building renovation, with special emphasis on modelling, communication, risk management, process optimization through simulation and continuous improvement. It will allow the renovation designer/planner to define different workflows for different types of jobs or processes for the design, construction and delivery of the works. These may include automated transmission of designs for approval by the building owner, routing of appropriate information to the various tools of the BIMERR system, job planning and scheduling on the construction site considering dependencies between them. The workflow automation tool will also enable interactive adaptation based on information from other tools. For example, non-availability of the building owner to provide access to workers may delay the project schedule, or unexpected severe weather conditions may change the order of scheduled activities for the same workers. Once each task is complete, the workflow management tools ensures that the individuals responsible for the next task are notified and receive the data they need to execute their stage of the process.

In particular, the PWMA Toolkit facilitates the construction phase of the renovation project and is mostly targeted to renovation planners, project managers and construction contractors/workers. It includes:

i. a back-end application for the modelling and adaptive monitoring of the entire renovation process as well as information management that will ensure synchronization of up-to-date

information across tool & stakeholders leading to delivery of as-built documentation after works are completed;

ii. dedicated applications targeted to stakeholders in the renovation site (contractors/workers & building residents) to provide on-site guidance so as to expedite the work through better synchronization of different activities and real-time work monitoring and reporting to facilitate information flow, enhanced collaboration and early conflict detection.

4. Reference Processes, Workflows, and Tools

An important feature of the PWMA Toolkit is to include best practice reference models that can be reused in actual renovation projects and customized based on the desired renovation measures. Therefore, best practice processes and workflows have to be captured from domain experts. The technical partners in WP6 use these descriptions among other requirements to develop and to provide the PWMA Toolkit. A description of existing tools in this section augments the approach.

On an abstract level, the best practice renovation process is covered in Section 3.1.2. However, more detailed descriptions of these abstract processes and workflows are required, as the PWMA Toolkit also provides focused support for the interplay between architects, construction companies, workers, and residents. Therefore, Value Steam Mapping (VSM) is applied in this section as a foundation for T6.2, which has the objective to capture desired reference models.

4.1 Value Stream Mapping

The construction industry struggles with inefficient construction processes, which affect construction productivity as well as the project time and budget. Koskela (1992) claims that construction processes can be characterized by non value-adding activities (NVA), which lead to poor productivity. Based on scientific sources of Koskela (1992), Weeleng (2004), Abdel-Wahab et al. (1999), Table 10 shows the identified waste in construction. This table is cited from Vilasini & Gamage (2010).

4.1.1 Value Stream Mapping (VSM) Approach

Taiichi Ohno, Toyota's chief engineer, recognized the following seven main wastes or *muda* within the production system (Liker, 2004) that can be identified in the construction industry:

1) **Overproduction**: producing ahead of demand, in quantities greater than the market needed.
2) **Idle time waste** (waiting time/queue time): waiting time between different stages in production that results in lost labor.
3) **Transporting/conveyance waste**: transporting of goods that can be avoided generated additional costs.
4) **Processing waste**: additional processing due to inefficient methods, tools results in more inputs than necessary to deliver needed outputs.
5) **Inventory waste**: unnecessary stock results in additional inventory costs.
6) **Wasted operator motion**: unnecessary movement of people or equipment results as non-productive time.

7) **Producing defecting goods**: defective production results in additional cost and effort put in reworks.

Table 10 Type of construction waste according to Koskela (1992), Weeleng (2004), and Abdel-Wahab et al. (1999)

Waste	Cost (total of project cost)	Country
Quality costs (non-conformance)	12% 30% 30%	US UK Australian
External quality cost (during facility use)	4%	Sweden
Lack of constructability	6-10%	US
Poor materials management	10-12%	US
Excess consumption of materials on site	10% on average	Sweden
NVA activities on site	Approx. 2/3 of total time	US
Lack of safety	6% 3-6%	US UK
Potential labour efficiency	40%	UK

All the above wastes exist in the construction industry. The construction industry suffers cost and time overruns, which are caused by current project management (Alsehaimi & Koskela, 2008). In 2004, the Construction Industry Institute (CII) published a report, comparing wasted time versus productive time in the manufacturing and construction industry. From the analysis, it has been demonstrated that 57% of time during the construction is waste (non-added value). In contrast, the production industry only has 12% of time waste (CII, 2004).

Beyond aforementioned seven *muda* of Ohno, Koskela (2004) introduced another category of waste in construction, so-called "making do". It describes "*a situation where a task is started without all its standard inputs, or the execution of the task is continued although the availability of at least one standards input has ceased*" Koskela (2004, p. 1). This term refers to all resources like materials, tools, machinery, people as well as instructions, documents and external conditions. According to Koskela, making do is a common phenomenon and this problem should be addressed to lean construction. Koskela (1992) has summarized lean thinking into eleven heuristic principles, Womack and Jones (1996) identified five principles of lean construction, which were focused on creation of value flow, achieving pull process at the right time and introducing the continuous improvement processes. The same approach was presented by Lean Enterprise Institute (2009) and Bashir et al. (2011). However, they called these five elements differently. Lean principles identified by Koskela (1992), Womack and Jones (1996) and Bashir et al. (2011) and Lean Enterprise Institute (2009) are presented in Table 11. This table is cited from Marhani et al. (2012).

Table 11 Lean construction principles according to Koskela (1992), Womack and Jones (1996), Bashir et al. (2011), and Lean Enterprise Institute (2009)

Author(s)	Lean Construction principles
Koskela (1992)	1) Reduce the share of non value-adding activities (so-called waste) 2) Increase output value through systematic consideration of customer requirements 3) Reduce variability 4) Reduce cycle times 5) Simplify by minimizing the number of steps, parts and linkages 6) Increase output flexibility 7) Increase process transparency 8) Focus control on the complete process 9) Build continuous improvement into the process 10) Balance flow improvement with conversion improvement 11) Benchmark
Womack and Jones (1996) and Bashir et al. (2011).	1) Specify value 2) Identify the value stream 3) Flow 4) Pull 5) Pursue perfection
Lean Enterprise Institute (2009)	1) Identify value 2) Map the value stream 3) Create flow 4) Establish pull 5) Seek perfection

Lean Construction is a potential solution towards construction management problems. Lean construction techniques can be used to design production (construction) systems to minimize waste of materials, time, and effort in order to achieve the highest value (Koskela et al., 2002). Lean construction is a management approach based on principles of the Toyota Production System, which has been adopted by the construction industry. It focuses on removing waste, creating value for the customer, and continuous improvement (Sacks et al., 2010). Lean construction emerged in the mid-1990's as a new concept of the construction management. construction. Construction projects are highly labour intensive with basic hand tools and equipment. Organisations have found that, by identifying and removing waste, as well as implementing key lean tools, they can continuously improve their productivity, increase quality, and become more cost effective.

The are many lean methods, which can improve the process. One of such method is **Value Stream Mapping (VSM)**. The Value Stream is a methodology that comes from the manufacturing sector and it is used to map the production process within a factory. However, it can be easily adopted to the construction sector. VSM is used to map the current construction process and reduce non value-adding

activities and time wastes during each construction stage. VSM provides a common language for process owners to identify the current process and process deficiencies as well as to improve it. The main steps of VSM are as follows:

1) **Preparation:** identification of the process to be mapped mapping team.
2) **Current state map**: all the data for current state map are collected based on current practices and experience of stakeholders involved in the studied process.
3) **Future state map**: after analyzing current state map, the waste areas are identified, and some corrective changes are proposed.
4) **Planning and implementation:** development of an action plan to achieve future state map and implement

This methodology illustrates on in A3 sized layout the construction process, business process, delivery process, as well as resources, material flows and information flows. An example is showed in Figure 9. The modelling of construction value stream is based on six basic elements, which are as follows:

1) **Construction Process** stands for construction activities on site referred to a specific construction work (e.g., window replacement);
2) **Business Process** describes commitments of a construction company as well as other involved stakeholders (e.g., architect) including executive design, material purchasing, construction management and quality control;
3) **Material Flow** is the movement of materials between supplier and the construction site;
4) **Information Flow** stands for the transmission of data and documents between individual business processes and towards construction processes;
5) **Customer** reflects the customer demand that should be met by the construction company (e.g., window replacement);
6) **Supplier** represents the material and component supply (e.g., window manufacturer).

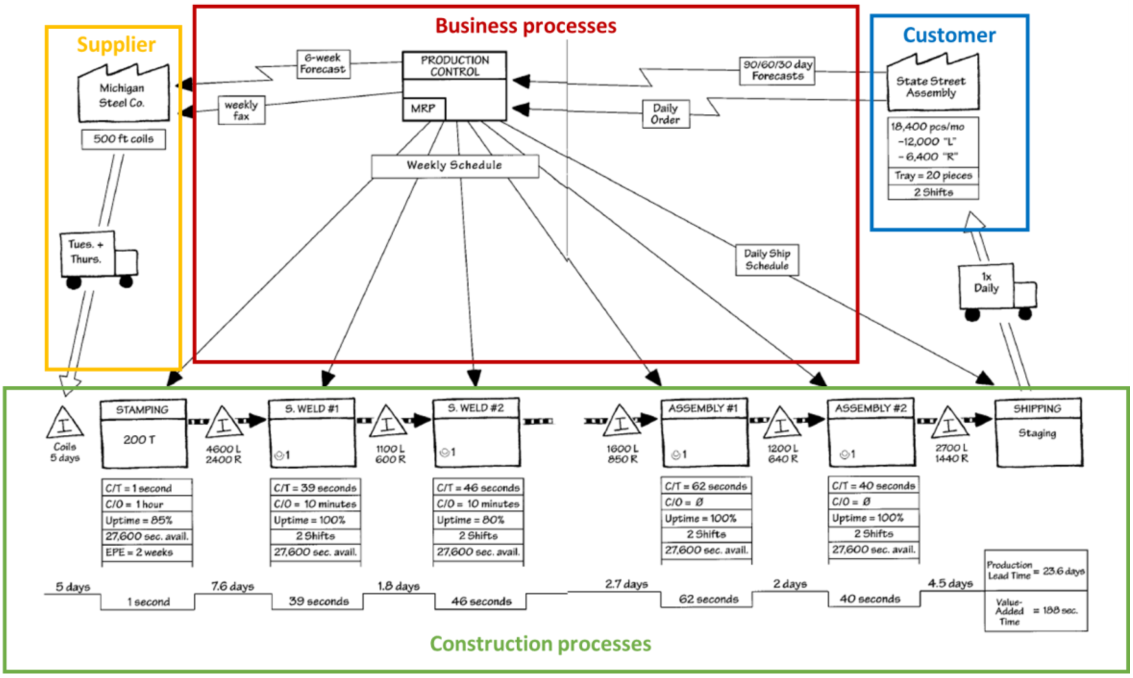


Figure 9 Example of VSM with mapped processes of a product production.

Business and construction processes

The value stream methodology is using several symbols to define working processes that should be performed to create a product, construct, etc. Generally, one has to distinguish between physically applied work that is directly adding value to a product and supporting processes. Supporting processes during the construction phase can consist of purchasing processes (orange boxes) or quality checks (violet boxes). These activities are normally not supposed to add direct value to the desired product but are necessary for the completion of the customer demand (e.g. window replacement). In the context of construction domain, the customer demand can be defined as, for example, replacement of 40 windows in a building. However, from the lean management perspective, these supporting activities have to be shortened and become as efficient as possible to minimize waste along the construction process. In this case such waste is usually defined as waiting time. The value-adding processes (where physical work is applied) are illustrated as green boxes and defined as construction activities. Moreover, both construction activities and supporting processes are described by parameters like operation time (OT) or productivity per item (P), number of item (#I) and information related to needed documents, materials, equipment, verification checklists, etc. Moreover, the sequence of activities (workflow) should have a start and end date (in the context of the project schedule) and relationship between activities should be defined (e.g. start to end). These data boxes are represented as tables below the actual activity they are associated to. Data boxes are followed by possible needed material box. The command line on-site during the construction phase is usually committed to the responsible site

manager. The site manager coordinates every material- and information flow, has the power to stop and trigger activities and represent the contact point for incoming and outgoing data regarding the process both in digital and paper-based ways. This construction controlling entity is pictured as an oval grey shape. A list of symbols used to describe processes are illustrated in Figure 10.

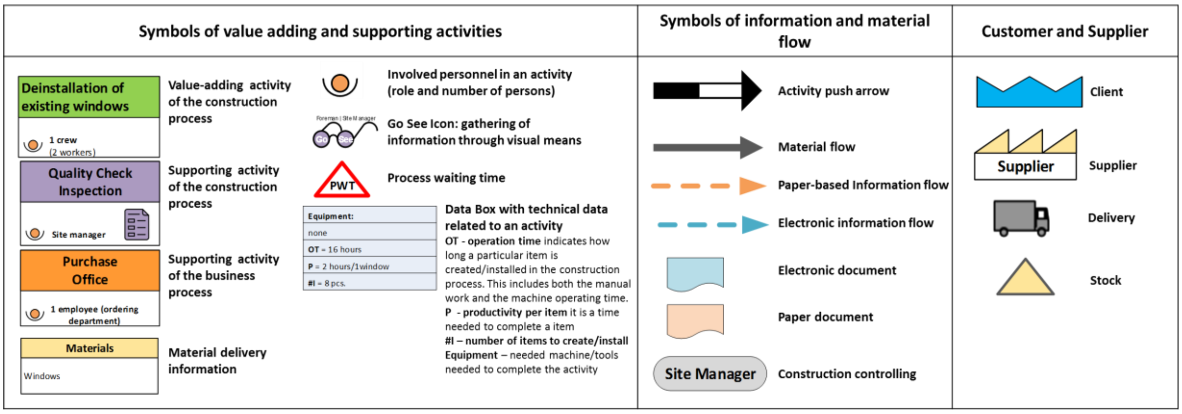


Figure 10 Symbols used to create VSM in the context of the construction site

Information and material flow

The above described activities need to be brought in a determined sequence for defining an explicit workflow to complete the customer demand (e.g. window replacement). Therefore, connectors between those activities are required. Connectors denominate the flow of both materials and information. Material flows are presented through a grey arrow, while dashed arrow indicates the flow of information, that can be subdivided into paper-based information flow (orange arrow) and electronic information flow (blue arrow). Key documents transmitted in this flow are pictured as sheet document icon of the respective colour (orange or blue). Moreover, there is an arrow, so-called activity push arrow, which represents the "pushing" of material from one activity to the next activity. A list of symbols used to describe material and information flow are illustrated in Figure 10.

Customer and supplier

Special symbols are assigned to customer (client) and supplier. The customer – according to pull principles – has to be understood as initial point for every action taken among the predecessor activities. Along with that, the customer defines the demand of the particular product in terms of quantity, time and properties. Therefore, the customer provides requirements for the whole production process. In the context of the construction industry, the customer will be the construction company that performs renovation works on a building.

Delivery processes from a supplier to the construction site by any type of transport system are indicated by truck icon and can be provided with additional information such as delivery times, tact definitions

and/or routines. Deliveries can be carried out directly to the construction site or stocks/warehouses. The stocks/warehouses are presented by yellow triangle with information regarding the maximum stock size or costs. A list of symbols used to describe customer and supplier are illustrated in Figure 10.

4.1.2 How the VSM can be used in PWMA tool?

The information collected from pilot site partners (construction companies) by means of VSM can help technological partners (IT developers) to understand construction process and collect user requirements in the context of the construction process. VSM helps in defining standardized workflows related to the construction works that can be used in PWMA tool. Using VSM for a specific construction work, it can provide the following information to the technological partners:

- Definition of workflow, composed of construction activities referred to a specific construction task;
- Parameters needed to describe a construction activity;
- Resources and materials needed to perform a specific construction task (workflow);
- Quality procedures linked to the workflow;
- Relationship between different stakeholders;
- Data/documents exchanged between different stakeholders.

As an example of a construction task – window replacement is provided to show how the construction process can be mapped using VSM. This process is presented in Figure 12.

The process starts with the **Client** (Construction company), who defines the quantity of work and time frame of its execution. The **Construction Control** coordinates all activities needed to complete the task within the time and budget. Construction Control is managed by a site manager. Firstly, the site manager orders to make a purchase of the defined quantity of windows and windowsills. The **Purchase Office** sends to a supplier a window and windowsill schedule with an order request. Based on this document, the **supplier** produces windows and windowsills, which will be delivered on the construction site according to the agreed delivery time. Usually, just in time (JIT) delivery is preferable in order to avoid any issues and costs related to a storage. The site manager is starting with **construction activities** (workflow), which are presented as green boxes. The following information are defined for each activity:

- Number of human resources (number of workers) needed to complete the activity;
- Equipment: machinery/tools needed to execute a construction tasks;
- Time needed to install one item (e.g. one window);
- Number of items to install (e.g. number of windows to replace)

- Overall time needed to complete the activity (e.g. installation of all windows)

This information presents a baseline data of the construction process. If the construction process is monitored, this data can be used to be compared with real data and calculate KPIs related to the up to date process status and progress.

Moreover, the sequence of activities should have a start and end date (in the context of the project schedule) and relationship between activities should be defined as well (e.g., start to end). The delivery of specific materials to the activity is described in Material Box. Considering a standard window replacement process (removal of current windows and installation of new windows), the following process has been mapped as shown in Figure 11. At the end of the process, there is a supporting activity related to the quality check of construction activities. Usually it is documented by an inspection report done by the site manager and/or supplier. The process can vary based on the installation procedures of a specific product.

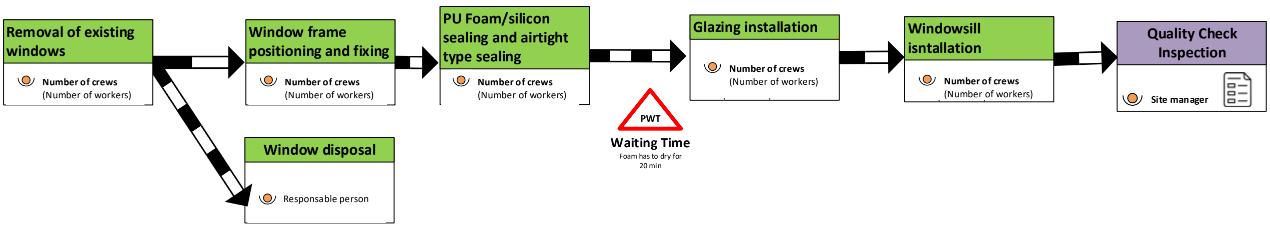


Figure 11 Sequence of construction activities related to the window replacement task

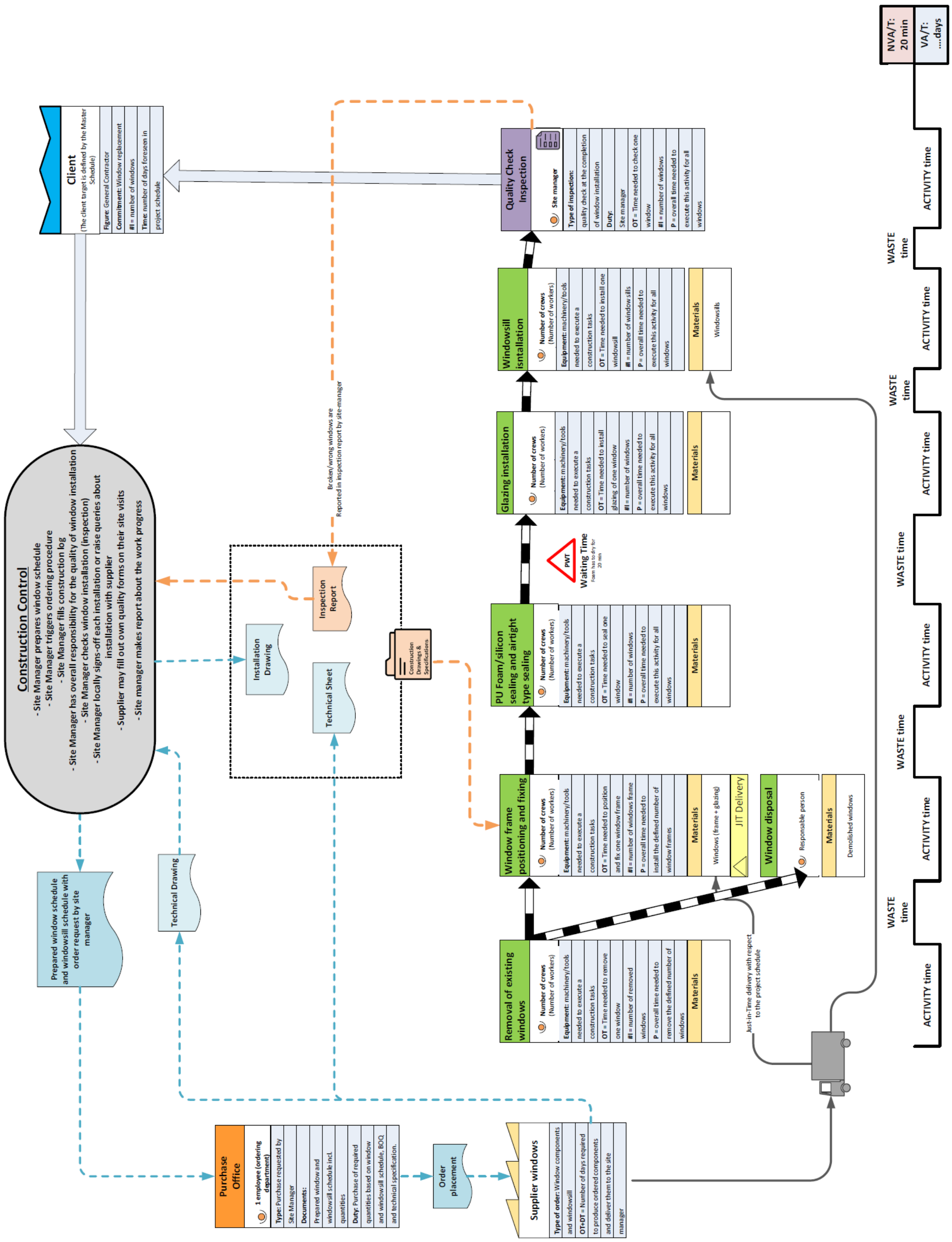


Figure 12 VSM of the window replacement process on the construction site

4.2 EXISTING TOOL SUPPORT

Table 12 List of Existing Tools and their Properties

Functionalities	MS Project Professional	Autodesk ® BIM 360 Build™	Autodesk ® BIM 360 Plan™	Visi Lean	Synapcus	IPM project management software	Orocon
Work planning	✓	✓	✓	✓	✓	✓	✓
Task list related to locations		✓	✓	✓			
Quality Checklists linked to tasks		✓		✓			✓
Construction progress and performance tracking	✓	✓	✓	✓	✓	✓	✓
Construction progress and performance reporting (dashboard)	✓	✓	✓	✓	✓	✓	✓
Mobile app		✓	✓			✓	
Resource management	✓				✓	✓	
Finance management	✓	✓			✓	✓	✓

4.2.1 MS Microsoft Project Professional

Microsoft Project is web-based, SaaS, hosted on-premises, proprietary software- cloud source software.

It is a specialized, advanced and very popular system offering clear tools for planning activities, building schedules, supervising the implementation of projects and reports. Main features are focused on task scheduling and identification and allocation of resources (people, material, and machines, etc.) to tasks.

It deals with project implementation control, work progress managing and KPI monitoring.

To manage projects in the most effective way, it is integrated with Microsoft Office package such as Microsoft Outlook and Microsoft Excel.

Project creates budgets based on work assignments and resource rates (people, equipment and materials) are used to calculate resource assignment costs which are rolled up and summarized at the resource level. Each resource can have its own calendar (with defined days and shifts when resource is available)

and can also be assigned to multiple tasks in multiple plans and each task can be assigned to multiple resources.

Additionally, Microsoft Project can recognize different classes of users and differing access levels to project data.

4.2.2 Autodesk® BIM 360™ Build

Autodesk® BIM 360™ Build is a cloud-based field and project management tool combining a mobile application at the construction site with collaboration and reporting about schedule and tasks helping at the same time to deal with work planning.

It is an integrated field and project management tool that allows users to get instant (offline and online) project updates both in the office and in the field for different stakeholders depending on permissions by user, role in the project and company.

This service enables entirely new ways of managing field processes having quality control programs, safety management and features commissioning checklists, status tracking and safety reporting. Furthermore, it helps with distributing plans, accessing 2D drawings and BIM models, reducing time, rework, and at the same moment, improving quality and safety. It has many additional features such as tracking not only tasks and performance but also equipment and assets.

4.2.3 Autodesk® BIM 360 Plan™

BIM 360 Plan is designed as a cloud-based software version of the sticky note planning process that helps construction teams develop work plans by following Lean Construction principles such as the Last Planner System™.

As a cloud service, BIM 360 Plan enables to engage project stakeholders, to access and update schedules and tasks. It very similar solution to **Autodesk® BIM 360™ Build**, but main difference is rather work planning and updating between members of the construction team with track performance.

A short producers movie about the program: https://www.youtube.com/watch?v=6M3m9trgrtQ

4.2.4 VisiLean

VisiLean is a cloud & web based and mobile app for the construction management service that offers a direct integration of the collaborative planning and workflow controlling using BIM 3D and 4D functionality. It offers a real time sharing of information.

This solution is based on a lean construction and visual management approach to achieve significant efficiency savings, improve decision-making and clash-free construction delivery by enhancing individual and team productivity.

VisiLean provides specifically designed modules that support the whole production, considering short-time and long-time planning.

VisiLean enables real-time tracking of these plans through mobile apps and execution views, where crews can report progress data and attach photos, and notes.

4.2.5 Synapcus

Synapcus as a producer claim - "Synap-se with your Cus-tomers", is a web-based enterprise software (ERP) developed specifically for architectural offices, construction companies and real estate developers as well. It consists of six main modules helping in seamless communication, customer relationship management, project management, human resource management and all these modules are integrated in cloud environment.

The Synapcus web-platform allows all participants access to information based on different specific rights, sends notification whenever the situation in a project runs out of control, which greatly aids the successful completion of projects by contract management and supplier evaluation, resource planning, budget and time tracking and risk management.

4.2.6 IPM Project Management Software for Construction

IPM Project Management Software for Construction powered by Microsoft Dynamics with a native interface of Microsoft Outlook which delivers a 360 degree real-time view of projects, job tasks and operations – combined with extensive reporting, tracking activity with subcontractors, business partners.

Main features of this solution is milestone tracking, resource management and financial information, managing change requests and change orders, contracts, submittals, resources, timesheets, job tasks and its progress billing and invoice generation, purchase order (PO) creation and maintenance, creation of approval workflows, subcontracts and subcontract variations, and jobs setup and budgets.

The Microsoft Dynamics® environment is employed by IPM to ensure access to people and company data to support and enhance project management features. IPM provides full CRM functionality, using contact information to support the document, document control capabilities and contract control process with issue and defect recording, job checklists, site instructions, and notice of delay creation.

4.2.7 Orocon

OROCON is a construction site project management software used to reduce construction operational problem, and coordinate actions across a growing network of subcontractors, planning, tasks, drawings, finance. OROCON's solution gives project overview that provides on-site data collection and accurate predictive analytics and forecasting. It allows users to manage and control tasks along with their progress. The most important elements are, above all, the possibility of creating tasks for subcontractors and accounting for their work based on completed tasks. In addition, they also have the option of extending documents and building a knowledge base. Moreover, it can integrate with our solutions or be a source of data for our solutions.

5. PWMA Tool Architecture and Responsibilities

This section presents the architecture of the tools/components that make up the PWMA Toolkit based on (1) the stories of users interacting with the PWMA Toolkit and corresponding requirements from the renovation process elaboration as told in Section 3, (2) the overall architecture of the BIMERR system as a result of T3.5, and (3) to some extent the best practice models of the renovation process and existing tools from Section 4. The information exchange between these tools/components is described. As a result, the different responsibilities for all the tools/components are identified.

5.1 Architecture

We introduce the Innovation Laboratory as a concept to support the extraction of knowledge about energy-efficient building renovation processes (Walch, Utz, & Woitsch, 2019). It is illustrated by Figure 13 based on the foundation of how to conceptualize and operationalize models and modelling methods according to (Bork, Buchmann, Karagiannis, Lee, & Miron, 2019).

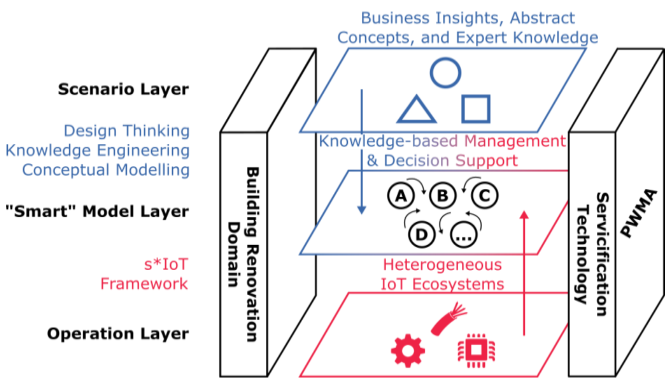


Figure 13 The Innovation Laboratory to Support Process Modelling

Figure 13 presents three layers. On the scenario layer, the focus is on human expertise, collaboration, and the design and knowledge captured in the heads of people. On the "smart" model layer, bridging opportunities between the decomposed scenario layer and the abstracted operation layer are provided. On the operation layer, different IoT enabled and end-user devices provide input for a digital twin of the real-world environment. These three layers are framed on the one hand by a domain, which implies domain-specific knowledge and on the other hand by ICT infrastructure providing tooling support on all three layers.

The three-layer concept is relevant for BIMERR, as it is influencing the PWMA Toolkit architecture. Correspondingly, the PWMA Toolkit must be able to decompose knowledge and design from the scenario layer. At the same time, it must be able to abstract from the operation layer. However, the core

focus of the PWMA Toolkit is on the middle layer, where a model-based approach is used for bridging, which results in a model-based digital twin of the renovation process design and operation.

The model-based approach is heavily influenced by concepts from IBPM as shown in Figure 14. IBPM translates the well-established business process management into the industry domain. The goal is to support industry during the planning of optimal processes, the adaptive execution and monitoring of processes in a real-world environment, and the reaction to experiences in the previous steps. Correspondingly, some core features of IBPM are the collaborative design of processes, simulation-based process analysis, process execution, process monitoring from micro and macro points of view, and process optimization by means of re-configuring and re-design. To support the approach, tooling support can be provided in form of a diagrammatic modelling environment providing two levels of interpretability: one for people engaged in design activities and one for automation in intelligent environments.

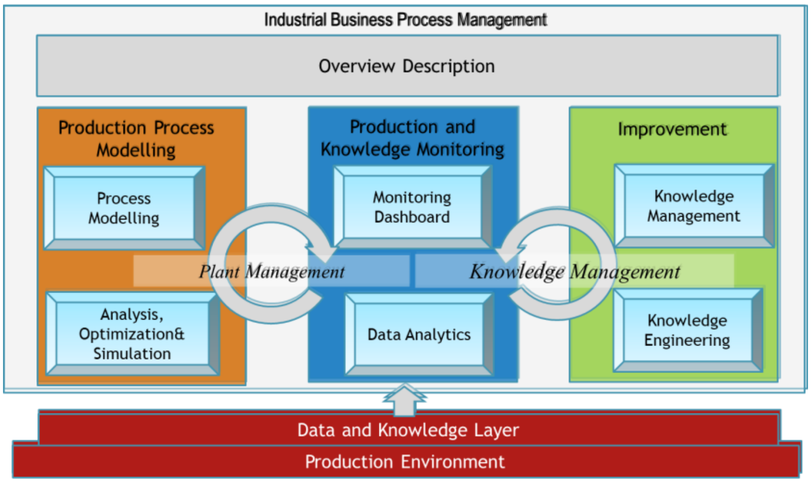


Figure 14 IBPM Elements

5.1.1 High-level conceptual Architecture of the PWMA Toolkit

As a result of applying the framework shown in Figure 13 and considering the success of IBPM illustrated in Figure 14, a high-level conceptual architecture emerges. The core of this architecture is a model-based approach that is supported by tangible ICT artifacts, i.e., the PWMA Toolkit. The model-based approach features two levels of interpretability: one for people engaged in design activities and one for (semi-)automated operation.

These two levels of interpretability are the architectural foundation of the PWMA Toolkit as shown in Figure 15. Correspondingly, two environments separate responsibilities of the PWMA Toolkit at an abstract level. In a Design Environment, the task is to capture the knowledge of experts in models and to employ models for providing experts with feedback that they can understand. In an Operation

Environment, the state of activities in the cyber-physical world that corresponding to a designed model are managed and monitored including the flow of information, tasks, and events. BOC and NT provide tools for the two environments, where each tool can be extended, configured, and consists of many components. The information exchange between these tools/components and their specification is described in the following sections.

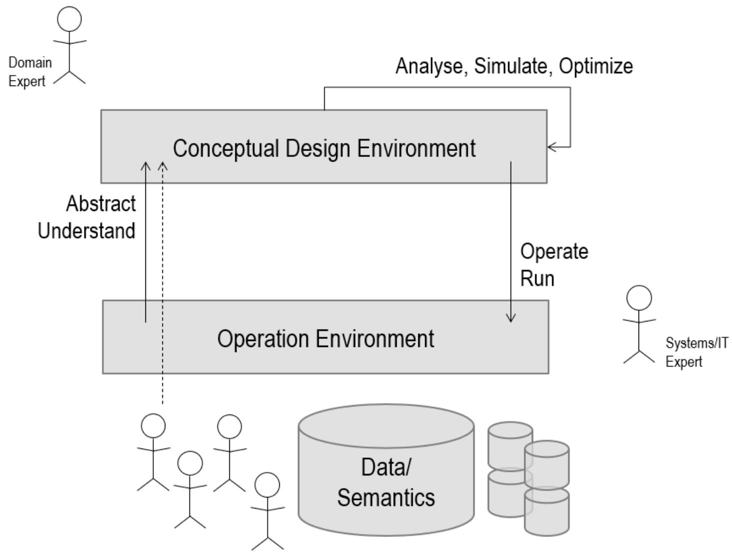


Figure 15 Two Levels of Interpretability of the Renovation Process

Generally, decisions that are made in the Design Environment propagate to the Operation Environment but are also influenced by feedback from the Operation Environment. This design-execution feedback loop is a source of complexity. Knowledge-based decision support is an approach to mitigate this complexity.

The potential to realize comprehensive decision support for the renovation process requires an extension to - or refinement of the two environments. Thereby, the goal is to employ smart model-based processing functionality to improve the performance of all stakeholders in the renovation process. From an architectural point of view, this means to structure components for

- Modelling: Components are required realizing (1) human-computer interfaces for different channels to interact with users, (2) (hybrid) modelling methods to design and formalize the renovation process, and (3) processing capabilities to formally verify and simulate models.
- Allocation: Once execution-invariant models of the renovation process are formalized, it is necessary to refine them and to assign resources representing an actual renovation project context. Semantic alignment components are responsible for relating the model information to project-specific information sources that are often heterogeneous in nature.

- Execution: To turn the designed model into actions performed in the real cyber-physical space of a renovation project, a transfer of information from the Design Environment to the Operation Environment is necessary. Thereby, model standardization enables tool modularization. As a consequence, workflow engines are able to import standardized models from the Design Environment, adapt them as necessary for execution providers, and log the behavior of model execution.
- Monitoring: Monitoring provides users with information feedback. Semantic data aggregation, data abstraction via knowledge discovery, and analytical engines take execution logs, models, and IoT and other data as an input.
- Evaluation: The monitoring output is stored in a semantic repository for further evaluation. Evaluation can require human action but can also be supported and automated by intelligent algorithms. Likewise, neural-network enabled deep dashboards can detect anomalies in status reports and KPI behavior automatically, rule-based systems can react to evaluation results with immediate corrective measures, and pattern analysis can produce insights for knowledge bases.
- Learning: Evaluation results enable another type of components responsible for long-term improvement. Actual process execution results are combined with knowledge bases containing simulation parameters, enabling long-term improvements in simulation prediction reliability at design time. Collective attributes enable the integration of expert knowledge and self-learning.

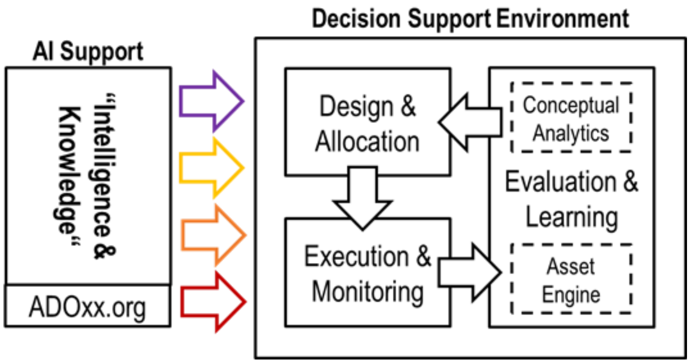


Figure 16 Utilizing AI for Decision Support

An initial abstract structure for the components of the PWMA Toolkit is presented in Figure 16. On the right of Figure 16, the high-level overall structure of components realizing knowledge-based decision support for IBPM and the information flow between them can be seen. The idea is to have a dedicated component in the PWMA Toolkit architecture, as seen on the left of Figure 16, which can be enriched with external – possible intelleigent – Microservices that are integrated

Different items of different type could be provided by the AI innovation shop/marketplace. Examples for data & knowledge assets are domain-specific ontologies, rule-bases for expert-systems, and neural

network models & training data. AI enabled microservices can provide capabilities for agent communication & negotiation, semantic data analytics, inference & reasoning, image classification, and natural language processing. Innovation items can include next to AI solution hosting packages & SLAs, handbooks, and training materials. Intelligent products are then the modular composition of the previous resources as a package to be integrated with the other components of the PWMA toolkit while considering also the benefit of such an integration from a business perspective.

5.1.2 Ideal Technical Architecture of the PWMA Toolkit

Figure 17 shows a more detailed look on the architecture of the PWMA Toolkit based on the ideas of knowledge-based decision support for IBPM. One can identify the conceptual elements from Section 5.1.1 at a higher level of detail. Likewise, components realizing the Design and Operation Environment are shown. The Modelling Component enables experts to model the renovation process and to simulate various parameters based on an underlying knowledge base. Information flows from the modelling to the Execution Component, where processes are decomposed and executed in different run-time environments. The output from the Execution Component, data from the run-time environment, and other retrieved data is collected in the Evaluation Component, where it is aggregated and analyzed. This allows users to track the progress of processes and other KPIs in various dashboards. These results are compared against the expected values from design simulations in the Improvement Component. The results of this comparison are analyzed and corrective measures are initiated, which can mean to change current process designs in an agile manner or to evolve knowledge bases for long-term impact. Many of these components can benefit from integrating AI. While it is possible to implement AI technologies in the components themselves, the idea is to facilitate AI reusability in a dedicated AI innovation shop/marketplace. For the components in Figure 17, different TRLs can be expected as an output of the BIMERR project. In this regard, concrete responsibilities are listed in Section 0.

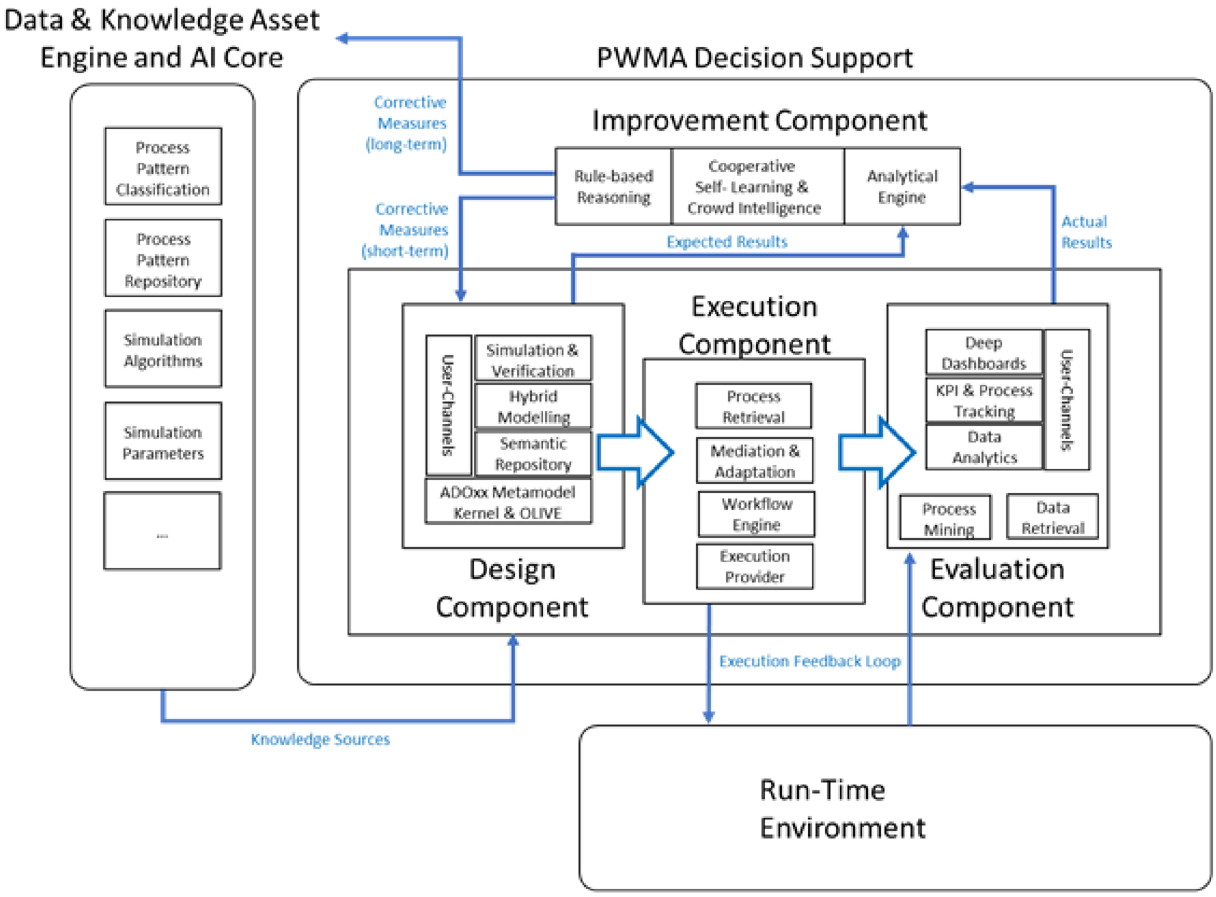


Figure 17 Component Overview of the PWMA Toolkit enabling Knowledge-based Decision Support

The PWMA Toolkit relies on the architecture shown in Figure 17. It provides as an entrance point a platform, from which other tools/components can be accessed. An end-user of the PWMA Toolkit has in this platform the option to enter four core components for modelling, execution, evaluation, and improvement. A Data & Knowledge Asset Engine, as well as an AI core, innovation shop, and marketplace have a supporting role for the four components.

5.1.2.1 DESIGN ENVIRONMENT

The Design Environment is realized mostly by BOC as a Modelling Component, an Evaluation Component, and an Improvement Component. The Modelling Component can be used to design processes and to analyze, simulate, and optimize their expected behavior. The Evaluation Component can be used to track at multiple levels the actual performance of the processes executed in the real world. The Improvement Component can be used to research the difference between expected and actual process behavior, based on which it is possible to produce technical and organizational reactions.

The Modelling Component provides interfaces for end-users to formalize their processes. Web- speech-, and app-based modelling interfaces are provided. The users and their models are managed in a repository. Reports and exports can be created in different formats. All this is enabled by a modelling method definition that is specified on the metamodel-level and executed on a metamodel kernel. A semantic alignment kernel enables modelling method hybridization. This hybridization allows the seamless integration of an executable workflow modeler in the Modelling Component. APIs at different levels provide interfaces to the Modelling Component. One noteworthy example is the capability to export processes in the BPMN DI format to the Data and Knowledge Asset Engine and to make these exports accessible to the BIMERR Interoperability Framework through interoperability wrappers. These BPMN DI exports can be retrieved in the Operation Environment directly from the Data and Knowledge Asset Engine.

The Modelling Component supports custom modelling extensions. A first extension in the BIMERR context is a module for verification. This module formally verifies processes and checks readiness levels for, e.g., whether a process can be simulated, executed, or mined. A second extension is provided by different simulation modules. Knowledge-based simulation modules can be employed to explore domain-specific design alternatives, e.g., a knowledge base of subcontractors could be used in the BIMERR context to find optimal solutions by simulating different renovation price and duration alternatives. Another option is to use process log-based simulation, which can help to predict the behavior of process patterns based on past executions. The readiness checks support model processing by providing information to end-users about what actions they must take to enable, e.g., process simulation, execution, and mining.

The Evaluation Component enables end-users to monitor the behavior of executed processes and to keep track of KPIs that they defined. Hybrid dashboards display information at different aggregation levels, which relies on an analytical engine running in the background. The analytical engine feeds the dashboards with the necessary information based on data retrieved from the Operation Environment through the Data and Knowledge Asset Engine which also accesses the BIMERR Interoperability Framework. A semantic repository supports the analytical engine by providing inference capabilities based on the fusion of data and knowledge resources.

The Improvement Component is fed with real-world execution results from the analytical engine in the Evaluation Component and with expected behaviors based on simulation results from the Modelling Component. Pattern and data analysis are applied to understand possible reasons for deviations. Reactions to possible deviations are possible due to suggested actions from rule-based decision support in which expert knowledge is employed. Alternatively, machine learning can be used to classify problematic deviations, based on which corrective actions can be triggered automatically. Collaborative attributes enable a combination and alignment of corrective actions that originate from expert knowledge and from machine learning.

5.1.2.2 OPERATION ENVIRONMENT

The Operation Environment links the Execution Component to a Run-time Environment. The Execution Component retrieves the processes and their tasks to be executed from the Data and Knowledge Asset Engine. These processes include start dates to enable the initial scheduling of actions corresponding to a task. Therefore, the process mediator turns the process into executable form, which usually has to be adapted to the specifications of the execution provider engine. The execution provider engine has interfaces to the Run-time Environments of connected systems, e.g., the smart glasses, end-user apps, and logging services. A supporting user workspace allows end-users to make final changes. The monitoring engine allows for the direct tracking of workflow statuses and reactions to them. APIs at different levels of the Execution Component enable automation. One example is a continuous BPMN DI export in which the execution status of processes is stored. These exports can be accessed via the Data and Knowledge Asset Engine.

5.1.2.3 DATA & KNOWLEDGE ASSET ENGINE AND AI CORE

The Data and Knowledge Asset Engine manages the data and knowledge resources of the PWMA Toolkit. It also relies on collecting data from IoT sensors and process logs, on integrating open data and knowledge, and on linking relevant data and knowledge sources from the BIMERR Interoperability Framework. The Data and Knowledge Asset Engine also provides resources to the BIMERR Interoperability Framework upon request.

Like the Data and Knowledge Asset Engine, the AI core has a supporting role for the PWMA Toolkit. It is a centralized component that provides the capabilities of intelligent products from the AI innovation shop and marketplace for the PWMA Toolkit. Of course, it is also possible that components in other ways integrate AI innovation and exploitation items from the AI innovation shop and marketplace.

5.1.2.4 AI INNOVATION SHOP AND MARKETPLACE

As previously mentioned, the AI Innovation Shop and Marketplace provides a central repository of resources associated with AI at different levels of maturity. These resources can be used in the BIMERR project and by the PWMA Toolkit. Thereby, the main idea is to facilitate reuse of different AI aspects. The structure proposed for different AI resources is to group data and knowledge assets that fuel AI capabilities, (micro-)services that provide AI capabilities, innovation items that go beyond capability provision, and intelligent products that integrate a selection of different AI resources for a specific purpose.

5.2 Information Exchange

The PWMA Toolkit exchanges information with the rest of the BIMERR system and within the tools/components of the PWMA Toolkit. Therefore, this section first illustrates the information roundtrip within the PWMA Toolkit. Afterwards, the information exchange with the rest of the BIMERR system is briefly stressed. Further information on the latter part can be found in the results of T3.5.

5.2.1 Information Exchange within the PWMA Toolkit

Standardized interface formats exist for the information exchange between the Design and the Operation Environment. For example, BPEL, XPDL, and BPMN DI can be employed by different tools/components that focus on process and workflow modelling. The general approach is that a domain specific modelling method is mapped to a modelling standard or that direct modelling in a modelling standard takes place. The resulting model is based on a standardized modelling method like BPMN and can be enriched with extensions. This enables export in standardized formats like BPMN DI which can be imported by different tools/components alike that again map the import to the domain-specific modelling method that they support.

The user story illustrating information exchange starts with domain, business, and process experts that model processes in a Design Environment. Their modelling focus is on fulfilling documentation requirements, creating a base for issuing work instructions, optimizing processes, audits, and so on. This results in a business graph that can be understood easily by those users. The business graph is transformed into an initial workflow graph by domain, business, and ICT experts. Elements from the business graph are decomposed based on standard notations like BPMN in the Design Environment. Elements from the process and workflow graph are selected for (semi-)automated execution. The results are exported to the Operation Environment for further decomposition and execution based on standards like BPMN DI. The result is an execution graph that is extended by execution parameters by ICT experts. However, the information can also flow in the opposite direction. Thereby, the aggregation of execution graphs containing execution reports is exported from the Operation Environment to the Design Environment based on standards like BPMN DI. Importing and further aggregating execution graphs in the Design Environment creates knowledge that is crucial when domain, business, and process experts have to make decisions. Together, the two directions of information flow result in an information roundtrip at different time scales.

Figure 18 shows the information roundtrip between the design and the Operation Environment for the process and workflow modelling case. (1) Processes are modelled from a management view. (2) These models are transformed into BPMN models. (3) An initial workflow model is created by selecting executable models, by further decomposing them, and by extending them with information necessary

for execution. (4) Initial workflow models are exported from the Design Environment to the Operation Environment based on BPMN DI. (5) The initial workflow models are extended into executable workflow models by adding additional details and further decomposition. The models are executed, and run-time feedback is collected. Initial feedback selection and aggregation is performed, and the results are reintegrated in the workflow models as execution reports. (6) The workflow models are exported in BPMN DI and aggregated again for import in the Design Environment where they are further processed.

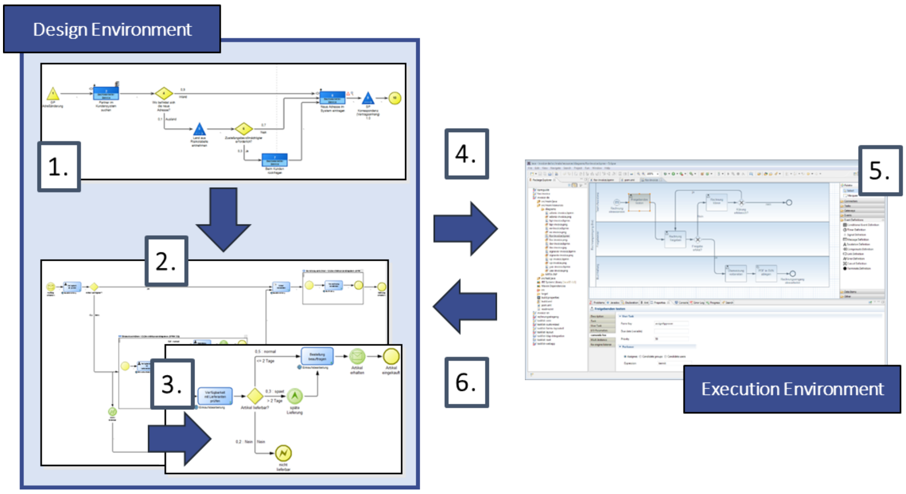


Figure 18 Information Roundtrip between the Design and Operation Environment

In addition to the information roundtrip based on standard formats, another way to collect execution reports exist. Thereby, the workflow engine issues execution orders like previously described, but in addition to the workflow engine collecting execution reports, log files are created in the run-time environment by the executing entities. These log files can be mined by process mining tools to create additional knowledge useful in the Execution and Design Environment.

In the context of the PWMA toolkit, the information roundtrip supports the following:

1. The high-level renovation process is modelled in a BIMERR-specific modelling language and further detailed in sub-processes including resources planned and information exchanged. The processes are optimized based on simulation results, from which an initial schedule (start date, duration) of sub processes emerges.
2. The models formulated in the BIMERR-specific modelling language are mapped automatically to the BPMN standard.
3. The tasks of all executable sub-processes are extended by information from the execution environment. This extension enables mapping in the Execution Environment of (a) tasks to actions that need to be precisely scheduled and executed, (b) planned resources to available resources, and (c) information exchange design to technical specifications.

4. The extended processes and sub-processes are exported in BPMN DI format from the Design Environment and imported in the Execution Environment.
5. Sub-processes are further decomposed by separating the involved tasks based on the swim lanes defined. Tasks are decomposed into actions to be performed. Actions are precisely scheduled based on available resources. The resulting workflow is executed based on technical details and systems available to the Execution Environment.
6. Status updates of the execution are collected and periodically exported from the Execution Environment in BPMN DI format. These exports are imported and aggregated in the Design Environment.

5.2.2 Information Exchange with other Toolkits in the BIMERR Context

The PWMA Toolkit is also linked to other toolkits in the BIMERR system. This link is realized by information exchange via the BIMERR Interoperability Framework, where the following information is exchanged:

- The PWMA Toolkit imports from RenoDSS the renovation measures to be performed. These planned renovation measures are needed to suggest to the renovation manager appropriate reference processes which can then be refined in the PWMA Toolkit.
- The PWMA Toolkit may import from RenoDSS KPIs that are defined for renovation measures. These KPIs can then be detailed from a process perspective in the PWMA Toolkit.
- Project level information is exported from the PWMA Toolkit for other tools to make use of.
- The KPIs defined in the PWMA toolkit are exported so that other tools like RenoDSS may make use of them.
- Execution status reports are exported by the PWMA Toolkit to enable insight of other tools into the actual renovation progress.
- For simulation, scheduling, and other smart capabilities, the PWMA Toolkit relies on data and knowledge imports from the renovation domain. For example, a task might be to replace 40 windows of a certain type. If a process including such a task is to be simulated, the duration of actions required to replace 40 windows has to be aggregated in a parameter of that task, which requires data to be queried from the BIMERR Interoperability Framework or other knowledge sources.

5.3 Responsibilities

This section looks at the ideal technical architecture from Section 5.1.2 and assigns responsibilities. Correspondingly, the requirements are fulfilled while additional components can also be produced but possibly at a lower TRL of the latter.

Based on the BIMERR project idea, the essential components from the architecture are (1) the Modelling Component in which the renovation process is modelled, verified, and simulated and (2) the Execution Component and run-time environment in which the modelled renovation process is decomposed for end-users and for automated systems to interact with in an adaptive manner. Components crystalized during requirement elicitation are: (1) the additional Evaluation Component that provides KPI and multi-level analysis capabilities to stakeholders concerned with monitoring the renovation process; (2) the Improvement Component that enables advanced process re-design and learning for future project iterations; and.

BOC provides existing foundations for components of the Design Environment through the ADOxx tools, NT provides existing foundations for components of the Operation Environment through the I3D tools, and NT, CERTH, and GU provide existing foundations and apps for end-user interaction (e.g., apps for workers) in the run-time environment.

The following tables provide an overview on the integration and interaction components required to realize the PWMA Toolkit based on the considerations above.

Table 13 Basic Model and Metamodel Processing

PWMA Functionality: Basic Model and Metamodel Processing	
Description	Generic backend support for a modelling method like model storage, manipulation & management, queries, and semantic lifting
Realized by architecture in Figure 17	Component Category • Design Environment (ADOxx Tools) Core Component • Modelling Component Sub-Components • Semantic Repository • Metamodel Kernel • OLIVE
Related Use Cases from D3.1	UC-05, UC-06, UC-07, UC-08

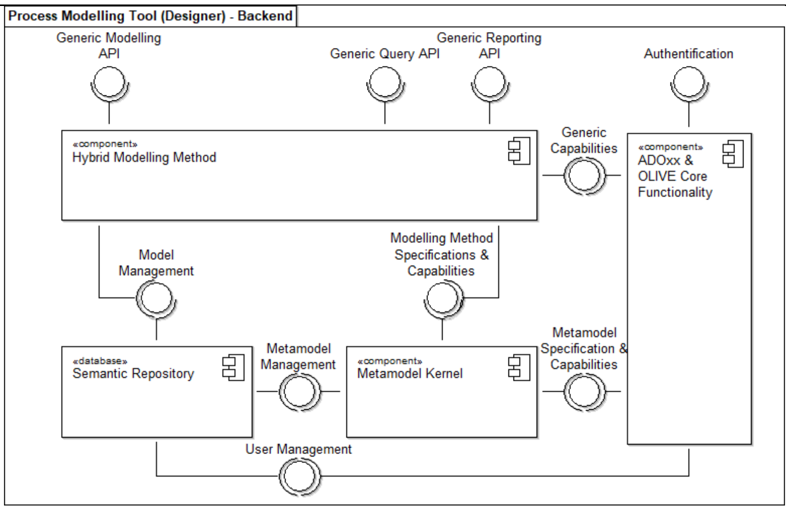
Functional Capabilities	Enables user management; creation, versioning, modification, and deletion of models and model elements; repository queries; standard model import and export; and standard report generation.
Access	Backend APIs for other PWMA components, not directly accessible for users • ADOxx CE Platform: Proprietary Message Port • ADOxx Industrial Platform: HTTP(S) API
Interactions	
Dependencies	none
License	ADOxx CE Platform (Designer): open use license (community version). ADOxx Industrial Platform: closed source license for commercial platform.
Deployment	Integrated in the BIMERR system • ADOxx CE Platform: Backend installed on server hardware, local installations of standalone client application • ADOxx Industrial Platform: Webserver software and backend installed on server hardware
Expected TRL	9
Responsible Partner	BOC

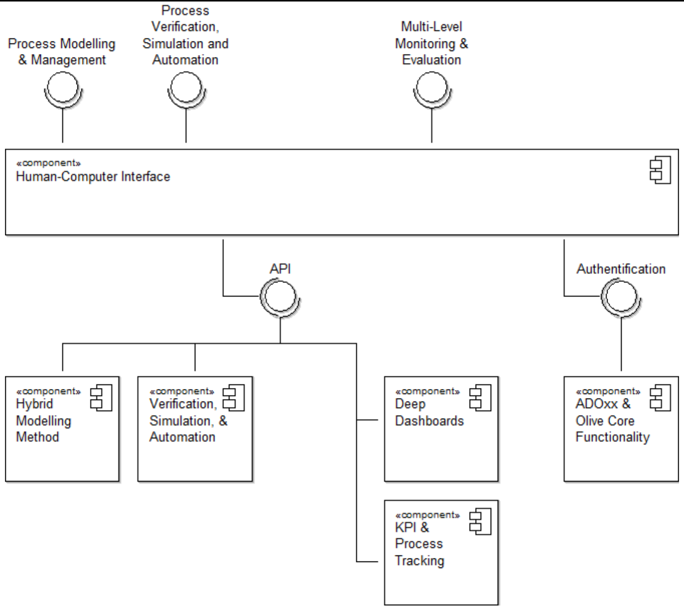
Table 14 Diagrammatic Metamodel Specification & Reference Model Repository

PWMA Functionality: Diagrammatic Metamodel Specification & Reference Model Repository	
Description	This part of the PWMA Toolkit is the specification of a modelling method on the meta level as discussed in Section 6.1.1. Reference models are designed using the modelling method and stored in a repository for reuse.

Realized by architecture in Figure 17	Component Category • Design Environment (ADOxx Tools) Core Component • Modelling Component Sub-Components • Semantic Repository • Metamodel Kernel
Related Use Cases from D3.1	UC-05, UC-06, UC-07, UC-08
Functional Capabilities	The metamodel specification of the modelling method defines a diagrammatic modelling language, modelling procedures, and mechanisms & algorithms. It enables a specification and extension of generic functionalities (e.g., model “drawing”) provided by the modelling component and the addition of specific functionalities.
Access	Metamodel read access via the Metamodel Kernel Metamodel write access vie proprietary metamodelling tool from BOC Repository read & write access via Model Management
Interactions	
Dependencies	Basic Model and Metamodel Processing
License	Open use
Deployment	The Diagrammatic Metamodel Specification & Reference Model Repository is deployed with Basic Model and Metamodel Processing
Expected TRL	7-8
Responsible Partner	BOC

Table 15 Design & Evaluation User Interface Provider

PWMA Functionality: Design & Evaluation User Interface Provider	
Description	End-users of the PWMA Toolkit interact with it on different channels. Standard user channels and corresponding human-computer interfaces are provided for Basic Model and Metamodel Processing. Extension and configuration of channels and interfaces is possible.
Realized by architecture in Figure 17	Component Category • Design Environment (ADOxx Tools) Core Component

	• Modelling Component • Evaluation Component Sub-Components • User Channels
Related Use Cases from D3.1	UC-05, UC-06, UC-07, UC-08, UC-9, UC-10
Functional Capabilities	Human-computer interfaces provide efficient and innovative process modelling and automation capabilities. Information from the backend is visualized and user input is translated to API calls.
Access	Human-computer interaction frontend of the PWMA Toolkit (design & Evaluation Component) • ADOxx CE Platform: Desktop Application, website provided via all modern web browsers • ADOxx Industrial Platform: Website provided via all modern web browsers
Interactions	
Dependencies	Basic Model and Metamodel Processing Diagrammatic Metamodel Specification Multi-Level Monitoring
License	ADOxx CE Platform (Designer, Dashboard): open use license (community version). ADOxx Industrial Platform: closed source license for commercial platform.
Deployment	Integrated in the BIMERR system

	• ADOxx CE Platform: Deployed in part with Basic Model and Metamodel Processing, websites deployed on webserver • ADOxx Industrial Platform: Micro frontends deployed on webserver
Expected TRL	7-9
Responsible Partner	BOC

Table 16 Verification, Simulation, and Automation

PWMA Functionality: Verification, Simulation, and Automation	
Description	Models of the renovation process can be improved during the planning phase by verification and simulation. Once models are optimized, they can be transformed and transferred to execution.
Realized by architecture in Figure 17	Component Category • Design Environment (ADOxx Tools) Core Component • Modelling Component Sub-Components • Verification & Simulation • Hybrid Modelling • Metamodel Kernel
Related Use Cases from D3.1	UC-05, UC-06
Functional Capabilities	Functional Capabilities for • generic verification and simulation capabilities of modelling methods • specific verification and simulation capabilities for the modelling method underlying the process modelling tools of the PWMA Toolkit • Information transfer from the Modelling Component to the Execution Component
Access	Interaction with End-Users via extension and configuration of the Design & Evaluation User Interface Provider • ADOxx CE Platform: Desktop Application • ADOxx Industrial Platform: Website provided via all modern web browsers

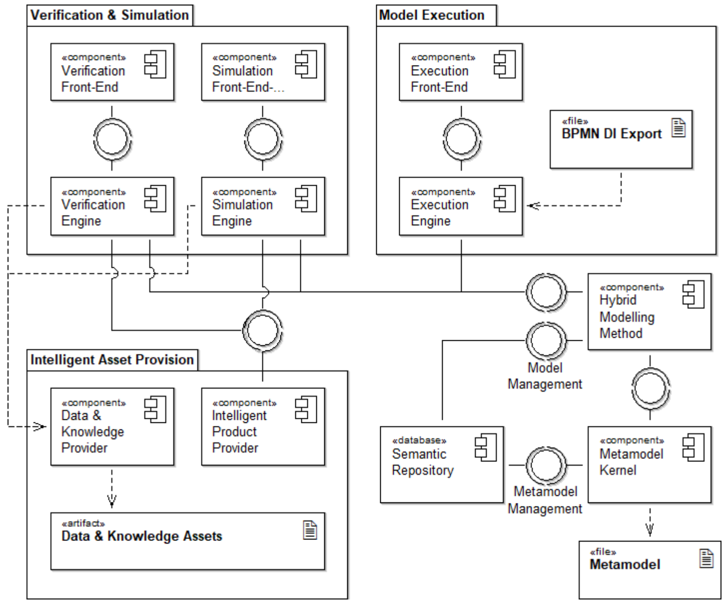
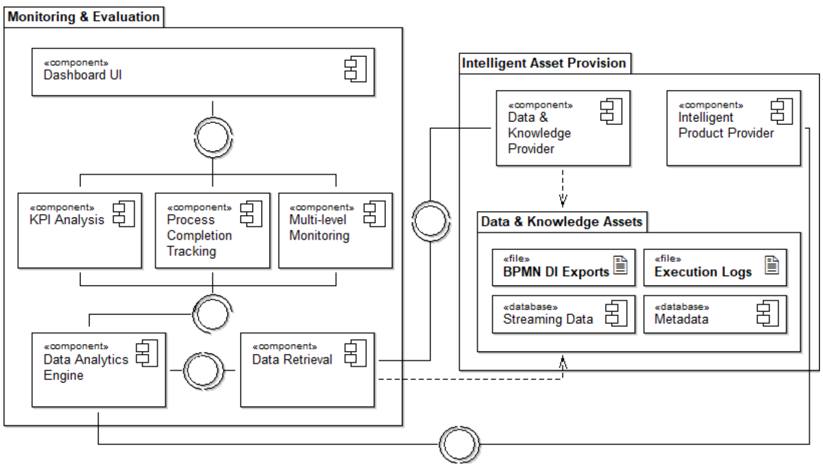
Interactions	
Dependencies	Basic Model and Metamodel Processing Diagrammatic Metamodel Specification Design & Evaluation User Interface Provider Intelligent Asset Provision
License	ADOxx CE Platform (Designer): open use license (community version). ADOxx Industrial Platform: closed source license for commercial platform.
Deployment	Integrated in the BIMERR system • ADOxx CE Platform: deployed in part with Basic Model and Metamodel Processing • ADOxx Industrial Platform: Microservices and Micro frontends deployed on webserver
Expected TRL	7-8
Responsible Partner	BOC

Table 17 Multi-Level Monitoring

PWMA Functionality: Multi-Level Monitoring	
Description	Keeping track of progress in actual renovation projects is necessary at different levels of detail. Monitoring and evaluation are not only required close to the workflow execution level, but also from a process perspective. This enables tracking KPIs, process completion, and other criteria.

Realized by architecture in Figure 17	Component Category • Design Environment (ADOxx Tools) Core Component • Evaluation Component Sub-Components • Data Retrieval • Process Mining • Data Analytics • KPI & Process Tracking • Deep Dashboards
Related Use Cases from D3.1	UC-07, UC-09, UC-10
Functional Capabilities	Data collection from heterogeneous sources Data abstraction, semantic lifting, and knowledge discovery Visualization for decision preparation
Access	Interaction with End-Users via extension and configuration of the Design & Evaluation User Interface Provider • ADOxx CE & Industral Platform: Website provided via all modern web browsers
Interactions	
Dependencies	Design & Evaluation User Interface Provider Intelligent Asset Provision
License	ADOxx CE Platform (Dashboard): open use license (community version). ADOxx Industrial Platform: closed source license for commercial platform.
Deployment	• ADOxx CE Platform: Webservices and webpages deployed on a webserver

	• ADOxx Industrial Platform: Microservices and micro frontends deployed on a webserver
Expected TRL	7
Responsible Partner	BOC

Table 18 Workflow Import, Mapping to Actions & Resources, and Scheduling

PWMA Functionality: Workflow Import, Mapping to Actions & Resources, and Scheduling	
Description	Design-time functionality required to enable workflow execution
Realized by architecture in Figure 17	Component Category • Operation Environment (I3D Tools) Core Component • Execution Component Sub-Components • Process Retrieval & Decomposition • Resource Allocation & Scheduling • Workflow Management and User Interface • Workflow Engine
Related Use Cases from D3.1	UC-06, UC-08
Functional Capabilities	• Definition of renovation actions • Import of renovation processes and sub-processes • Decomposition of renovation processes and sub-processes including tasks in swimlanes into workflows • Mapping of workflow tasks to renovation actions, assigning of resources to actions • Scheduling of renovation actions • Workflow management • User interface
Access	Website provided via all modern web browsers

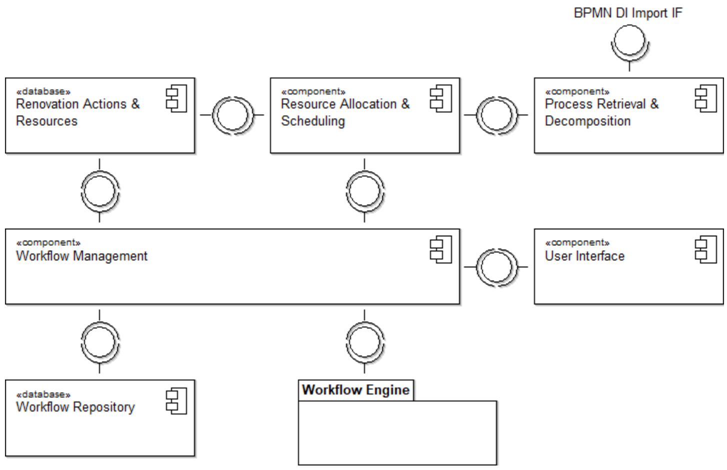
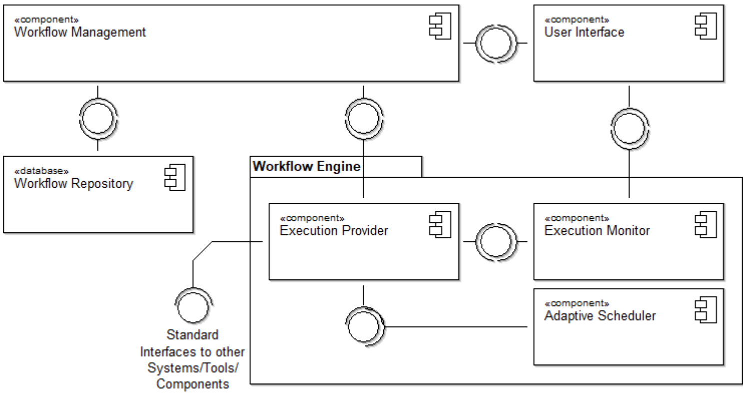
Interactions	
Dependencies	None, but a correct export of renovation processes by *PWMA Functionality: Basic Model and Metamodel Processing* is required including the initial schedule; provided via *PWMA Functionality: Intelligent Asset Provision*
License	Closed source license
Deployment	Webservices and webpages deployed on a webserver
Expected TRL	7-9
Responsible Partner	NT

Table 19 Workflow Execution, Monitoring, and Adaptive Rescheduling

PWMA Functionality: Workflow Execution, Monitoring, and Adaptive Rescheduling	
Description	After the workflow is assigned with resources and scheduled, it becomes possible to automate its execution. Therefore, an execution provider is be set up, technical details for the execution of actions are configured, and preconditions & blockers for the execution are specified. Finally, the workflow is executed, monitored, and rescheduled in an adaptive manner.
Realized by architecture in Figure 17	Component Category • Operation Environment (I3D Tools) Core Component • Execution Component Sub-Components • Execution Provider • Execution Monitor • Adaptive Scheduler • Workflow Management and User Interface

Related Use Cases from D3.1	UC-06, UC-08, UC-09
Functional Capabilities	The execution provider manages the event bus corresponding to a workflow coming from workflow management. Its sends and receives messages from other tools using standards. The execution monitor provides insights into the status of the workflow execution. When problems occur during execution, actions are rescheduled.
Access	I3D Platform - Website provided via all modern web browsers
Interactions	
Dependencies	Workflow Import, Mapping to Actions & Resources, and Scheduling
License	Closed source license
Deployment	Webservices and webpages deployed on a webserver
Expected TRL	7-9
Responsible Partner	NT

6. PWMA Toolkit Specification

The PWMA Toolkit links several tools that aim to optimize the renovation process in terms of cost and time. It integrates bespoke tools for: i) the modelling of the process and the workflow, including necessary information exchange among stakeholders, ii) adaptive workflow management to orchestrate the renovation process by triggering activities, work-items and information exchanges, iii) an Augmented Reality enabled application for on-site guidance of construction workers and contractors, and iv) an application for the building residents that inform and alert them about aspects of the renovation they must be aware of (e.g. scheduling appointments with contractors, works progress, hazards in the building, etc.).

6.1 Tool Support for Renovation from a Process Perspective

One tool of the PWMA Toolkit is responsible for renovation process modelling, i.e., the design environment of the PWMA Toolkit. This tool employs a modelling method including a modelling language with graphical notation, which can be used to model holistically (a) high-level processes such as process maps, or SCOR I level equivalent processes, describing the intentions of activities (b) low-level processes in relation to organizational diagrams and renovation-related operations, describing the exact procedure of tasks (c) the technical layer consisting of wares, materials, systems, data and interfaces to other systems describing the operation. This modelling is the pre-condition to provide a common conceptual and semantic description, on which algorithms can be either directly applied – in case of human interpretation - or applied only after formalizing the models – in case of machine interpretation. The main goals of these algorithms are to:

- Support the generation of the simulation and optimization framework that includes the initial acquisition of the renovation process in a digital twin and the specification of intended answers of the simulation model.
- Semantically lift the relevant data analysis and data anomaly detection. Anomaly detection provides findings on possible anomalies, which are not interpretable without proper semantic; introducing more semantics can automate interpretation via machine learning. Sematic enrichment brought in by human-experts, enables their efficient and targeted interpretation.
- Facilitate Plan-Do-Check-Act cycles to systematically manage the contingency actions after decision making.
- Knowledge support for the decision making by first providing human-interpretable decision trees that are continuously transformed into automatic interpretable rules in order to generate a knowledge base for construction decision making.

6.1.1 *Meta Models as an Implementation approach*

The representation of the renovation process in conceptual models aims to capture relevant parts of the real world. The benefit of conceptual models is their simplified and formalized view on the real world that enables a focus on relevant aspects, thereby facilitating knowledge transfer and automation capabilities. Likewise, ICT-based support can be provided for conceptual models, e.g., for visualization, queries, simulation, and transformation. To support building conceptual models, a modelling method is specified on the meta level as a foundation for a modelling tool.

6.1.1.1 THE MODELLING METHOD

"Model" is a term with ambiguous meaning. Here, it is interpreted as discussed in the feasibility study of the Open Models Laboratory (Karagiannis, Grossmann, & Höfferer, 2008), where a model is a representation of either reality or vision (Whitten, Bentley, & Dittman, 2014) that is created for a certain purpose (OMG, 2014).

A subset of models are linguistic models that are based on a set of pre-defined descriptions. Conceptual models are a kind of linguistic models that enrich the pure textual models (such as mathematical formula) with diagrammatic notations. These pre-defined diagrammatic concepts with a specific meaning are used in order to (1) specify, (2) support execution, (3) represent knowledge or (4) evaluate the business and IT-alignment. As a consequence, conceptual models are useful for:

- Enabling structured approaches, specifying desired targets, reducing complexity, and facilitating participative modelling practices based on a common understanding (Whitman, Huff, & Presley, 1997).
- Supporting software implementation in a (semi-)automated manner like in the context of workflow orchestration or model-driven architecture. Likewise, this can be seen as models providing execution support (Kokol, 1993).
- Human interpretation and documentation tasks. Therefore, conceptual models offer benefits for knowledge management.
- Comparing the current as-is status against the targeted to-be goals.

A generic modelling method specification framework is proposed in (Karagiannis & Kühn, 2002). It is shown in Figure 19. The framework identifies all relevant parts that need to be considered for conceptual modelling. While the framework enables the domain independent specification of conceptual models, it is a powerful approach also for considering aspects relevant for business. It is also a foundation to support the engineering of conceptual modelling tools.

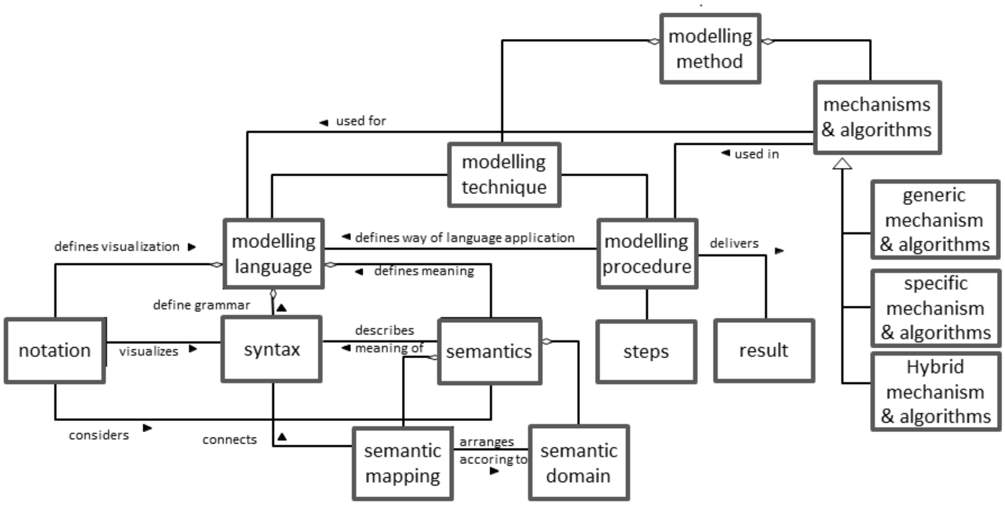


Figure 19 Modelling Method Framework

Three building blocks are considered by the framework: (1) the modelling language providing semantics, syntax, and graphical notation in form of concepts associated with conceptual models; (2) the modelling procedures defining the stepwise usage of the modelling language; (3) mechanisms and algorithms that enable ICT-based processing of models. A modelling tool based on this framework provides user interfaces and execution environments supporting all three building blocks to enable modelling scenarios like specification, execution support, knowledge representation and evaluation. For developing tools, different levels of support can be provided by the three building blocks of a modelling method. For example, the modelling language for entity relationship diagrams has a modelling language, modelling procedures, and algorithms that enable the translation of the model into a relational database schema. UML in contrast has an expressive modelling language but no modelling procedure explaining the stepwise approach to UML modelling. Similarly, OWL heavily relies on concepts defined in a modelling language and provides extensive algorithms for ontology inference but does not define a procedure of how to build a model. In any case, all conceptual modelling approaches, hence also the BIMERR approach, can be described with the aforementioned framework.

6.1.1.2 The Meta Model Approach

To simplify the development of conceptual modelling tools, a meta model approach can be employed (Fill & Karagiannis, 2013). Abstraction enables the efficient engineering of common elements in modelling methods. Only the specific elements of a modelling method have to be defined on the meta-level. As a consequence, meta models can be used to engineer tooling support through inheritance without re-implementing common aspects.

Based on (Strahringer, 1996), (Karagiannis & Kühn, 2002), and (Karagiannis & Höfferer, 2006), Figure 20 introduces the different layers of the meta model approach.

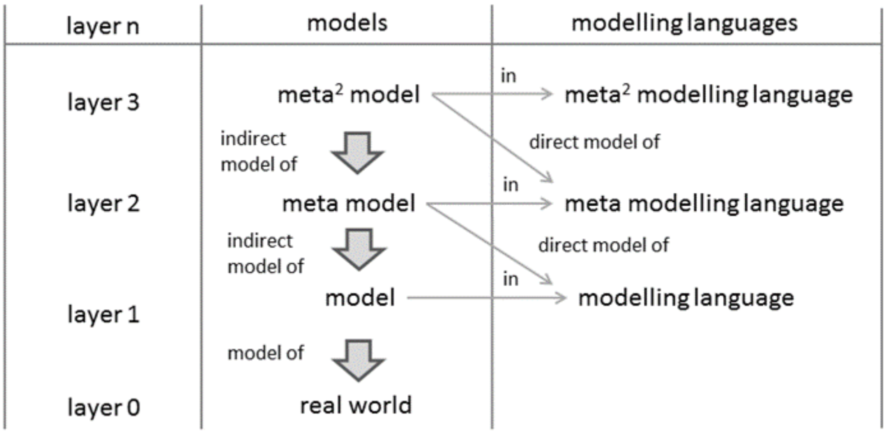


Figure 20 Meta Model Layers

The meta model layers allow for different meta model approaches, which have been analyzed in (Karagiannis & Höfferer, 2006), where a distinction is made between approaches that focus on (1) domain, (2) design at macro and micro level, and (3) integration. Examples for macro-level design approaches are (a) Business Rules (Herbst, 1996), (b) Decision Support (Aalst, Weske, & Grünbauer, 2005), (c) Business Process and - Workflow Management (Chiu, Li, & Karlapalem, 1999; Rolland, Souveyet, & Moreno, 1995), (d) Information Systems: Web-based Systems (Nikolaidou & Anagnostopoulos, 2005) and Agent-oriented Systems (Wagenr, 2003), and (e) Data Processing (Vassiliadis, Simitsis, Georgantas, Terrovitis, & Skiadopoulos, 2005). Examples for micro-level design in different domains are (a) Knowledge Representation (Mylopoulos, Borgida, Jarke, & Koubarakis, 1990) and (b) Data Processing with TIGUKAT (Peters & Ozsu, 1993), FORM (Kim & Park, 1997), and ULD (Bowers & Delcambre, 2006). Meta model approaches for integration and interoperability are (a) Object Modelling Framework (Hillegersberg & Kumar, 1999), (b) Situational Method Engineering (Brinkkemper, Saeki, & Harmsen, 1999), (c) Integrated Requirement Analysis (Nissen & Jarke, 1999), and (d) Data Processing Schema Mapping (Zaniolo & Melkanoff, 1982; Cheung & Hsu, 1996).

In all these meta model approaches, a modelling method is used to specify a meta model. This modelling method is derived from a meta meta model. Meta modelling toolkits implement such meta meta models. Examples for meta meta models and/or the Tools that implement them are (a) Ecore from the Eclipse platform (Budinsky, Steinberg, Merks, Ellersick, & Grose, 2004), (b) GOPRR from MetaEdit+ (Kelly & Tolvanen, 2008), (c) MS DSL Tools and MS Visio (Cook, Jones, Kent, & Wills, 2007), (d) MOF, which is realised on different UML Profile platforms (OMG, 2002), (e) ADOxx based on the equally named platform ADOxx (ADOxx.org, 2013), (f) Obeo Designer on Eclipse (OBEO.fr, 2018), and (g) Generic Model Environment GME (Bézivin, Brunette, Chevel, Jouault, & Kurtev, 2005).

The renovation process can be seen as layer 0. To enable the creation of a model of the renovation process on layer 1, a set of concepts is required. These concepts come in form of a modelling method

(i.e., a modelling language, a stepwise modelling procedure, and mechanisms & algorithms), which is specified on layer 2. Enabling this specification is the ADOxx metamodelling toolkit which implements the generic meta meta model from layer 3. Furthermore, the ADOxx metamodelling toolkit allows to turn the modelling method specification into a modelling tool that makes use of a wide variety of ICT capabilities. This modelling tool supports modellers in creating models of the renovation process on layer 1 and in exploiting these models on layer 0.

6.1.2 Development Methodology

Various tools will be adapted according to the re-purposed modelling method for the renovation process.

- Business Process: Based on available modelling tools, a new meta model will be introduced to create a renovation process overview.
- Simulation Support: The renovation process is elaborated through simulating BIM and BPMN to create a digital twin that defines the micro-steps, design/planning/construction stages, material/ component flow and installation, etc.
- Monitoring: Based on available dashboards, a cross-layer monitoring ecosystem will be developed, enriching low-level data streams with semantic and applying mapping and interpretation algorithms to transform the indicator to a top-level management dashboard, from which all renovation activities can be followed at real-time.
- Knowledge Support: knowledge support in the appropriate tools enables the iterative knowledge transfer from expert to machine decision making, allowing quicker and broader alternative discussions for decisions, as some of those alternatives are triggered automatically.

Two variations of the ADOxx modelling ecosystem are employed for development: an experimentation edition and an industrial edition. The experimentation edition focusses on rapid prototyping with agile modelling method engineering and fast product iterations while making no compromise on the quality and applicability of developed modelling tools. It is well integrated with scientific and open developer communities. The experimentation edition is free to use. The industrial edition focusses on transforming innovation items that are engineered in the experimentation edition into commercial products. This implies further integration in company ICT infrastructure, SLA agreements, customer support, and a business plan.

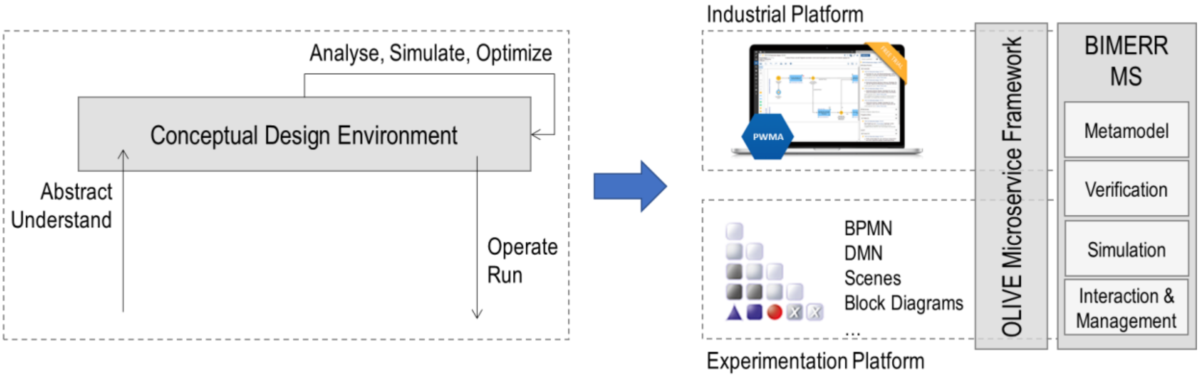


Figure 21 Mapping the Design Environment of the PWMA Toolkit to the Technological Solution Space based on the ADOxx Modelling Ecosystem

In the BIMERR project, the two editions of the ADOxx modelling ecosystem as shown in Figure 21 play different roles at different times. From the point of view of engineering the Design Environment of the PWMA Toolkit, two phases structure the timeline of the project. The first phase results in D6.2 and D6.4, where the focus is on the experimentation platform as shown in Figure 22. These results are extended and improved in D6.3 and D6.5, where the focus is on the industrial platform as shown in Figure 23. The experimentation edition of the ADOxx modelling ecosystem will be employed in both phases, while the second phase also introduces the industrial edition to the project. This approach is chosen to realize an engineering focus in the first phase and to work towards exploitation in the second phase.

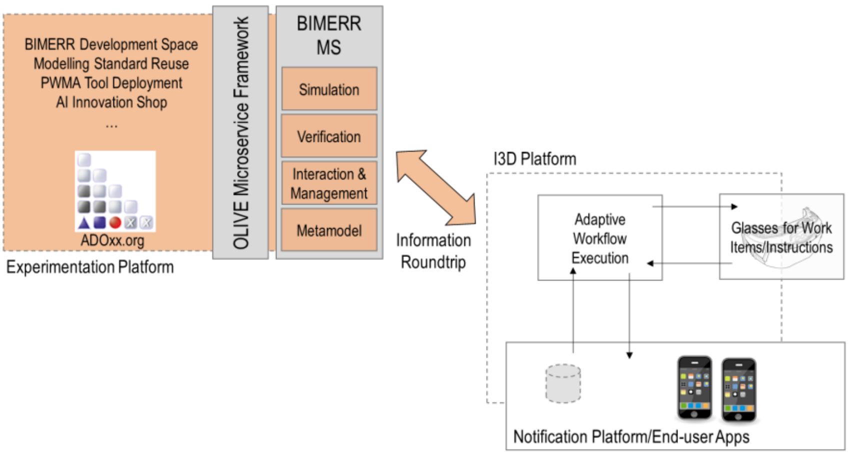


Figure 22 Focus of the Development Methodology for the Design Environment of the PWMA Toolkit in the First Phase

An additional problem to consider for the development methodology is the scope of integration between the PWMA Toolkit and the rest of the BIMERR system. Two questions arise. The first question is how the PWMA Toolkit as a whole is integrated with the rest of the BIMERR system. The second question

is to which extent that the PWMA toolkit makes use of the BIMERR interoperability framework for the communication between the tools/components that the PWMA Toolkit comprises. A modular approach is chosen to tackle these questions. In the first aforementioned phase, the focus will be on the PWMA Toolkit as a standalone innovation item. Thereby, the issues to be solved are, e.g., the implementation of model management and automation functionality, the information exchange between the tools/components of the PWMA Toolkit, and the design of user interfaces. In the second phase, engineering will continue to solve the issues of the first phase. However, additional issues are tackled in the second phase as well. In particular, it will be explored - from a technical perspective - to which extent that the interoperability framework can be employed in the communication between the tools/components of the PWMA Toolkit, how the PWMA Toolkit can be deployed as a coherent component of the BIMERR system, and how information exchange between the PWMA Toolkit and the rest of the of the BIMERR system takes place.

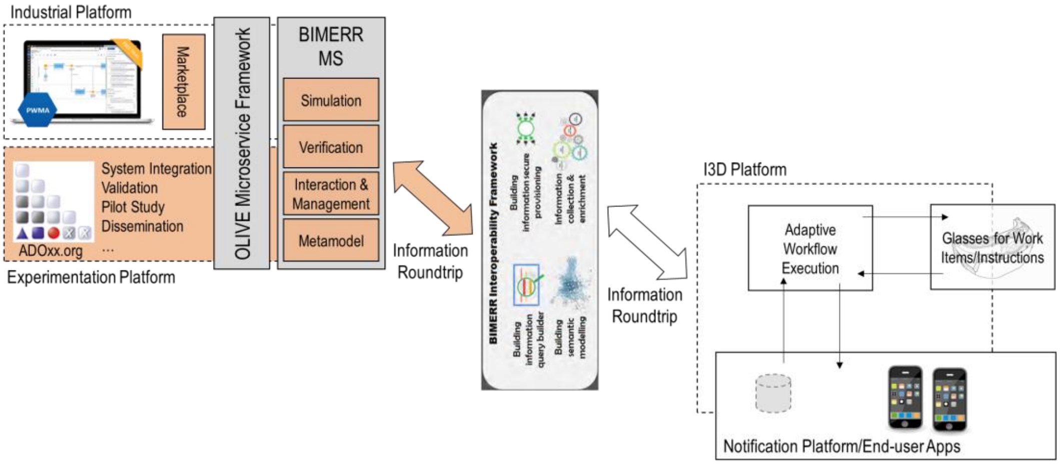


Figure 23 Focus of the Development Methodology for the Design Environment of the PWMA Toolkit in the Second Phase

6.1.3 Research Prototype

At this early stage in the project, a research prototype for the Design environment of the PWMA Toolkit is already available. The research prototype focusses on the design component and will be improved in many aspects. However, some early functionalities and User Interface options can already be understood based on the annotated screenshot in Figure 24.

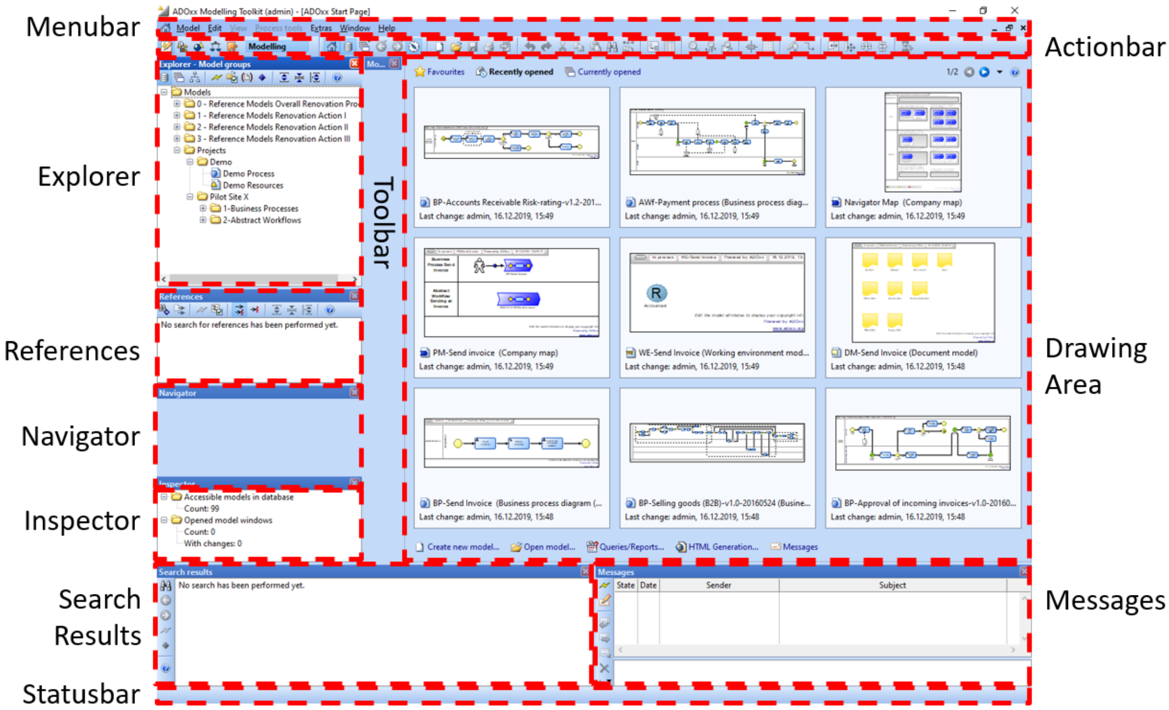


Figure 24 Windows of the Design Component in the ADOxx Experimental Platform

6.2 Tool Support for Renovation from a Workflow Perspective

The PWMA Toolkit will include a dedicated tool that will manage the workflow execution from beginning to end of the renovation process in order to ensure the optimal information flow among all the necessary stakeholders, while adapting to real-time modifications in the contents or the schedule of the renovation design and works. This tool will be integrated with the AR onsite guidance application in a seamless environment that will enable user-friendly design, execution, monitoring and adaptation of the workflow, with automated updates to and from the construction site based on worker generated content about work progress or workflow adaptations. The tools will be based on the I3D platform of NT, which has been developed for and demonstrated in the industrial sector and will re-purposed appropriately to provide the necessary fundamentals and semantics for the building construction/ renovation sector. BIM visualization will be aided by tools and smart glasses. The I3D platform will include dedicated user interfaces for the different stakeholders involved in the process. Renovation designer/planners will be able to define work instruction sets (workflows, steps & actions), define work safety instructions for on-site workers and design material for on-boarding & training new workers. Project managers and contractors will be able to issue work orders to the workers and download them to their smart glasses, monitor work progress, report major achievements, risks or problems, etc. Finally, workers will benefit from the availability of the app by easily reporting progress in a multi-model

manner (text, voice, images), which will be automatically propagated to all necessary parties in order to synchronize activities globally in the renovation site and design.

6.2.1 Adaptive Workflow Management and Automation

Adaptive Workflow Management and Automation (AWMA) means managing processes under circumstances which are not always foreseen. This brings the problem to be prepared for outer influences. To achieve this, we must keep control on workflow actions by events which are handled by end events of actions realized before and other conditions. These conditions give us the possibility to handle the process by outer influences too.

To get this target structure of our process we must do the following:

- create simple (atomized) actions, inside which is low probability of outer influence
- define start conditions for actions
- define end events for actions
- create mechanism for work with additional objects (e.g. multimedia files, providers, tools, ...)
- create mechanism to operate by conditions and events (with reporting tools)
- create mechanism for data exchange between administrator and client (worker)
- create mechanism for outgoing data manipulation, time recalculation, notification
- create mechanism for offline work too

These are the main characteristics of AWMA. Many of them are included in NT's I3D system for smart glasses. However big deal of success depends on effectual definition of actions.

6.2.2 On-Site Renovation Worker Support

The on-site renovation support for workers will be provided via smart glasses. The activities to be provided by workers will be defined by the site manager in advance. Once the work process template is prepared, it needs to be locked against additional changes to ensure work safety. The site manager is approving the defined work process and is responsible for workers safety as well as for the correct definition of the processes provided by the workers.

Typically, a work process is a sequence of actions grouped by steps. Steps are connected to locations. Every action can generate several ending events. Each action can have one or more starting event, which need to be fulfilled to start the execution of the action. The site manager can attach to the work process template additional resources, which will help the worker to execute the work on-site. This is supported by the I3D data structure shown in Figure 25.

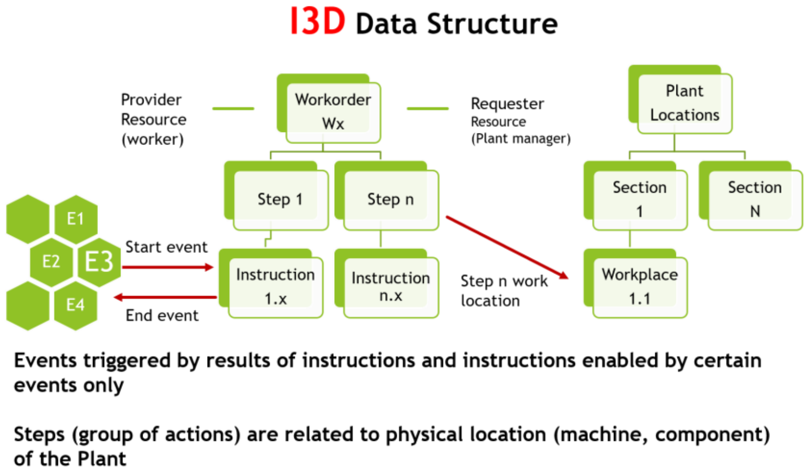


Figure 25: I3D Data Structure

The work process templates prepared by the site manager will be used by operator to issue work orders to be executed by selected workers at defined specific time and with support of the selected smart glasses. The operator can monitor the status of execution of the work orders and can generate reports from the completed work orders.

The worker will see for every step, where he needs to provide the work. For every action, the worker will see exact instructions, what to do and, what is the time dedicated to executing the action and provide the work. The execution of every action will start a counter, which will measure the effectivity of the worker and will indicate, if execution of any actions took longer than planned. On top of it, the worker will produce real-time evidence about the provided work by pictures and video-recordings created during the execution of actions.

All the collected information, including the produced multimedia content will be attached to the work order and will be accessible via work order report.

The execution status of the actions, steps and whole work orders will be available via API, which will be the connecting point between the PWMA and the "On-Site Renovation Worker Support tool". The PWMA will automatically change the status of the work orders, and in case of need, will re-schedule the already issued work orders.

6.2.3 Monitoring and Alerting for Residents

Monitoring and alerting for residents will be achieved by the development of a mobile application. The application's role is to inform the residents of the renovation work done on the site while giving them, at the same time, the opportunity to contribute to the renovation process by providing relevant input to the renovation activity.

The application can access the workflow and state of the renovation. The residents, by logging in the app, will be informed of the progress of the work with the calculated KPIs, similar to the PWMA's dashboard. In the event of an arising issue that could lead to a planning modification, notifications will be sent to the users to keep them updated of the altered workflow and progress. Moreover, the application will enable residents to communicate and schedule meetings with other stakeholders. The communication will be achieved through a message platform to arrange a meeting. The information of the meeting, such as data and subject, will be stored and shared between the relevant parties.

When visiting the renovation site, residents will be able to provide feedback and introduce changes. The UI of the application will display the building model to compare the results with the original plans. The residents could give as input to the application, the mark of the location and the desired change in the form of a note. Resident's proposal will be examined by the site manager.

The workflow and current state of the renovation, the KPIs, the connection with other platforms to communicate with the stakeholders and feedback provision will be made possible through APIs to enable communication between PWMA and End-User Apps.

7. Conclusion & Outlook

This report contains the innovation methodology of WP6 as a guiding instrument for the tasks in WP6. Furthermore, it presents the progress made during T6.1: (1) Use cases, user stories, and tooling support requirements of BIMERR are extended and framed from the process and workflow tooling perspective, which implies a specialization of the BIMERR overarching story formulated by the BIMERR consortium and D3.1 *Stakeholder requirements for the BIMERR system*. (2) First progress is made towards collecting best practice reference models to be included as part of the PWMA Toolkit. (3) The architecture of the PWMA Toolkit is specified as a specialization of D3.5 *BIMERR system architecture 1st version*. This allowed for the concrete assignment of responsibilities to partners and the definition of expected TRLs for components of the PWMA Toolkit. Furthermore, the information exchange between the components of the PWMA Toolkit and between the PWMA Toolkit and the rest of the BIMERR system is described. (4) The functionalities of the PWMA Toolkit are discussed considering especially formal verification, knowledge-based simulation, scheduling, and the execution or renovation actions. This section critically reflects on the results using a SWOT analysis and concludes further actions. Therefore, the SWOT analysis identifies strengths, weaknesses, opportunities, and threats.

The results are based on a close collaboration of pilot partners representing end-users, the partners providing technical solutions, and the whole BIMERR consortium. A clear method is formulated for all contributions based on the higher-level WP6 innovation methodology. Requirements are homogenized using, e.g., design thinking and advances digital design thinking tools. The formulation of an optimal technical architecture for the PWMA Toolkit provides a visionary outlook while the assignment of concrete responsibilities and expected TRLs is a commitment to developing tangible results that make significant progress towards achieving the vision. As the architecture of the PWMA Toolkit also relates requirements to already existing solutions that partners can build upon, significant progress is expected. Furthermore, the specification of components already contributes a first progress in the implementation of the PWMA toolkit even before some of the corresponding development tasks start.

While the concept for other deliverables – e.g., in T3.5, T4.2, and T10.4 – is to provide multiple reports on a task during the project duration, this report captures the situation at an early stage in the project. Despite the careful execution of the conceptualization effort in T6.1, changes are to be expected during the project duration. Therefore, the report requires ongoing iteration during the evolution of WP6. Within the BIMERR consortium, opportunities include the integration of the PWMA Toolkit and RenoDSS.

At the moment of writing and submitting this deliverable, there is an uncertainty regarding the smart glasses that should interface with the PWMA Toolkit. While there will be time to address these

uncertainties during the remaining tasks in WP6, this deliverable cannot report on such future actions and their potential outcome.

Overall, this report provides a foundation for the tasks following in WP6 and beyond. It facilitates a common understanding of all involved partners and is well integrated with other activities in the BIMERR project. As an outlook into future steps, the following activities are proposed:

(1) The collection of best practice reference models of the renovation process. The models should be structured by different renovation measures to be performed and increasing granularity. This allows (semi-) automated mapping of renovation measures selected by the user to reference processes and the decomposition of these reference processes into executable form.

(2) Monitoring of process execution relies on data collected from different ICT systems. To enable flawless monitoring, processes should be checked for their data mining readiness level before execution.

(3) Scheduling and execution of workflows implies automation using different ICT systems. A class of interfaces or standards should be selected for which automation is supported.

The proposed activities are required in the implementation tasks that follow in WP6.

References

Aalst, W. M., Weske, M., & Grünbauer, D. (2005). Case handling: a new paradigm for business process support. *Data & Knowledge Engineering*.

Abdel-Wahab, M. S., A. R. J. Dainty and I. S.G. 1999. A review of the relationship between skills and productivity in construction. In ASC Proceedings of the 35th Annual Conference, 165 – 178.

Alsehaimi, A. and Koskela, L. (2008). What can be learned from studies on delay in construction, in: Proceedings of the 16th IGLC Conference, Manchester, UK.

Bashir, M. A., Suresh, S., Proverbs, D.G. and Gameson, R. (2010). Barriers towards the Sustainable Implementation of Lean Construction in the United Kingdom, Part of an on-going doctoral study. University of Wolverhampton.

Bézivin, J., Brunette, C., Chevel, R., Jouault, F., & Kurtev, I. (2005). Bridging the Generic Modeling Environment (GME) and the Eclipse Modeling Framework (EMF). *Best Practices for Model Driven Software Development at OOPSLA'05.* San Diego.

Bork, D., Buchmann, R. A., Karagiannis, D., Lee, M., & Miron, E.-T. (2019). An Open Platform for Modeling Method Conceptualization: The OMiLAB Digital Ecosystem. *Communications of the Association for Information Systems*.

Bowers, S., & Delcambre, L. (2006). Using the unilevel description (ULD) to support data-model interoperability. *Data & Knowledge Engineering*.

Brinkkemper, S., Saeki, M., & Harmsen, F. (1999). Meta-Modelling Based Assembly Techniques for Situational Method Engineering. *Information Systems*.

Budinsky, F., Steinberg, D., Merks, E., Ellersick, R., & Grose, T. J. (2004). *Eclipse Modeling Framework.* Addison Wesley.

Cheung, W., & Hsu, C. (1996). The model-assisted global query system for multiple databases in distributed enterprises. *ACM Trans. Inf. Syst.*

Chiu, D. K., Li, Q., & Karlapalem, K. (1999). A Meta Modeling Approach to Workflow Management Systems Supporting Exception Handling. *Information Systems*.

Cook, S., Jones, G., Kent, S., & Wills, A. C. (2007). *Domain Specific Development with Visual Studio DSL Tools (Microsoft .Net Development).* Addison-Wesley Longman.

Construction Industry Institute (CII).(2004). Application of Lean Manufacturing Principles to Construction. RR191-11.

Falcioni, D., Gadowsky, C., Utz, W., Woitsch, R., Gaertner, D., Di Pasquale, M., . . . Werner, F. (2019). *Decentralised architectures for optimised operations via virtualised processes and manufacturing ecosystem collaboration.* http://www.disrupt-project.eu/.

Fill, H.-G., & Karagiannis, D. (2013). On the Conceptualisation of Modelling Methods Using the ADOxx Meta Modelling Platform. *Enterprise Modelling and Information Systems Architectures*.

Herbst, H. (1996). Business Rules in Systems Analysis: a Meta-Model and Repository System. *Information Systems*.

Hillegersberg, J. v., & Kumar, K. (1999). Using Metamodeling to Integrate Object-Oriented Analysis, Design and Programming Concepts. *Information Systems*.

Karagiannis, D., & Höfferer, P. (2006). Metamodels in Action: An Overview. *First International Conference on Software and Data Technologies.* Setúbal.

Karagiannis, D., & Kühn, H. (2002). Metamodeling Platforms. *3rd International Conference EC-Web 2002 - Dexa 2002*.

Karagiannis, D., Grossmann, W., & Höfferer, P. (2008). Open Model Initiative - A Feasibility Study. Project Study on behalf of the Austrian Federal Ministry for Transport, Innovation and Technology.

Kelly, S., & Tolvanen, J.-P. (2008). *Domain-Specific Modeling: Enabling Full Code Generation.* John Wiley & Son, Inc.

Kim, D., & Park, S. (1997). FORM: A Flexible Data Model for Integrated CASE Environments. *Data & Knowledge Engineering*.

Kokol, P. (1993). Metamodelling: How, why and what? *SIGSOFT Software Engineering Notes*.

Koskela, L. (1992). Application of the New Production Philosophy to Construction, Technical Report No. 72, CIFE, Stanford University, CA.

Koskela, L. (2004). Making do-the eighth category of waste. Proceedings of the 12th Annual Conference on Lean Construction, C. T. Formoso and S. Bertelsen, eds., Lean Construction–DK, Elsinore, Denmark.

Koskela, L., Huovila, P. and Leinonen, J. (2002). Design management in building construction: from theory to practice, Journal of Construction Research, 3(1), pp. 1–16.

Lean Enterprise Institute. (2009). Principles of lean. Available from: http://www.lean.org [13 December 2019].

Liker, J.K. (2004). The Toyota Way, 14 Management Principles from the World's Greatest Manufacturer. McGraw-Hill, New York.

Marhani, M.A., Jaapar, A. and Ahmad Bari, N.A. (2012). Lean Construction: Towards Enhancing Sustainable Construction in Malaysia. Procedia - Social and Behavioral Sciences. 68, pp. 87–98.

Muck C., Miron E.-T., Karagiannis D. and Lee M. (2018). Supporting Service Design with Storyboards and Diagrammatic Models: The Scene2Model Tool. *Joint International Conference of Service Science and Innovation (ICSSI 2018) and Serviceology (ICServ 2018)*

Mylopoulos, J., Borgida, A., Jarke, M., & Koubarakis, M. (1990). Telos: representing knowledge about information systems. *ACM Trans. Inf. Syst.*

Nikolaidou, M., & Anagnostopoulos, D. (2005). A Systematic Approach for Configuring Web-Based Information Systems. *Distributed and Parallel Databases*.

Nissen, H. W., & Jarke, M. (1999). Repository Support for Multi-Perspective Requirements Engineering. *Information Systems*.

OMG. (2002). *Meta Object Facility (MOF) Specification 1.4.* Object Management Group.

OMG. (2014). *MDA Guide revision 2.0.* Boston: Object Management Group.

Peters, R., & Ozsu, M. (1993). Reflection in a Uniform Behavioral Object Model. *12th International Conference on Entity-Relationship Approach.*

Rolland, C., Souveyet, C., & Moreno, M. (1995). An Approach for Defining Ways-of-Working. *Information Systems*.

Sacks, R., Koskela, L., Dave, B.A. and Owen, R. (2010). Interaction of Lean and Building Information Modeling in construction. Journal of Construction Engineering and Management, 136(9), 968-980.

Strahringer, S. (1996). *Metamodellierung als Instrument des Methodenvergleichs: Eine Evaluierung am Beispiel objektorientierter Analysemethoden.* Aachen: Shaker.

Vassiliadis, P., Simitsis, A., Georgantas, P., Terrovitis, M., & Skiadopoulos, S. (2005). A generic and customizable framework for the design of ETL scenarios. *Information Systems*.

Vilasini, N. and Gamage, J.R. (2010). Implementing Value Stream Mapping Tool in the Construction Industry. In proceedings of the International Research Conference on Sustainability in Built Environment, Sri Lanka.

Wagenr, G. (2003). The Agent-Object-Relationship meta-modell: towards a unified view of state and behavior. *Information Systems*.

Walch, M., Utz, W., & Woitsch, R. (2019). Knowledge-based Decision Support based on integrated IoT Data for Energy-efficient Building Renovation. *Sustainable Solutions for Growth (SSG).* Wroclaw, Poland.

Weeleng, T. 2004. The application of lean construction to reduce wastes in construction process flow. In School of Housing, Building & Planning, 189. Penang: University Sains Malaysia.

Whitman, L. E., Huff, B. L., & Presley, A. R. (1997). Structured models and dynamic systems analysis: The integration of the IDEF0/IDEF3 modelling methods and discrete event simulation. *29th Conference on Winter Simulation*.

Whitten, J. L., Bentley, L. D., & Dittman, K. C. (2014). *Systems analysis and design methods.* Boston: McGraw-Hill Irwin.

Womack, J.P. and Jones, D. T. (1996). Lean Thinking. Simon and Schuster, New York, USA, pp 350.

Zaniolo, C., & Melkanoff, M. (1982). A Formal Approach to the Definition and the Design of Conceptual Schemata for Database Systems. *ACM Trans. Database Syst.*