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ACRONYMS

BPMN	Business Process Model and Notation
BPMN DI	BPMN Diagram Interchange
DES	Discrete Event Simulation
KPI	Key Performance Indicator
PWMA	Process and Workflow Management and Automation
BIM	Building Information Modelling
SATE	Sistema Aislamiento Térmico Exterior (external wall insulation system)
SLA	Service Level Agreement

EXECUTIVE SUMMARY

This document introduces renovation process management as one approach within the Building Information Modelling (BIM) ecosystem. The modelling of renovation processes is used to introduce a process-oriented structure into the BIM tools and data with the goal of enabling a process-oriented simulation, execution, and monitoring to manage costs and times of renovation projects. The process model is conceptually defined as a directed graph with additional attributes that introduce a domain-specific context. Hence, simulation, execution and monitoring can be in general applied to all process models, whereas additional aspects can be added to fit the domain-specific purpose of BIM-based renovation projects.

We apply the well-established Plan-Do-Check-Act framework ([4] Gidey et al., 2014; [7] Meiling et al., 2014; [6] Lundkvist et al., 2014) by introducing a **design phase** (Plan), an **execution phase** (Do), a **monitoring phase** (Check) as well as a **reflection and improvement** phase (Act), to provide a decision support environment for renovation project managers.

The renovation process **design phase** and its corresponding tools enable the design, the analysis, the formal verification, the documentation, and the transformation into executable formats of renovation processes. We propose full-fletched modelling tools that use standard Business Process Model and Notation (BPMN) to design a renovation process. The usage of analysis for queries, formal verifications and assessments ensures the consideration of domain-specific necessities – in our case cost and time relevant probabilities – as well as the documentation and transformation for both – human interpretation of graphical models and workflow engine interpretation of formal correct workflows. We consider renovation process templates in the form of: (a) Facade improvement outside, (b) Facade improvement inside, (c) Roof improvement outside, (d) Roof improvement inside, (e) Window exchange. Those templates are then transformed both into processes for a concrete renovation project and an executable workflow that guides the project manager. We will also focus on a holistic workflow to orchestrate all the phases of the renovation process.

The renovation process **execution and monitoring phase** with its corresponding tools support the execution of a renovation process - which is still executed manually on the construction site - with monitoring, simulation, and workflow execution tools. The monitoring displays KPIs in form of actual or simulated time and costs. Furthermore, KPIs are defined by planned or target figures, actual or current figures as well as estimated or simulated figures. The monitoring cockpit composes those factors into KPIs in order to present the different actual costs and times compared to the planned figures and provide a continuous simulation of the expected trend of those indicators. This trend calculation is performed by knowledge-based simulations, where past data and expert knowledge is extracted in the form of configuration files for simulations of the process models. This extracted knowledge can be iteratively improved, when creating a digital twin with extended log-files from a workflow engine. Relevant personnel, material, and machine-rental costs as well as execution and duration times along the renovation process are continuously monitored and it is predicted how those costs and times will likely be developed in the future.

The **reflection and improvement phase** and its corresponding tools support the collaborative reflection of a renovation project. Collaborative platforms enable comments on the decisions taken during the renovation process as well as enable the evolution of the extracted knowledge that is used for simulation and KPI calculation. In case the workflow engine created an enriched digital twin of the renovation process, process mining can identify improvement potentials out of the log-files.

1. Introduction

1.1 Objectives of the Deliverable

This deliverable provides the renovation process, KPI, data and workflow models for the BIMERR scenario.

The renovation processes describe the sequence of tasks that are necessary to start from the existing building and result in the renovated one. Typically, a process is continuously triggered and runs often in form of multiple instances of the same process. In the case of the renovation process, we observe the logical sequence of tasks of companies that perform – continuously and in form of multiple instances - the renovation of buildings. The management of those renovation processes can have several objectives like: (a) Raising the quality due to documentation and standardisation, (b) Involving relevant stakeholders for contribution, reflection and knowledge extraction by using semi-formal graphical models, (c) Raising efficiency in form of optimising times and costs, (d) Extracting process-specific knowledge from human domain experts that can be considered and used by smart software as well as (e) Providing a know-how platform across the whole socio-technical ecosystem of a renovation process to design, monitor and innovate the complex dependencies of the ecosystem. However, there is a variety of objectives for the management of renovation processes besides the mentioned ones.

The renovation domain leads to the emergence of some challenges. The **first challenge** is that every renovation project of a building has its own – use case specific – characteristics, hence it has more the behaviour of a "project", which in contrast to a "process" is usually performed only once. To apply the aforementioned objectives, the first challenge is to abstract the concrete use case specific renovation projects to such a level that process management can be applied. Therefore, the correct level of abstraction, called "flying height", needs to be identified with the goal to stay concrete enough to apply standardised documentation, raise potentials for higher efficacy and apply knowledge-based algorithms. On the other side, we must stay abstract enough to keep the processes simple and manageable and not "destroy" any potential benefit of efficiency with the costs of process management.

The **second challenge** is to identify the appropriate part of the overall ecosystem, where the management of renovation processes and process-oriented decision support system using knowledge-based algorithms has the potential to provide sufficient benefit. Analysing the different phases of a renovation project, the “*cost calculation*” during the “*architectural and design phase*” as well as the “*budget control*” during the “*construction renovation implementation phase*” are candidates, where renovation process management is potentially beneficial.

The **third challenge** is to introduce smart algorithms that can interpret the models and the additionally provided knowledge to apply so-called “knowledge-based” algorithms. Knowledge can either be provided in human or software interpretable form. Human interpretable knowledge can be the design of graphical models, the entering of assessments and opinions in form of estimated input figures or the description and commenting for instance. On the contrary, semantic specifications, rules, and algorithms belong to the software interpretable knowledge category.

Concluding the above, the main objectives of this deliverable are:

- Provide the correct level or abstraction to describe the renovation process.
- Identify the relevant renovation processes and provide a set of process templates.
- Refine a set of renovation process templates in executable workflows.
- Indicate how algorithms that process the models could provide decision support.
- Explain how those findings are applied in a concrete use case.

1.2 Introduction of Taxonomy and Methodology

The process-oriented simulation of times and costs for renovation supports the decision making, based on estimated, simulated, and measured times and costs that occur during the process of a renovation. This renovation process management environment is hence part of the overall tool-suite of Building Information Model (BIM) tools. Although the actual process model is not part of the BIM data structure, the process model accesses the data, which are defined in the BIM data structure, and enable the digital transformation of the renovation activities.

Therefore, we position our process-oriented simulation of times and costs as a "Smart Decision Support Tool" for digital twin, that is specifically configured for the purpose of renovation processes and BIM-based data input.

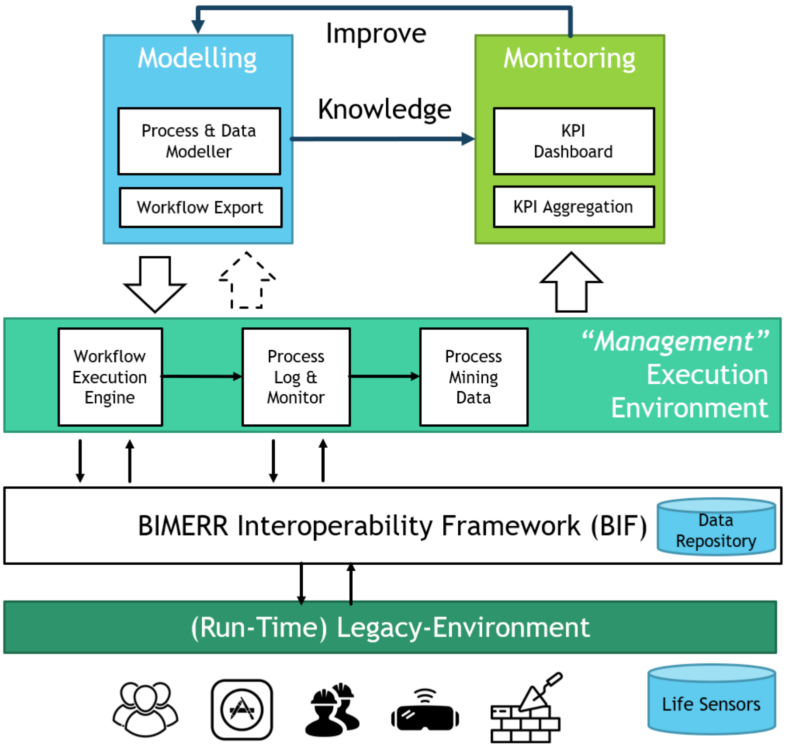

Figure 1: Process-Oriented Management of Times and Costs

Figure 1 introduces the overall approach, where:

1. The process is designed, structured, and enriched with domain specific knowledge ([8] Karagiannis & Woitsch, 2010; [13] Woitsch & Karagiannis, 2005), so that the workflow environment can create a meaningful digital twin of the renovation process.
2. The digital twin is created mainly out of workflow logs – that are structured according to the designed process – and additional information retrieved to document the status, decisions and actions per time are stored.

3. The evaluation unit continuously monitors the process status, enables a forward-looking simulation, and offers process mining on the digital twin of the renovation process.
4. To enrich the digital twin of the renovation process with real data from the legacy environment, the workflow is constructed in such a way that necessary information is acquired from the BIMERR interoperability framework (upon being extracted from the legacy environment).
5. Improvements and lessons learned are extracted based on the results of the evaluation and the comparison between planned vs actual renovation process, as well as predicted simulation vs actual occurrences.

1.2.1 Design of Renovation Processes

In this phase the decision makers create a business process like a task dependency plan that will be executed when the renovation process is started. To support user-friendly and efficient modelling of such renovation processes, we apply a so-called template repository, which consists of the most common pre-defined renovation processes. Those template processes can be selected for a concrete construction site and remodelled to a concrete business process that describes the renovation process in the same granularity as a project task dependency plan. Although there are conceptual and technical differences between a process and a project task-dependency plan, we consider it at this stage as similar for the purpose of an overall introduction.
All the renovation process models described in this deliverable can be visualized directly from the Process and Workflow Management and Automation (PWMA) modelling platform[1].

1.2.2 Monitoring and Evaluation of the Execution of Renovation Processes

In this phase the aforementioned concrete renovation process is executed. Here we have different application scenarios identified:

[1] https://bimerr.boc-group.eu/ADONISNP10_0/

a) ***Costs and times estimation to support "cost calculation" during the "architectural and design phase":***

We refer to the overall "Best Practice Renovation Process"[2] that identifies different phases of performing a renovation process. In the second phase "Architectural Design of Renovation" there is an activity called "Cost Estimation for the Client".

In this phase, the contract with the client is not signed yet, but for making a proper offer, the renovation company needs to have a good cost and time estimation. At this stage, the aforementioned process templates are used to compose a renovation process for the concrete offer at hand on an abstract and not too detailed level for an indicative time, cost, and risk assessment.

The provided simulation results are considered as a support for decision makers during the offer generation.

b) ***Preparation of simulation and measurement to support "budget control" during "construction renovation implementation":***

We refer to the overall "Best Practice Renovation Process"[3] that identifies different phases of performing a renovation process. In phase 5 "Constructions and Renovation Project Implementation" there is an activity called "Budget Control, Work Progress Monitoring and Quality Inspection".

We support this task with detailed process monitoring in combination with a process simulation. The aforementioned high-level process model, which was used for estimating times and costs during the offer generation phase, is now transformed onto a detailed description level. We consider a similar level of detail like the one in the task-dependency plan used for the project management. The process model focuses on the logic of the execution, hence the task-dependency plan from the project management is used to provide the necessary input data for the simulation.

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[2] BIMERR deliverable D6.1, page 25, Figure 6

[3] BIMERR deliverable D6.1, page 25, Figure 6

Once the correct level of detail has been achieved, the concrete and executable renovation process is exported to the workflow engine.

c) ***Costs and times simulation and measurement during "construction renovation implementation":***

Our aim is to build a digital twin of the renovation process. Therefore, we digitize relevant aspects of the real-world renovation process that is executed on the construction site by using a workflow engine.

We start with actions, times, and costs for the first creation of the digital twin and may add additional aspects in case this is considered as useful.

The workflow engine runs in parallel with the real-world renovation and creates a digital twin in the form of log-files. If required, status checking tools are accessed for the provision of information like human resources in hours, used material, used machines or cost of rents.

All those data assets are collected by the workflow engine and provided in form of extended log-files to our process-oriented dashboard.

The process-oriented dashboard can now:

- **Measure the current times and costs per status report.**
- **Simulate the predicted times and costs based on potential risks in the future.**

1.2.3 Innovation and Reflection of the Renovation Processes

Although the previous monitoring phase introduced a predictive simulation, it must be stated that the extracted knowledge for this predictive simulation relies on experiences of the past. Hence, it is a valuable experience that can be used to better assess the current status of the renovation process, but still, it is not an instrument to pro-actively design future challenges.

The next phase targets this issue by reflecting the past experiences, but also by triggering innovation to re-design the processes and to re-consider the experiences that are used for the simulations. In this phase, the assumptions that have been taken into account during all aforementioned phases are reflected with the goal of implementing lessons learned by:

- Improving the process templates and their usage for the offering phase.
- Improving the estimations performed in the offering phase.
- Improving the transformation into executable processes, especially for simulation relevant artefacts.
- Improving the calculations for the status measures.
- Improving the expert know-how relevant for the risk assessment.

Those improvements are performed using process mining and collective intelligence. Process mining is applied to analyse how the renovation process was performed and if potential improvements can be identified. Collaborative reflection of the renovation process is performed by using social media – in our case Wiki Pages – to collect expert opinions on the renovation project and extract improvements based on this feedback. The goal is to enlarge, enrich and improve the available process templates and the corresponding simulation relevant information, and hence improve the next life cycle of a renovation process.

1.3 CHANGES FROM DELIVERABLE D6.2

This document extends the D6.2 "Adaptive Renovation Process & Workflow Models 1" with the last improvements in the models created for the BIMERR use cases. In particular, in the **chapter 2**, where design phase of the renovation process is explained, the sections 2.3 and 2.4 have been updated providing the latest workflow and KPI details, while section 2.6 has been created describing the new model type to define microservices. In **chapter 3**, about the monitoring and evaluation phase, the cockpits have been updated (section 3.1.2), the previously introduced trustability indicators on the simulation results have been extended and refined (section 3.2.4), and the new details on the workflow execution for the digital twin have been described (section 3.3). In **chapter 4**, where the innovation and optimization of the models are addressed, the section 4.2 has been extended introducing the mining of workflow execution logs. The **chapter 6** has been extended with section 6.2 where the workflow design for the renovation of the external facade of the

BIMERR Spanish pilot site has been introduced. **Chapter 7** has been added describing the work performed in the context of modeling the digital twin of the entire BIMERR renovation process, finalized to the orchestration of all the BIMERR tools in the different use cases and their KPIs. Finally, **chapter 8** provide the updated conclusions and outlook.

2. Design of Renovation Process and Workflow Models

Our process-oriented approach puts the focus on the renovation process in order to build a digital twin that is structured considering the renovation process model. It consists of values according to time stamps, cost calculations as well as additional domain-specific information that is provided by domain experts. It must also be considered that the renovation process model is mostly used in the renovation process simulation tool, whereas the renovation workflow model is used by the adaptive workflow management and automation tool.

2.1 Renovation Process Template

First, the renovation process model needs to be created. We propose a manual creation of templates that describe the most common renovation actions like: Facade renovation outside, Facade renovation inside, Roof improvement outside, Roof improvement inside, Window exchange, Heating system exchange, etc.

Figure 2 introduces the renovation process template for “Facade Renovation Outside”. Each template consists of five phases, in which process specific tasks are performed:

1. Preparatory Check – first preparation tasks on the construction site.
2. Preparation – preparations for the upcoming installations.
3. Installation – main part of the renovation process.
4. Finishing – finishing tasks such as cleaning.
5. Final Check – final quality check.

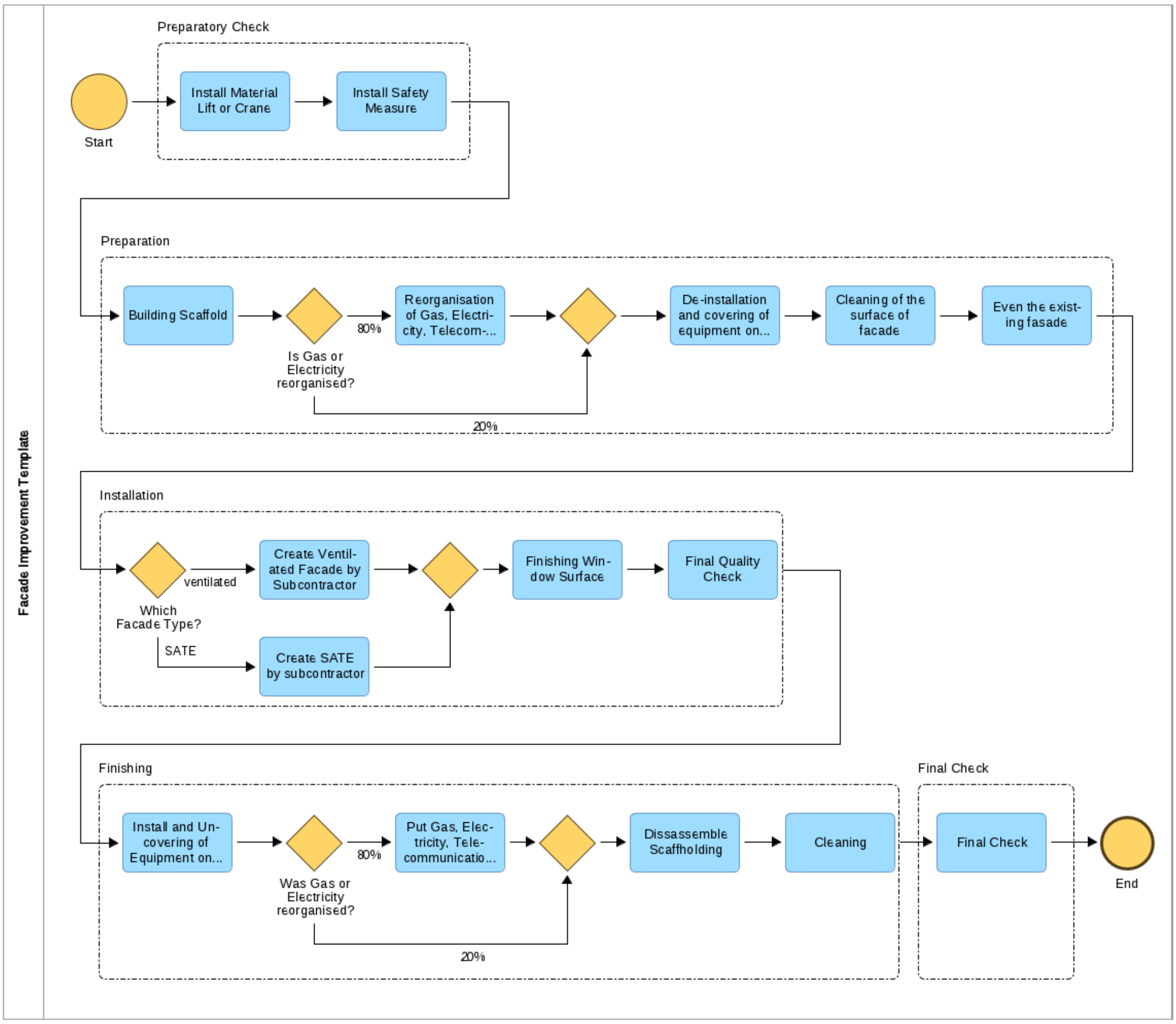

Figure 2: Renovation Process Template of "Facade Renovation Outside"

The different variations of a process are represented in form of decisions, where those decisions are not at instance level but describe different variations of possible processes on template level.

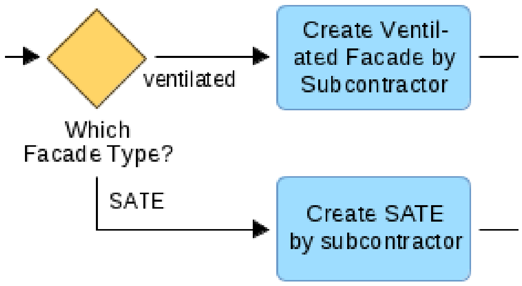

Figure 3: Sample of Process Variation

Figure 3 indicates such a variation, where either a "ventilated facade" or an "external wall insulation system (SATE)" is used for facade improvements. The variation that one of the two facade types can be used, is only on template level, as in a concrete use case, the facade type is defined, and hence there is no need for a decision. This template is transformed into a concrete renovation process where: (a) a particular process variation is selected and (b) all relevant templates that are used for a concrete use case are combined to one renovation process.

2.2 Renovation Process Model Instance

The instantiated renovation process template describes the process for a specific use case on a business level. This means that neither technical details nor resource allocations are performed but the sequence of actions that are required, is defined. Figure 4 shows a simple transformation from the template to the concrete process.

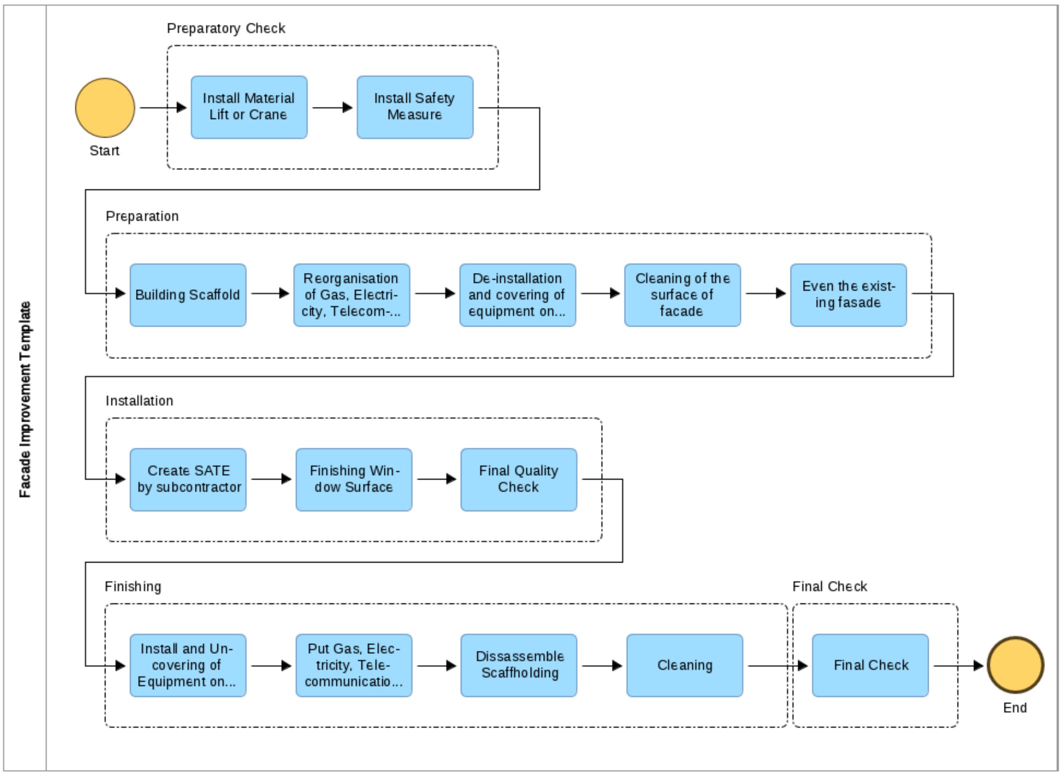

Figure 4: Concrete Renovation Process of "Facade Renovation Outside"

This simplified process representation enables simulations and monitoring of times and costs. As the activities are on a high level, the simulations are rough estimations. However, they can already incorporate expert knowledge for analysing the probabilities of times and costs.

The transformation from the template to the concrete process was performed by deciding which process variation is selected. It must be stated that more advanced transformations like including additional templates or highlighting a particular part of the process are possible.

2.3 Renovation Workflow Model

Finally, we approach to the most detailed process model that can be used for execution. In case a process model is used for execution, it must be on the same level of detail, as the actual execution takes place. A simplified transformation of our "Facade Renovation Outside" concrete process into an executable is indicated in Figure 5 and described extensively in section 6.2.

The workflow is detailed enough to describe not only the steps at the actual execution but also the services that must be called from the execution engine when an automatic action is performed. The service references to the microservice created with the Microservice Definition Model described in section 2.6.

The relation between the executable renovation process and Process and Workflow Management and Automation (PWMA) is twofold: its execution (a) **assists the project manager** in observing and managing the renovation process; and (b) accesses data repositories on pre-defined key points to **create a digital twin** of the process with status log-files that are enriched with legacy data and pre-defined structure process semantics ([14] Woitsch & Utz, 2015).

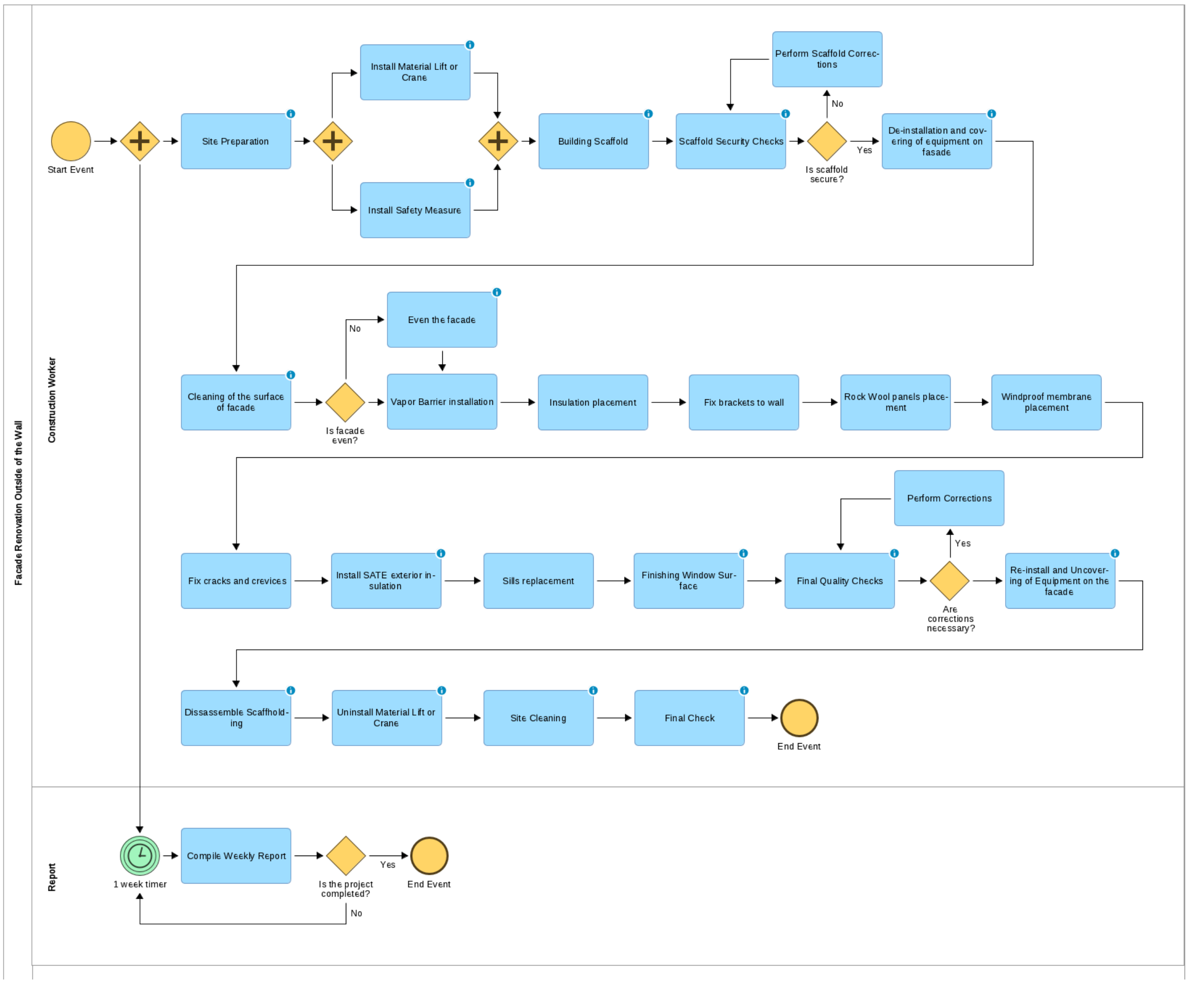

Figure 5: Executable Renovation Process of "Facade Renovation Outside"

2.4 Renovation Process KPI Model

Key Performance Indicators (KPIs) are used to measure the performance of processes. Although a variety of KPIs[4] exists, here we focus on times and costs of the renovation process. Our performance measurement is based on actual data as well as simulation data, which allow a comparison of effective and planned costs. KPIs can evaluate a variety of aspects, in the specific case of a "Best Practice Renovation Process"[5] that considers "budget control" for (a) Material, (b) Equipment and (c) Manpower with the goal to control the **times and costs**.

The foundation for the renovation process is therefore to (1) keep the overall costs within a threshold, and to (2) finish the project within a set time limit. The KPI models distinguish between:

- Perspective that groups similar indicators, like grouping all "Financial" indicators or all "Time" or "Quality" dependent indicators. In our sample based on the user feedback, we calculate costs and times.
- Goals and sub-goals that describe the objective to be achieved – in our case "Stay within estimated budget" and "Finish the project within the agreed duration".
- Indicators that describe measurable datasets that assess in combination with the indicator context (plan value, real value, thresholds, type of thresholds and meta-data about the indicator) whether the corresponding goal can be achieved or not.

[4] D3.3

[5] D6.1, page 25, Figure 6

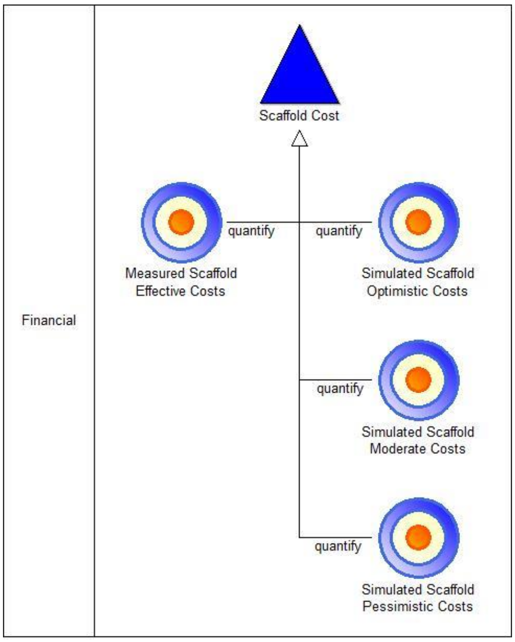

Figure 6: The Key Performance Indicator Model for the "Scaffold Cost"

The KPI model in Figure 6, gives an overview of the goal "Scaffold Cost" and the related KPIs "Measured Scaffold Effective Costs", "Simulated Scaffold Optimistic Costs", "Simulated Scaffold Moderate Costs" and "Simulated Scaffold Pessimistic Costs".

For explaining the KPI model type, we will use, as a sample, the scaffold costs of the renovation process, as it is a combination of costs of building the scaffold, costs of renting the scaffold over the duration and costs of removing the scaffold.

Hence the effective costs are initially estimated and considered as planned budget figures. They can be compared to the actual costs that occur when renting the scaffold, which are independent of the planned figures. Those two values – the planned "should value" vs. the actual "is value" – are compared in the KPI "Measured Scaffold Effective Costs".

To improve the monitoring of the costs, the three simulation scenarios – optimistic, moderate, and pessimistic – are modelled as additional KPIs, having the same planned value as the "Measured Scaffold Effective Costs" and can be compared with the simulated expected future costs.

The context of a KPI is modelled in the attributes of the KPI, depicted in Figure 7.

The “Fields” attributes describe the kind of data available for this KPI. In our case the scaffold cost KPI will contain a “cost” dataset containing the cost value in “Euro” and an “instant” dataset specifying the datetime of the KPI.

The “Data aggregation type” defines, if the KPI data is provided with some form of aggregation like a daily, weekly or monthly average or if is not aggregated at all.

The “Target range” represent the planned KPI value. In our case we estimated that a target range for our cost is below 20.000 Euro.

The “Alert ranges” specify thresholds used to notify when KPI value is approaching a value out of the target range. In our case when the cost is between 15.000 and 20.000 Euro, we want a “yellow” code alert.

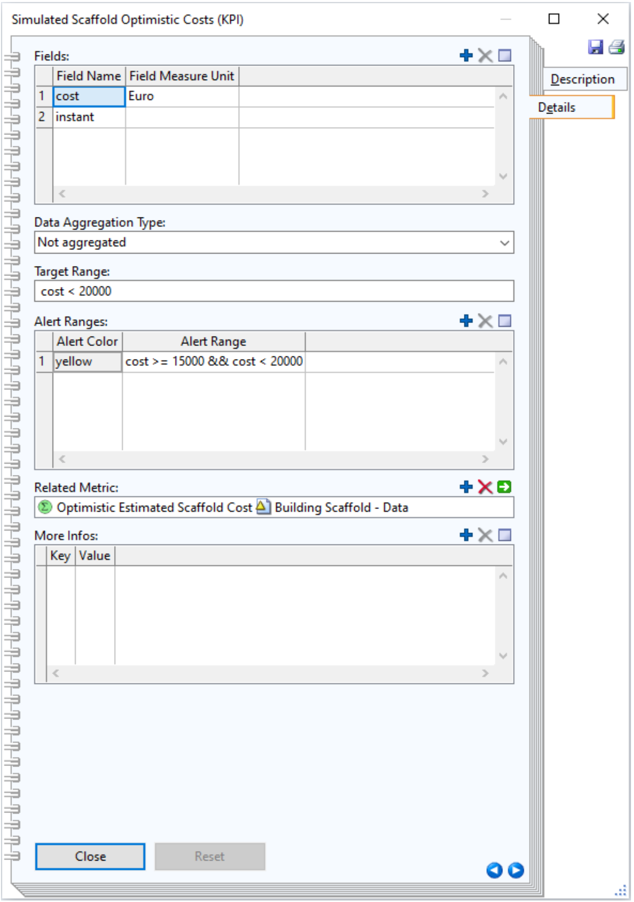

Figure 7: KPI Details

Each KPI is modelled as explained in Figure 7, whereas the “Target range” is estimated and the “Alert ranges” that describe the thresholds are based on “experiences” of experts. The definition of the target range and the threshold is use-case specific and depends on experiences of the involved knowledge experts. As a rule, the well-known SMART acronym is stated for completeness reasons ([3] Doran, 1981).

The “*Related Metric*” attribute is a technical configuration that links the mentioned KPIs with the relative metrics that are described in the “Data Access Model”. Hence, this KPI points to a data set that is further described in the data access model.

In order to provide an indicator on the reliability of a KPI, some parameters can be specified. In particular, in ([15] Mirnig et al, 2020) the reliability of a KPI can be estimated based on factors involving (a) the type of data used by the KPI, (b) the expertise of the responsible for KPI data, (c) the delay of the KPI data reporting and (d) the presence of penalties applied by Service Level Agreements (SLA) to the KPI.

The associated data can be of three types: Measured, Calculated and Known. When the KPI is calculated (like in the case of the Scaffold Cost) its data is provided by an algorithm. When the KPI is measured means that its data will be provided by a measuring device or sensor. On a known KPI the data is based instead on the expertise of the provider. In all the three cases the experience of the responsible for such data have a key impact on the KPI reliability. For this reason, every KPI has associated an attribute that specify specifies the actual responsible for the specific data and the required role that this person must cover.

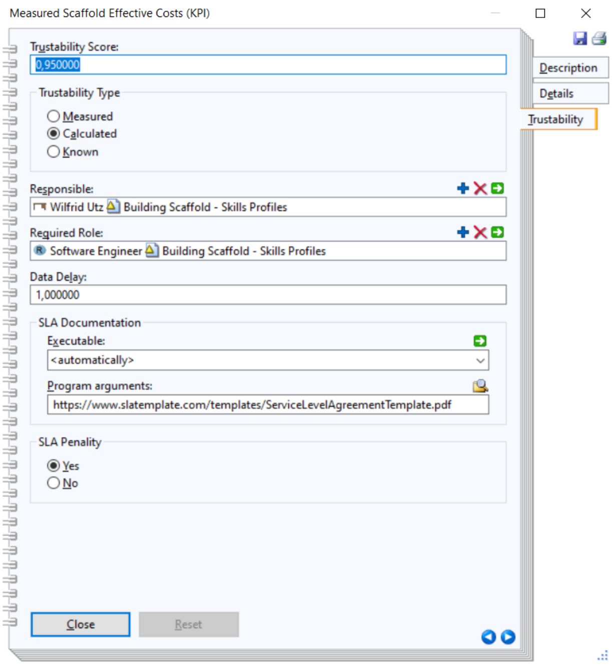

Figure 4 – Trustability Attributes

In the Scaffold Cost case, a software engineer with high expertise has combined metrics about the daily renting cost of the scaffold and its estimated required time on the construction site in order to calculate the KPI. The data for this KPI has been provided with 1 time unit (hour in this case) of delay, strictly dependent on the simulation scheduled time. At the end if there is an SLA associated to this KPI it can be referenced and enriched with the presence of a penalty. In this case the renting sub-contract is referenced as it is including fees in case of the renting time exceed the 4 months. These attributes contribute to the calculation of an overall reliability indicator for the specific KPI that will be visualized in the dashboard in order to understand how much a specific KPI value can be trusted.

The specification and visualization of reliability indicators has been possible thank to the collaboration between the national funded FFG project CALIBRaiTE[6] and BIMERR.

[6] https://projekte.ffg.at/projekt/3761903

2.5 RENOVATION PROCESS DATA ACCESS MODEL

Data models are required for creating a better understanding and expedited communication between managers, data analysts and other professionals ([12] Werner & Woitsch, 2018). The data access model describes how the different metrics are calculated and which data sources are accessed. It consists of (a) the technical necessary details to access a data source and retrieve the correct data, but also enables (b) the semantic description of a particular metric that may be needed later on during the usage of those data. For this purpose, we distinguish two types of objects:

- The "**Data object**" is considered as the "alpha-indicator", like the alphabet, those objects provide the alphabet of the dashboard, from which "words" can be composed to provide a certain meaning (blue objects in Figure 8).
- The "**Metric object**" is the composition of alpha-indicators and hence are the "words" of the dashboard. A semantic description may introduce a certain meaning to the measure (green objects in Figure 8).

Figure 8 shows how the KPIs from the aforementioned sample "Scaffold costs" are defined. The data is collected from external sources and calculated by defined metrics.

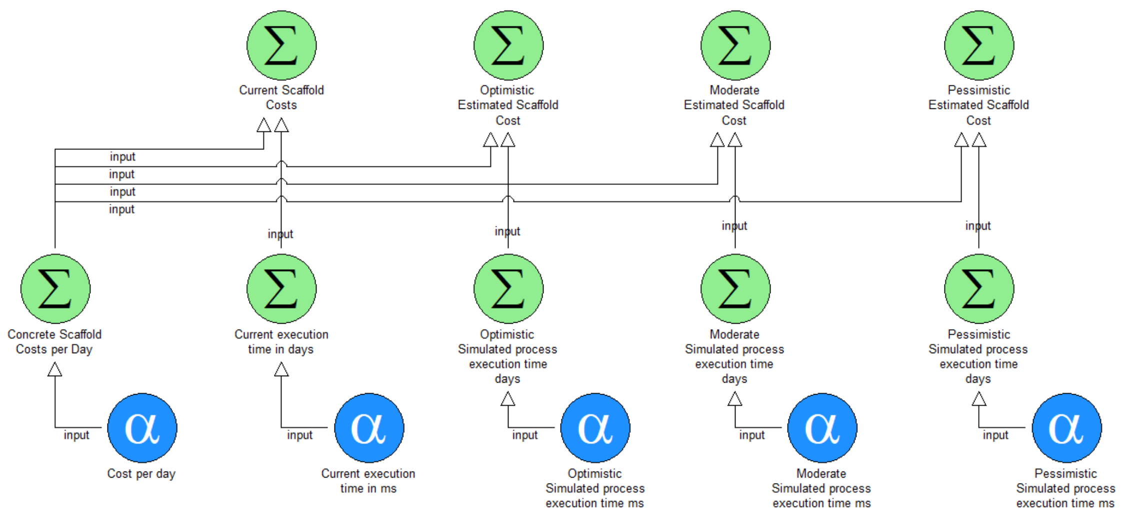

Figure 8: Data Calculation Model

Data objects describe how to access, log-in and retrieve data from specific external data sources.

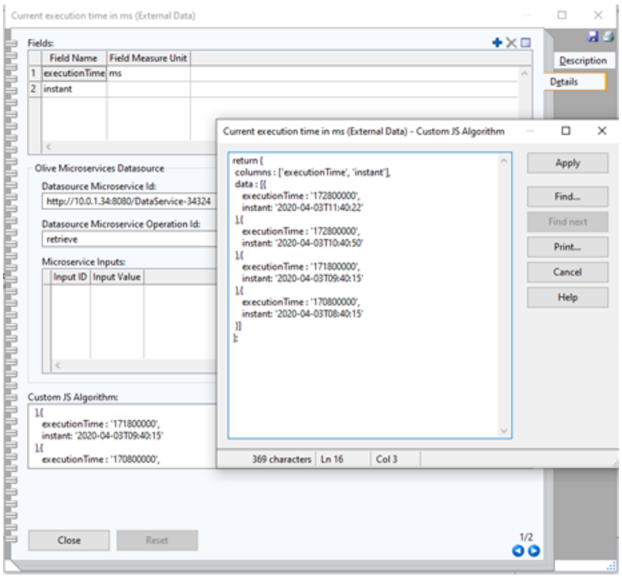

Figure 9: Data Access Specification

Figure 9 illustrates how the blue alpha-indicators are configured in detail to access external data sources.

The microservice ID and operation ID, of the Olive microservice retrieving the data are provided and the return value is allocated to the "Field Name" in our case "executionTime".

The calculation and the semantic meaning of the KPI data is provided when modelling the metrics. Figure 10 provides a sample, where "Concrete Scaffholding Costs per Day" are multiplied by "Current Execution Time in Days". First, the inputs are allocated to the variables a and b, whereas the object – the reference written in blue – points to the two measures in the model "Concrete Staffholding Costs per Day" and "Current Execution Time in Days".

The *"Fields"* box then contains the formula to calculate the results for the sake of example a.cost*b.executionTime, where "cost" and "executionTime" are the fields of the corresponding measures.

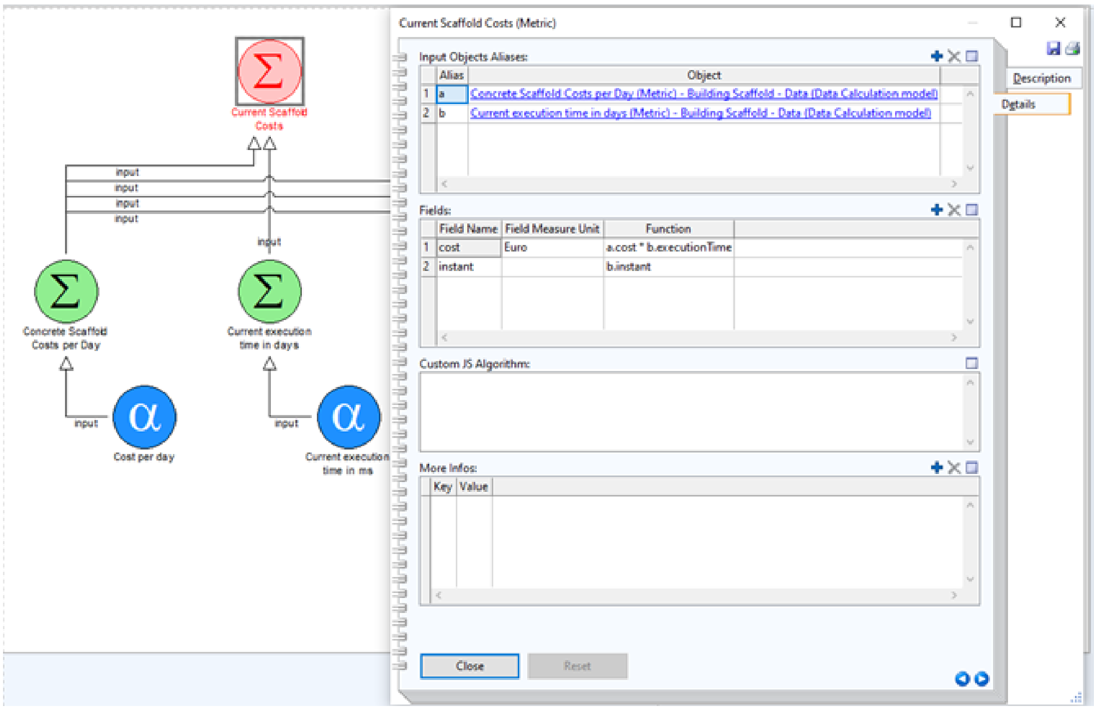

Figure 10: Metric Input and Calculation

Those data access models enable to use the datasets with intended meaning independently of how the underlying software is programmed or configured. The relevant knowledge to calculate and interpret the data is extracted and stored in a tool-independent way in the model.

2.6 Renovation Process Service Definition Model

The Service Definition Model associated to a renovation process completes the definition of the digital twin of the process, providing the definition of all the services involved in the renovation activities. Such services are called (a) by the workflow engine in case of an automatic activity, (b) by the PWMA modelling environment for integration with other BIMERR tools, and (c) by the KPI dashboard in order to retrieve execution logs of the renovation workflow for KPI calculation.

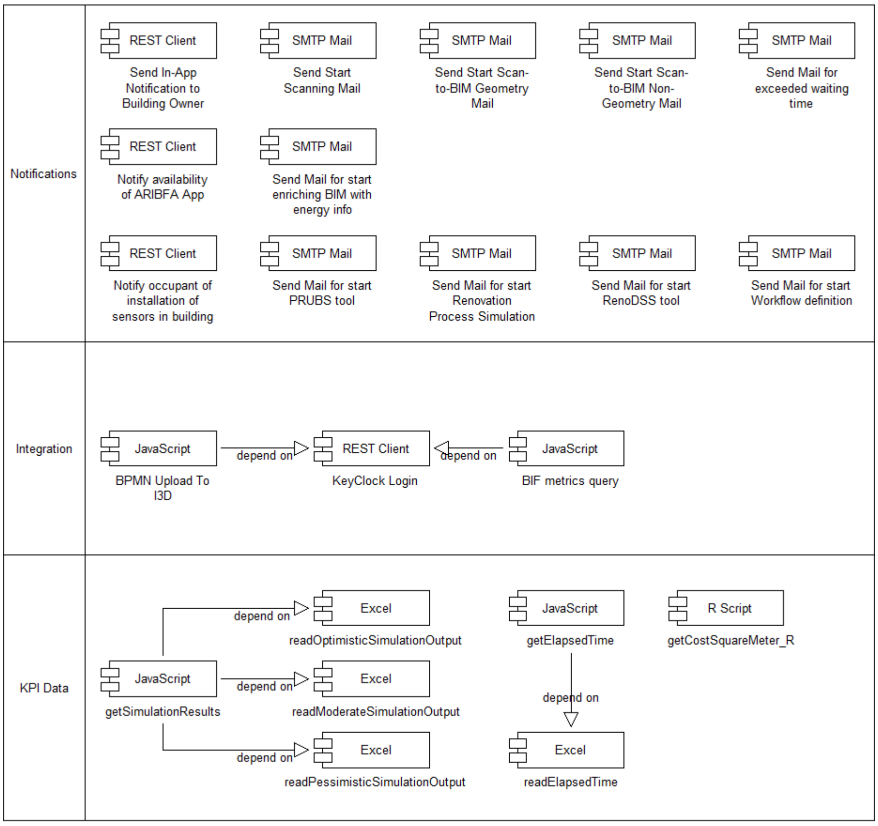

Figure 11: Service Definition Model

Each element in Figure 11 represents a REST[7] microservice that performs a specific action. The Olive microservice framework described in BIMERR deliverable D6.5 will use this model to automatically create, deploy and run the modelled service, making it available for the required component. Each microservice contain some general configurable parameters and some specific parameters for its "Connector" type. The connector specifies the type of feature that the service can provide, i.e., an Excel connector will allow the creation of services that interact with Excel files. This is a common case for services that need to read metrics provided in Excel format for KPIs calculation as described in section 7.3.2.

[7] https://en.wikipedia.org/wiki/Representational_state_transfer

3. Monitoring and Evaluation of Renovation Process and Workflow

We applied a process-oriented approach that focus on the renovation process for the creation of a digital twin. It is composed of time, costs as well as additional domain-specific information provided by domain experts.

This section describes how to use the domain-specific knowledge for:

- Process-Monitoring for Decision Support.
- Process-Simulation for Decision Support.
- Process-Execution for Enrichment of Digital Twin.

To see the whole architecture and technical details, we refer to BIMERR deliverable D6.5 Renovation Process Simulation Tool 2.

3.1 Renovation Processes-Oriented Monitoring

3.1.1 Models-based Monitoring Dashboards

A core element of the decision support tools is to represent the current status in form of a dashboard or alternatively called cockpit to the decision makers. There are several different approaches available that are basically distinguished in:

(a) The capabilities to represent the current status in form of visualizations, filter, compare or search features as well as analysis, drill-down or documentation capabilities and finally the possibility to involve other decision makers to perform cooperative decision making.

(b) The algorithms that are applied to collect, abstract, calculate and introduce a meaning to the data that are used by KPIs, as well as technology-specific characteristics like close-to real-time monitoring, introduction of artificial intelligence or human decision makers in the knowledge provision or interpretation as well as the specific data characteristic and format.

Renovation process-oriented monitoring introduces a complementary process-oriented context to the data algorithms. The aforementioned Renovation Process KPI models introduce the context of indicators and enable additional semantic enrichment on how the indicators are collected, manipulated and interpreted. This information is provided in the form of the trivial KPI model.

In cases where knowledge-based analysis is required, for instance fuzzy-logic, rule-based algorithms, semantic lifting, or similar approaches to introduce artificial intelligence into the data algorithms ([9] Nilsson, 2014), the aforementioned KPI models need extensions to also cover these aspects. This deliverable introduces the basic set of KPI models: hence, it provides the data access, data calculation and the basic KPI representation information.

To deliver a complete solution, a dashboard with basic features on how to represent the aforementioned modelled indicators, is also provided. The introduced dashboard is entirely based on models that enable the link between externalized knowledge and data. Since the scope of this deliverable is to introduce the concept of a process-oriented monitoring and not present the technical capabilities of our provided dashboard, the following subsection uses the open-source dashboard from the Microservice platform Olive[8] just to demonstrate how the modelled concepts can be used for a monitoring dashboard with the aim to support decision makers.

3.1.2 Process-Oriented Monitoring Cockpits

Dashboards are created for each use case, hence the process history for each renovation instance is monitored. We introduce the following concepts for monitoring cockpits:

- **Nested Monitoring-Aggregation** by aggregating several cockpits – e.g., several concrete use case cockpits from several sites are aggregated to an organisational wide cockpit.

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[8] https://www.adoxx.org/live/olive

- **Backward-looking monitoring and forward-looking simulations** using KPIs for the backward-looking monitoring or process-simulations for the forward-looking simulations.
- **Process-Oriented context of cockpits** by introducing different phases and dependencies for each construction site, as well as dependencies between several in parallel running construction sites by running complex process-simulations where the individual construction site process simulations provide the simulation results, which are then combined for an aggregated status report of all simulations.

Nested Monitoring-Aggregation:

The management of several use cases, and the management of several renovation initiatives correspondingly, in parallel can be managed by a so-called hierarchy of cockpits.

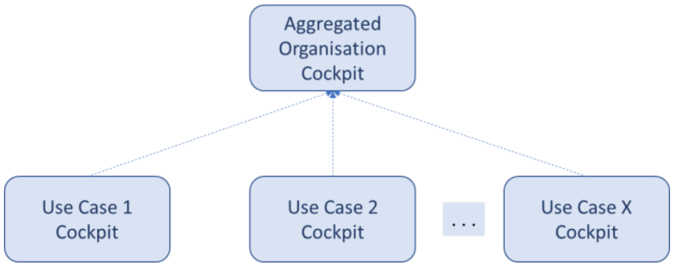

Figure 12: Hierarchy of Cockpits

The hierarchy of cockpits can be modelled by using a KPI from one cockpit and use it as a data source for an aggregated cockpit or other KPIs.

This means that the data access object that defines the input data stream for an aggregated cockpit accesses the resulting KPI from a concrete cockpit.

Figure 12 indicates that several concrete use case cockpits can be combined to one "aggregated" cockpit.

A simple version of nested KPI cockpit is performed by combining several individual renovation processes, for instance "Facade Renovation Outside", "Facade Renovation Inside" and "Window Exchange", which are three individual processes that are commonly performed in conjunction.

Backward-Looking Monitoring and Forward-Looking Simulation:

The cockpit for a concrete construction site consists of KPIs that are defined by the decision makers as relevant to make informed decisions. This is demonstrated by the KPI "*Scaffold Cost*", which consists of (a) the construction, (b) the dismantling and (c) the rental costs for the duration of its use at the construction site. As the scaffold is used in a period of the overall renovation, it is a perfect example for monitoring (backward-looking) and simulating (forward-looking) the costs considering the actual time.

The actual costs occur when building the scaffold, whereas the costs of dismantling need also to be considered. The rental costs depend on the actual duration of the construction site, which may deviate from the project plan.

Here, we introduce the process-simulation that forecasts the most likely duration to continuously assess the probable duration to derive the corresponding costs. We propose three simulation scenarios, the optimistic, moderate, and pessimistic scenario, that can be adapted to the requirements of the use case. Some KPIs do not need a simulation at all, or are appropriately covered with only one simulation, but there may be a KPI that is best simulated with several simulations.

Figure 13 shows a typical representation of KPIs using a picture of the location of the construction site and including the four KPIs: (a) actual scaffold costs as well as (b) optimistic, (c) moderate and (d) pessimistic scenarios of the simulated duration and the consequently resulting scaffold costs. An alternative representation are the graphs showing the history for each KPI. Colour codes – red, yellow, green – as defined in the KPI model display the status.

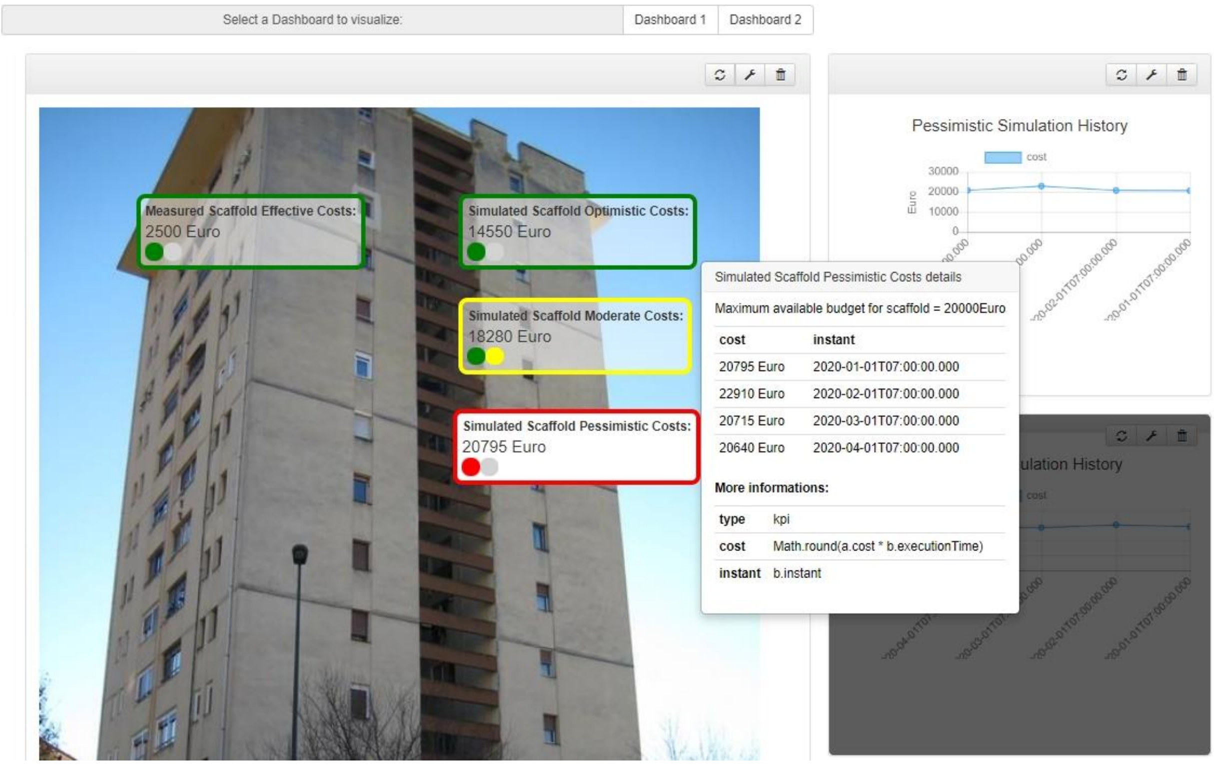

Figure 13: Backward-looking Monitoring and Forward-Looking Simulation of KPI-Scaffold Costs

<u>Process-Oriented Context of Cockpits:</u>

Figure 14 demonstrates the process-oriented context of the cockpit as the capability to link KPIs to different phases of the process. For each time slot, a process can be linked to the actual as well as the simulated KPIs.

The process-oriented representation also allows to drill the KPI down either in the process-oriented view, or as it is displayed at the bottom of the figure using the model-tree, which represents the KPIs as they are modelled in the KPI model.

Additionally, the trustability levels specified in the KPI model described in section 2.4 are visualized in the dashboard in form of percentage score and icons in order to have an immediate view on the reliability of each indicator. More details on the interpretation of the reliability score values are described in the BIMERR deliverable D6.5.

Hence the process-oriented representation is first an alternative visualization of the cockpit and second the method to additionally introduce the linkage of a process phase to a concrete KPI.

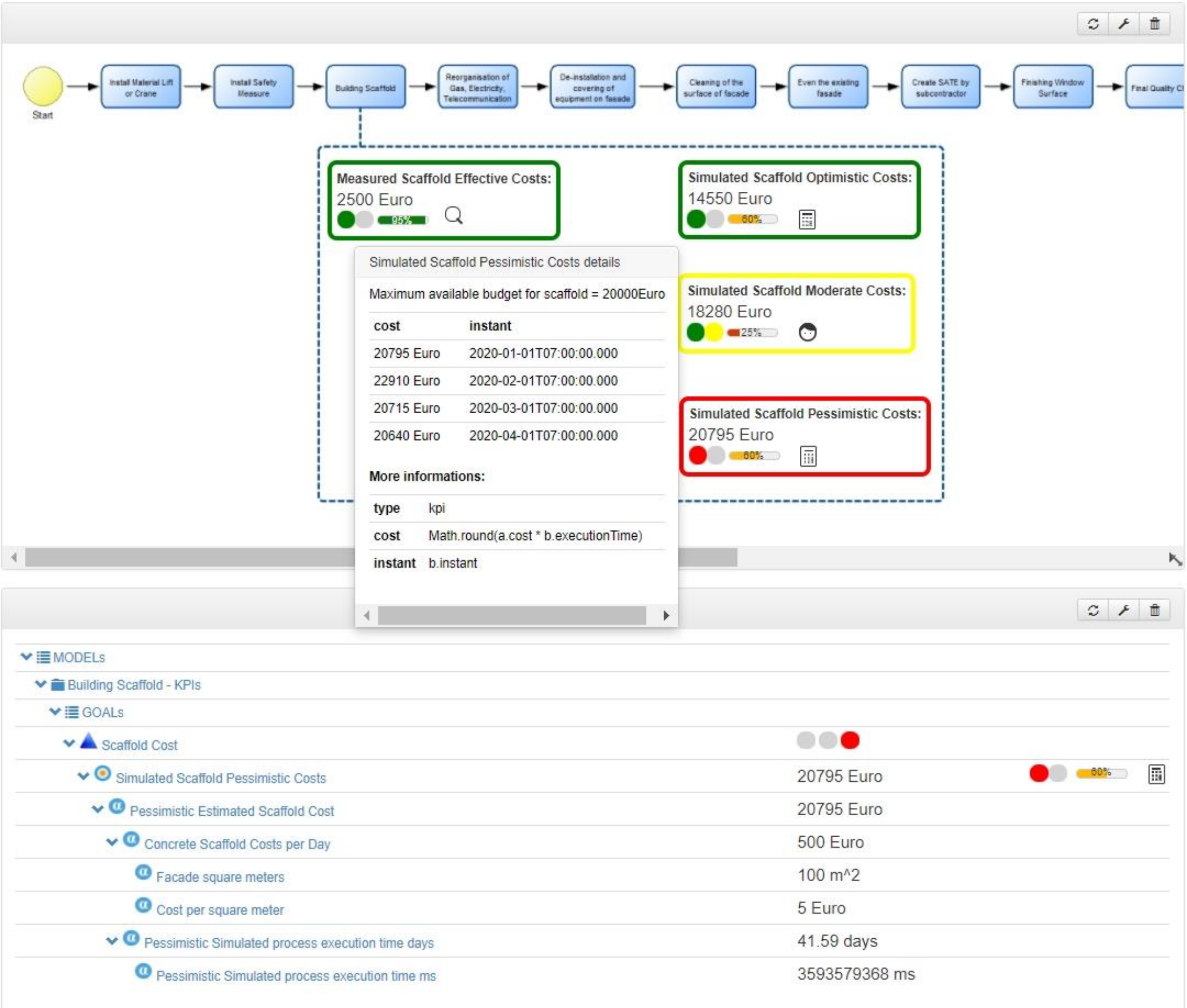

Figure 14: Simulation Output for KPIs

Such complex scenarios require complex modelling and knowledge externalization in the design phase, and hence may only be appropriate for specific cockpits. A simulation of one renovation process for the evaluation of one KPI will be introduced in the next section.

3.2 SIMULATION OF RENOVATION PROCESSES

The simulation of a renovation process complements the monitoring by providing a forward-looking simulation of the renovation process and hence estimates the expected duration and execution time. Consequently, the different costs can be derived using the results of the simulation.

3.2.1 Introduction into Process Simulation

Figure 15 shows a traditional Discrete Event Simulation (DES), where the process is interpreted as a directed graph and the time a so-called token needs to pass the directed graph is measured, ([5] Fishman, 1978). For the explanation of the principle, we focus on time, although other parameters can also be simulated, ([11] Tumay, 1996).

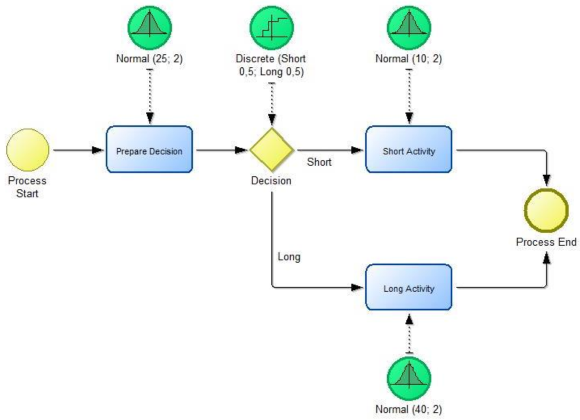

Figure 15: Process Simulation

In our sample, we applied different types of distributions for the generation of the execution time of activities and for the choice of paths. First a normal distribution that indicates that sometimes the activity is performed at different speeds, as well as a discrete distribution that indicates which path has to be performed. Based on the normal distribution on the activities and based on the discrete distribution on the decision, the execution time of the process is different. In a first step, the weights and distributions are estimated based on domain expert experience. Afterwards, adaptions and improvements can be conducted by applying process mining for instance. Parameters, weights, and distributions are changed until they can be externalised in the form of key learnings.

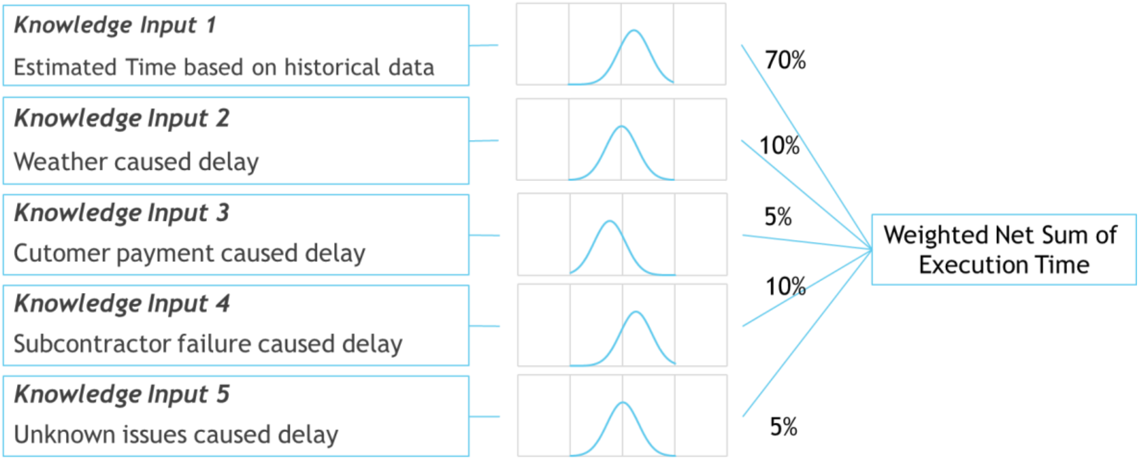

Figure 16: Mechanisms for "Knowledge-based Simulation"

Our "knowledge-based simulation" introduces a finer grained calculation of probabilities and distribution by introducing the concept of "weighted net sum" and applying it on the parameter of interest, as Figure 16 depicts. In our sample case, the "scaffold is in use" time is the parameter of interest as it is the basis to calculate the scaffold rental costs.

To calculate the respective weighted net sum the following inputs are used:

- Input 1 is historical data that provides the base distribution for the expected time.
- Input 2 is an estimation of the weather conditions causing a delay in the facade renovation.
- Input 3 quantifies the potential risk that the customer does not pay and therefore the construction site needs to pause – with the rental costs of the scaffold to be continuing.
- Input 4 refers to the potential risk that the subcontractor does not perform according to the contract, hence a substitute needs to be put in place – with the rental costs of the scaffold to be continuing.
- Input 5 indicates the likelihood of unexpected risks that may cause a delay.

Each of the knowledge input assets is described with the mathematical distribution and the weighted net summary calculates to what extend the various effects are considered.

The expert input hence needs to clarify (a) the **mathematical distribution** and (b) the different **weights** for the net summary. Both parameters are estimations that are first plausibly proposed, and continuously improved in form of observations and collaborations among experts to gain a setup that represents the individual expertise of a particular organization.

This process granularity allows forward looking simulations and enables the comparison with backwards looking measures. In case the knowledge needs to be represented on a more detailed level, the concrete process is detailed, hence the corresponding simulation can be detailed.

It must be stated that detailing the concrete process and the corresponding knowledge-based simulation becomes very complex, hence the benefit of a good simulation that warns for delays can be compensated by the effort of too detailed modelling. Therefore, the level of granularity of the concrete process strongly depends on the costs that arise in case of a threat that is simulated.

3.2.2 Extraction of Expert Knowledge about the Process

The knowledge that is used for the simulation is provided in the form of an input Excel file together with the corresponding renovation process model in BPMN Diagram Interchange (BPMN DI) format.

For each simulation run, a unique identifier with a corresponding start time (column B of Figure 17) is provided. Figure 17 introduces a simple simulation, where a default deviation (column D) is applied to the provided time (column C), which is provided as milliseconds for each activity. A loose coupling concept is provided here for the implicit mapping of semantics onto the tasks. In particular, the process tasks are mapped to the tab “C_TASK”.

	A	B	C	D
1	Install Material Lift or Crane	2019-06-03T07:00:00	1448892	default
2	Install Safety Measure	2019-06-03T07:00:00	1240270	default
3	Building Scaffold	2019-06-03T07:00:00	1531233	default
4	Reorganisation of Gas, Electricity, Telecommunication	2019-06-03T07:00:00	1465932	default
5	De-installation and covering of equipment on fasade	2019-06-03T07:00:00	1452233	default
6	Cleaning of the surface of facade	2019-06-03T07:00:00	1542882	default
7	Even the existing fasade	2019-06-03T07:00:00	1447758	default
8	Create SATE by subcontractor	2019-06-03T07:00:00	1414080	default
9	Finishing Window Surface	2019-06-03T07:00:00	1626861	default
10	Final Quality Check	2019-06-03T07:00:00	1510817	default
11	Install and Uncovering of Equipment on the facade	2019-06-03T07:00:00	1563641	default
12	Put Gas, Electricity, Telecommunication back again	2019-06-03T07:00:00	1314383	default
13	Dissassemble Scaffholding	2019-06-03T07:00:00	1418284	default
14	Cleaning	2019-06-03T07:00:00	1467456	default
15	Final Check	2019-06-03T07:00:00	1448293	default

Figure 17: Process Task List for Simulation

The execution time for each activity is the results of the combination of different knowledges. Figure 18 shows the realization of the aforementioned knowledge-based simulation. The knowledge-based simulation consists of several columns, whereas each of the columns represents the knowledge of an expert that is combined to calculate a weighted sum of the expected deviation for each activity. The calculated value is based on the mean and the deviation. Currently, we use the standard normal distribution of Excel with a given mean and standard deviation, to generate a random number, but more sophisticated tools can be used to fill the Excel sheet.

Each value is multiplied by its corresponding weight to get the weighted value, which is then converted from milliseconds to the time that is appropriate for the use case.

			Average Task Time				Payment Related Delay Time				Weather Related Delay Time			
	Weighted Caclulated time (ms)	Weighted Caclulated time (minutes)	Calculated	Weight	Mean	Deviation	Calculated	Weight	Mean	Deviation	Calculated	Weight	Mean	Deviation
3-Building Scaffold	1399907,472	23,33	20	0,60	20	3	32	0,10	30	3	26	0,10	30	3

Figure 18: Calculation of weighted time considering risks.

3.2.3 *Simulation Output Data*

The resulting simulation data is provided in an Excel sheet in the same format as the Excel file that is used for the input data – same tabs and columns. Having the same output format as the input format allows to run cascading simulations and use the results from one simulation to following simulations. Paths and traces both represent a sequence of actions. The difference between paths and traces is the presence of parallel tasks.

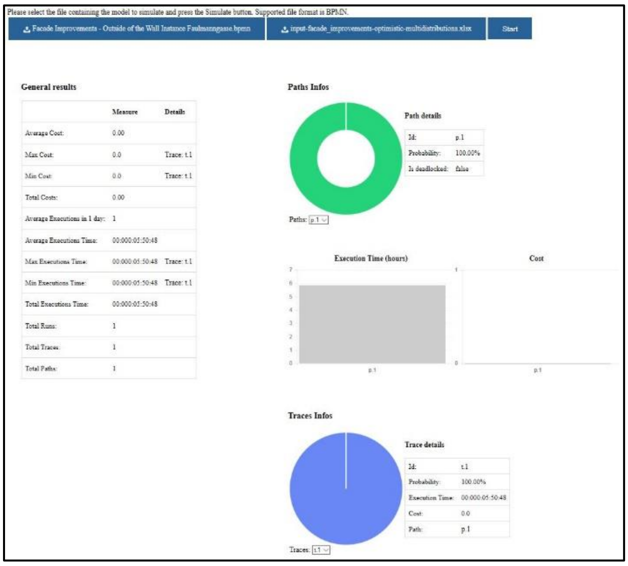

Figure 19: PWMA Simulation Output

The trace shows the tasks ordered in a sequence, whereas the path considers parallel tasks in the same sequence. So, if there are two tasks in parallel, they belong to the same path. However, there can be two traces, as one task can be in front of the other in the trace sequence and vice versa.

In case of the renovation process this detail is important, to distinguish between tasks that are performed by multiple sub-contractors (then the simple path analysis is sufficient) or performed by the same group of people like the same sub-contractor (then the more detailed view on traces needs to be considered).

Similarly, costs or dependencies may need detailed reflection via traces, in case the simple path analysis does not explain sufficiently the dependencies that occur in a certain sequence of actions. The simulation results shown in Figure 19 are used as an input for the monitoring cockpit to present the simulated KPIs. The drill-down of such a simulated KPI enables a more detailed analysis of the simulations results – e.g., the analysis of the paths and traces – by referring to the simulation result pages.

3.2.4 *Trustworthiness of Simulation Results*

Simulation results are estimations based on assumptions of possible future behaviours of a system. The challenge of trustworthiness is therefore twofold:

- To clearly indicate in the representation of the KPI, reliability displays of monitoring cockpits are worked out. The relevant figures for the KPIs can be based on three main data streams that might be compared for a higher trustworthiness:
    - **Measures** are straight forward. A sample would be that simply the occurrence of something, for instance the number of rainy days, is counted. The counts normally do not change, also if various people are counting the same occurrences.
    - **Estimations** are more complex, as those require specific knowledge. In most cases, domain experts might be responsible for the estimations, as those can narrow down the possible alternatives for figures best. Predictions and estimations cannot only be conducted by humans but also supported by artificial intelligence. The interpretations are taken over by a machine working with black-box (deep learning, neural networks) and white-box models (linear regression, decision trees)[9]. Black-box models tend to have observable input and output, however the procedures inside are not transparent. On the contrary, white-box models can be better understood and observed, hence they are often less performant.
    - **Calculations** can be supported by tools like a simulator. Keep in mind that such a simulator might lead to varying results for different simulation runs.
- To improve the reliability of the estimations and assumptions, a digital twin of the process is created, and the assumptions and estimations are approved using reflection techniques like process mining.

[9] https://blog.dataiku.com/white-box-vs-black-box-models-balancing-interpretability-and-accuracy

In ([15] Mirnig et al., 2020) the main factors affecting the reliability of an information have been identified and based on this the KPI model type has been adapted to (a) associate them to KPIs representing the specific data of interest and (b) visualize the KPI values and their relative reliability levels on the KPI dashboard. These reliability factors have been categorized in three groups, referring to (i) the reliability of the input source for the information, (ii) the information recency and (iii) the presence of a penalty related to that information. The reliability of the information sources as been addressed collecting the details of the source. In the building renovation domain, the information can be provided by (a) experts in the domain, (b) by devices and automated sensors and (c) as results of specific calculations. In case of information from expert, the trustability section of the KPI model allows to specify the level of expertise of a user in relation to a specific role, based on measurable skills. This results in a percentage indicator of the user experience in the specific field. In case of information provided by a sensor, as well as in case of information calculated by a formula the reliability is intrinsically more hight but also in this case the experience of the user who setup or use the sensor or wrote the calculation formula is crucial for the correctness of the procedure and so is considered in the reliability score.

The recency of the information is another important factor of its reliability. A close to real-time information is way more trustable than an information reported with a big delay especially in order to retrieve the cause of a problem in critical situations, as more distant events are, the more difficult is to retrace for any individual who was involved with them. The presence of a penalty related to the information can be used to integrate its reliability as people are generally more careful to report or work with data when a penalty is applied in case of wrong outcomes.

All these indicators are at the end combined using a weighted system to return an overall reliability indicator for the specific information.

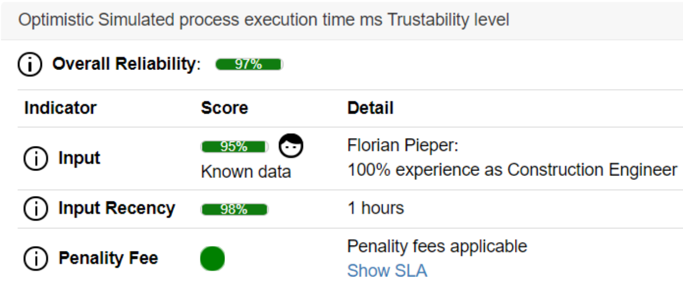

Figure 20: Trustability indicators in KPI dashboard

The KPI dashboard presented in BIMERR deliverable D6.5 allows showing all this reliability details for every KPI value with a simple bar indicator level that changes from green to red as soon as the reliability levels decrease. Detailed information of each reliability indicator is visualized such as the user providing the data and its expertise. The effective data delay and the SLA describe the penalty in case it is available.

3.3 Creation of Digital Twin with Workflow Execution

The workflow model is the effective enabler of the digital twin for the renovation process through its execution on the workflow engine (BIMERR D6.7) and the collection of the relative logs. The renovation workflow run in parallel with the renovation activities on the site, so it must be detailed enough to collect the information from all the tasks that must be executed. A refinement of the instantiated template model is for this reason required. Additionally, information about the performer and resources of each activity are required at this stage. The generated log will contain information mainly about the start and end time of each renovation activity, the resource used and notes on the activity provided by the performer. Such log data will be used to track the process status and as base for calculating some cost and time specific KPIs. Additionally, as explained in section 4.2 the workflow log will be used to calibrate future simulations with updated data and correct model inconsistencies identified after the application of data mining algorithms.

The creation of the executable workflow consists of two main steps. First the workflow process is modelled in BPMN format, describing the detailed sequence of actions that must be performed, the role of the responsible performer for each manual activity and the resources required to perform the task. In case of automatic or semi-automatic activities the details of the service to call, that realize the task functionality, must be specified. This is done referencing the microservice defined in the service definition model introduced in section 2.6. In this way the workflow engine knows which service should be call automatically when the task is executed. Commonly identified services as showed in Figure 21 are mainly about the generation of notification to the different stakeholders involved in the process and about metric collection for KPI calculation.

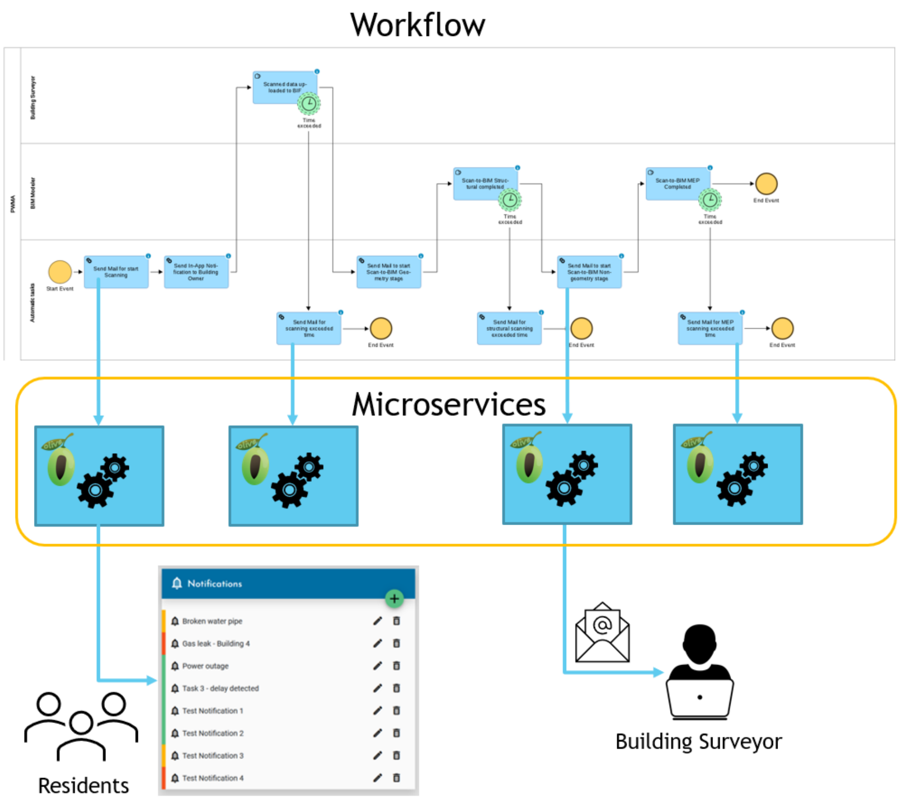

Figure 21: Workflow automatic tasks

As soon as the workflow model is completed it can be first formally verified using the PWMA tool described in BIMERR deliverable D6.5 in order to check structural problems like deadlocks or livelocks that may block the execution and correct them in time.

The second main step is the import of the finalized workflow model in the PWMA workflow engine environment described in BIMERR deliverable D6.7. Here the workflow actions are converted in specific work orders describing the schedule of the activities to perform. In this phase each work order has assigned the effective user who will perform the task, based on the role specified in the workflow model, and all the required resources specified in the workflow model are assigned to the work order based on their availability. Additionally, on every automatic task will be specified the parameters required by the assigned service.

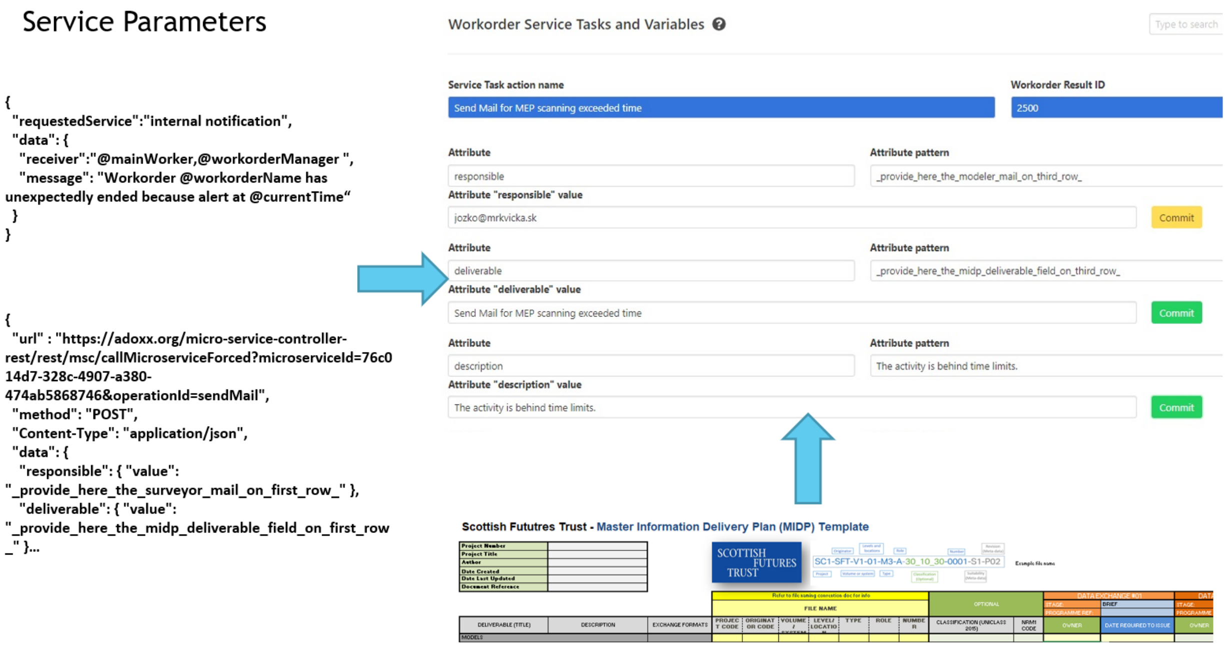

Figure 22: Work order automatic task parameters

Such parameters are exported from the microservice definition model, in a specific JSON format that will be used by the workflow engine to generate the UI for providing their effective value based on the schedule information available in the working plan (Figure 22).

As soon as this second step is completed, the workflow can be correctly executed as described in both BIMERR deliverables D6.7 and D6.9 (Figure 23).

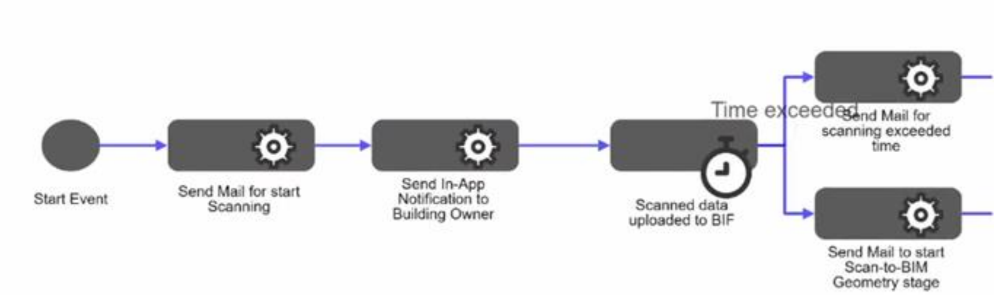

Figure 23: Work order definition

To finalize the digital twin, during the execution the real-time logs are made available through specific REST API from the workflow engine, in JSON format. Specific microservices will be used to extract the activities timestamps from such log files and convert both in CSV format as explained in section Process Mining of Renovation Process for data mining, and in the specific format for the KPI dashboard for calculation of dependent KPIs.

4. Reflection and Innovation of Renovation Processes

After the renovation work has been finished, the project manager as well as the involved stakeholders derived insights on how the extracted and designed knowledge was capable to support decision making during the execution of the renovation process. Hence, after finishing the renovation initiative, the relevant stakeholders are invited to reflect on the renovation process as well as the assumptions that have been made and adapt the externalized knowledge, which were estimations in the first place and are now – after each run of the process – improved.

In particular, we aim to:

- Improve the process templates and their usage for the offering phase.
- Improve the estimations performed in the offering phases.
- Improve the transformation into executable processes, especially for simulation relevant artefacts.
- Improve the calculations for the status measures.
- Improve the expert know-how relevant for the risk assessment.

Therefore, we propose two approaches:

1. **Collaborative Reflection of the Renovation Process** by using collaboration tools to discuss, comment and vote the relevant aspects of the renovation process model and incorporate the suggestions into the new renovation process for the next run.
2. **Process Mining** of log-files may lead to findings after analysing the different execution paths and traces. In case the log-files are enriched with additional information, we create a so-called digital twin of the renovation process, which has the potential to enable more sophisticated knowledge extraction of a process mining. Hence the potential of the process mining depends on the enriched log files.

In the following sections, we introduce the two approaches in more detail.

4.1 COLLABORATIVE REFLECTION OF RENOVATION PROCESS

Feedback and learning are collected by using a Wiki, where the renovation process model is published for a particular instance of a renovation process on a Wiki page. The corresponding stakeholders – project managers, sub-contractors, renovation domain experts, etc. – are invited to collaboratively reflect the execution of the process and comment, vote, or provide additional contributions to the process model. For this reason, a model wiki based on xWiki[10] allows commenting models and retrieving comments.

The wiki pages are structured according to the context of the process model, hence comments to particular phases can be directly related to the renovation process model. Figure 24 shows a sample of a wiki page, starting with the key figures of the renovated object. The corresponding renovation process is automatically extracted and the graphic as well as additional descriptions are published on a wiki page. Each activity is described in a sub-page. Comments addressing a particular activity – in our sample we introduce a comment about budget forecasts – can be imported into the model, as the context of the renovation process is implicitly provided in the structure of the wiki page.

[10] https://www.xwiki.org/xwiki/bin/view/Main/WebHome

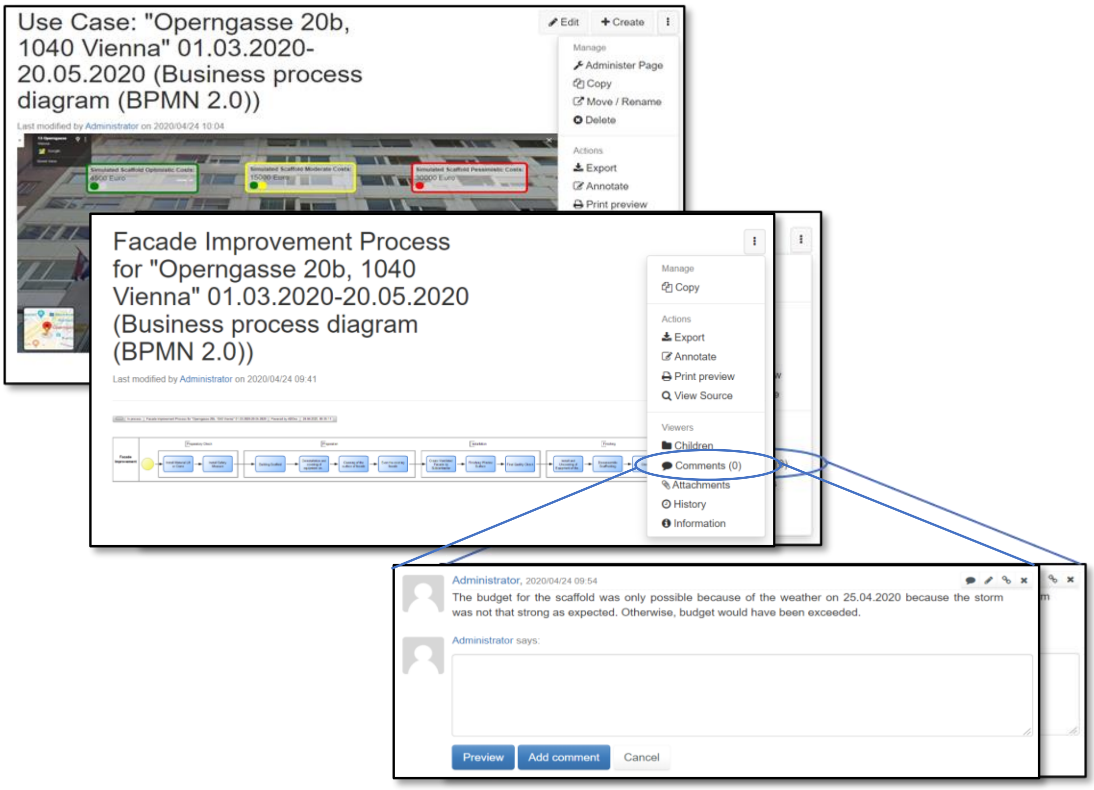

Figure 24: Collaborative Reflection of Renovation Process

After all comments have been collected, they can be retrieved back into the model, as explained in BIMERR deliverable D6.5. With this mechanism we propose lessons learned in order to improve the knowledge that is externalized in the models and in the different configurations of the simulation.

4.2 Process Mining of Renovation Process

Process mining is used to support the analysis and evaluation of business processes. Trends and patterns in the process data are interesting for the improvement of processes. Therefore, data mining algorithms are applied on the process data. Not only the efficiency of processes should be improved by process mining, but also the understanding, especially dependencies and interconnections should be clarified. It might not only be necessary to improve specific tasks regarding their execution time, sometimes a restructuring of the whole process is more reasonable. For mining the renovation processes, the process mining platform Celonis[11] is used. In the following, a description of the preparations, the creation of an analysis workspace and the results are provided based on our outside facade renovation process sample.

Workflow logs are first collected directly from the workflow engine and saved in CSV format as show in Figure 25. This is done through a microservice that communicates with the workflow engine API, extracts the status for each renovation activity, generates a CSV file and also use such information for the calculation of KPIs about the current status of the renovation process. The workflow log CSV format will be the same of the one resulting from the simulation. In this way, the process mining can be performed on the simulated log and the results be validated on the effective execution log.

	A	B	C	D
1	Run-1	Install Material Lift or Crane	2020-01-03T01:04:41.817	151481817
2	Run-1	Install Safety Measure	2020-01-04T06:12:12.156	148050339
3	Run-1	Building Scaffold	2020-01-06T10:38:47.291	188795135
4	Run-1	Reorganisation of Gas, Electricity, Telecommunication	2020-01-09T11:36:16.977	219449686
5	Run-1	De-installation and covering of equipment on fasade	2020-01-10T02:37:33.490	97276072
6	Run-1	Cleaning of the surface of facade	2020-01-12T04:55:35.579	137882530
7	Run-1	Even the existing fasade	2020-01-14T04:56:11.199	172835620
8	Run-1	Create SATE by subcontractor	2020-01-16T00:03:41.840	155249885
9	Run-1	Finishing Window Surface	2020-01-17T02:24:28.258	138047174
10	Run-1	Final Quality Check	2020-01-19T02:05:02.209	171633951
11	Run-1	Install and Uncovering of Equipment on the facade	2020-01-22T08:01:58.851	237416642
12	Run-1	Put Gas, Electricity, Telecommunication back again	2020-01-24T01:28:36.610	149197210

C_START_EVENT | C_TASK | C_END_EVENT | C_EXCLUSIVE_GATEWAY

Figure 25: Workflow log samples in CSV

A new workspace for analysis is created by importing the relevant process data. Within this analysis, we can choose the process explorer, where we can see a snapshot of the identified process. Various tabs provide detailed information about throughput times or the analysis for example. In Figure 26 the analysis tab for our sample workspace is shown.

[11] https://www.celonis.com/

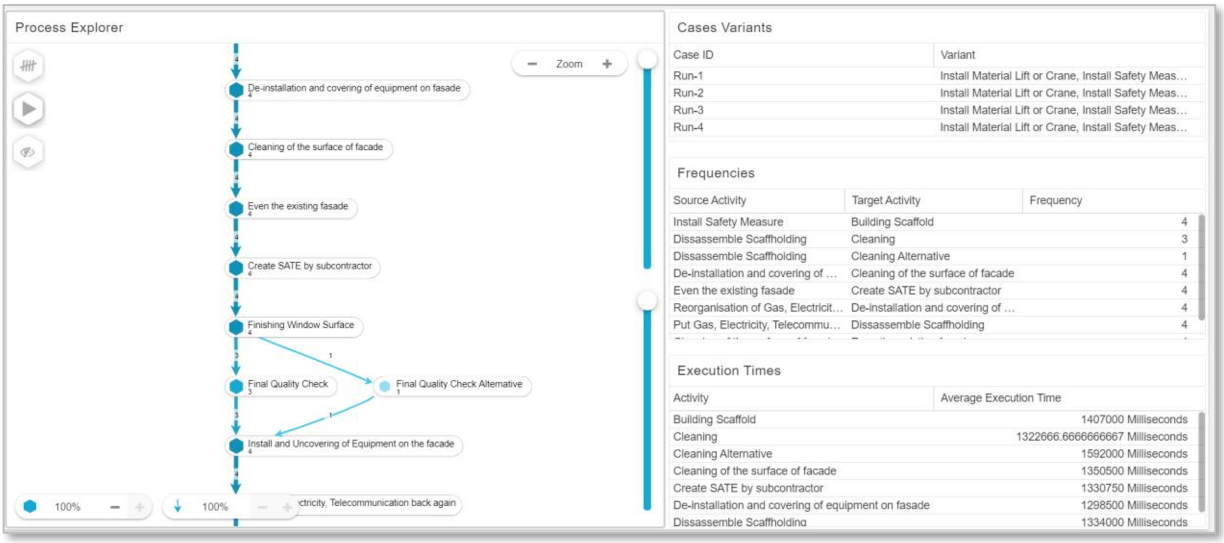

Figure 26: Celonis Analysis Workspace

Results of the process mining will give information about the alignment of the digital twin of the renovation process with the effective renovation activities, finding unhandled and exceptional cases and activities or inconsistencies in the flow of the renovation process. Additionally, the results are used to calibrate the models for future simulations with updated information on choices probabilities and average execution times of each activity.

The results of the process mining strongly depend on the available log data that are mined. The design of the renovation workflow which generates those log files, influences the quality of the log-file. Hence, the knowledge that can be extracted from process mining depends on the construction of the workflow and how the so-called digital twin of the renovation process – in form of the log file – is created by enriching the workflow log with complementary information.

The effort in producing such an enriched digital twin needs to be in a relation to the resulting added value as additional lessons learned. Stepwise enriching the digital twin of the renovation process enables the lessons learned that result in a reasonable added value.

5. Repository of Renovation Processes

5.1 Renovation Process Templates

In collaboration with the domain expert partners in BIMERR, the main tender scenarios for concrete use cases were collected in a process landscape, shown in Figure 27 and four major categories of processes were identified:

1. Improvement of Accessibility.
2. Improvement of Thermal Envelope.
3. Improvement of Installation.
4. Other Customer relevant Aspects.

Renovation processes focusing on specific areas, are sorted to one of those categories. It is also important to mention that not all processes in the mentioned categories are conducted at every construction site. The selection of processes depends on the customer, the building and expert evaluations, and suggestions. For example, not every building has a balcony, so this process is not obligatory. It might also be the case that some parts of the building are in good shape, whereas others are not.

For the first category, improvement of accessibility, especially two renovation issues are relevant. Therefore, there are two processes: (1) adding a ramp and (2) installing an elevator. Both might be essential so that the building is accessible also by handicapped persons. In particular, the obligation is the elimination of architectural barriers to ensure accessibility.

Secondly, there is a variety of improvements regarding the thermal envelope. Beginning at the bottom of a building, the ground slab can be improved. Furthermore, there are also processes for improving the first level slab and all other levels. There is an additional process for decks, floor, and slab improvements. Two more processes aim at improving a balcony and the windows. Especially, two kinds of facade improvements (1) outside and (2) inside may be essential to resolve thermal issues, as well as the renovation of the roof. Although the renovation of the carpentry might not have such a high influence on the thermal aspects of a building as the facade, smaller improvements can also be reached with this aspect.

Thirdly, the installation can be improved through attaching additional features or adapting existing ones. Changing the Heat system or the Air Conditioning system might improve the installation a lot throughout all seasons of the year and adding photovoltaic or solar panels increase the environmental friendliness of power production and might decrease the electricity bill in the long run.

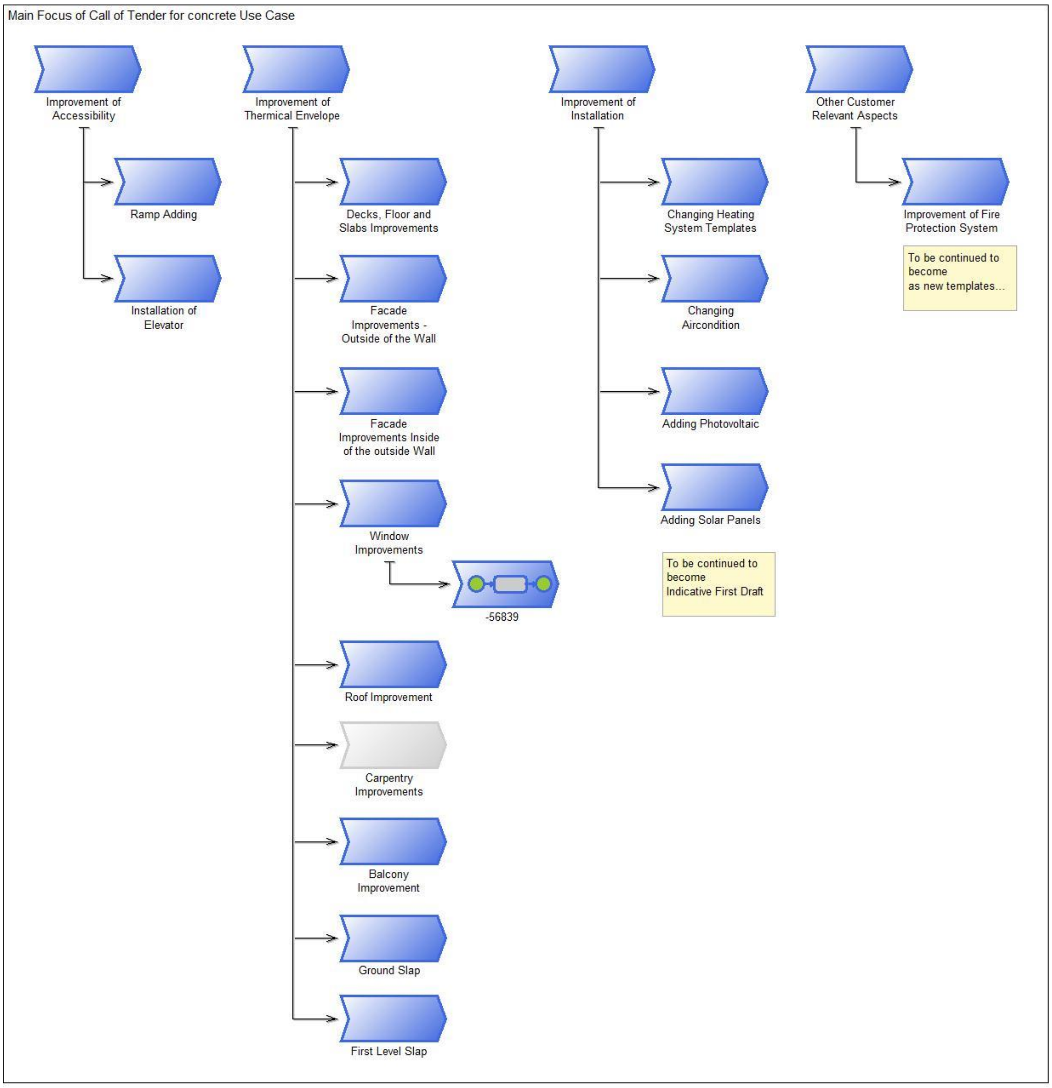

Figure 27: Process Landscape

The following subsections describe the five template processes required for a common building renovation. The template processes are created in BPMN with the BIMERR PWMA Modelling Toolkit. They are exported as BPMN DI for further processing steps. These template processes are valid for various construction sites. The processes include start and end events, gateways (parallel and/or exclusive) and tasks. The decision points, like exclusive gateways, in the template processes are only used on the template level. When a template process is transformed into a concrete use case, there is no need for a decision, as they are already defined. As already mentioned, the template processes are valid for a variety of construction sites. Therefore, additional information and parameter configuration is necessary for transforming a template process into a concrete use case. However, the introduction of knowledge filters, as well as rule-based systems enable the transformation of template processes into concrete use cases by checking various parameters. A detailed description of each template process can be found in the subsections below.

5.1.1 Roof Improvement – Outside

The roof improvement outside process, shown in Figure 28, explains the tasks required for external insulation. The box around the process, also called pool, indicates that the process is fully conducted by one organization. In this case, a common construction company or an enterprise specialized in outside roof insulation may take over this part of the renovation.

The start event indicates the start of the process. A parallel gateway follows. This means that the following two paths are conducted in parallel.

The first path starts with **installing safety measures**, which is required to ensure the safety of the construction workers and other passers-by. This task might include blocking the street or sidewalks that are close-by.

Afterwards, for easing the construction work the **scaffold is built-up**. This task includes the installation of handrails, the usage of a crane and various other security equipment. Meanwhile in the second path, it is **checked whether everything is prepared**, so that the real roof renovation can start.

A converging gateway merges the two parallel paths. Moreover, two more tasks are conducted in parallel. First, the existing **roof layer is cleansed and removed**. This step is necessary, as the new layer requires a smooth surface. For instance, all broken layers that might be drenched or mouldy, must be removed to guarantee the correct functioning of the new installations. Secondly, in parallel the **waste** resulting from the cleansing task is separated and disposed in accordance with the regulations. Again, both paths are merged. As the temperature inside the building and/or the attic is usually different compared to the outside temperature throughout the year, an installation for coping with vapor is necessary.

Therefore, the next task of the process is the **placement of a vapor layer**. Some characteristics should be fulfilled for classifying a roof as good. For instance, the heat, produced by the heating inside of the building should not be given off through the roof. For this reason, an insulation panel is placed that should provide insulation. In particular, in seasons with cold weather the insulation panel can save heating costs. A variety of insulation material, like fiberglass, mineral wool, cellulose, or foam, can be used for this task. However, not only the roof surface area must be insulated, but also the parapet wall.

So, the next process task is the **insulation of the parapet wall**. There are two different tasks, which are one after the other, for the insulation, as the roof surface and the parapet wall might require other insulation material as well as different equipment. One major function of the roof is to keep everything below dry. Hence, another additional layer is placed – the **waterproof layer**. For the installation of the waterproof layer, it is common to use bitumen. Bitumen is a mixture of sticky, viscous and waterproof organic substances.

Although this material is mainly used for road constructions, the characteristics are also beneficial for waterproofing roofs, especially flat roofs. A **sheet metal roof** is used for finishing. The additional layer of metal on top is exposed to weather and should prevent most influences from outside. For instance, it must withstand a storm, rain, sunshine, or hail.

The next task, which is **the installation of a drainage module**, is also very important considering weather and environmental influences. Before ending the roof renovation on the outside, everything is **cleaned** and cleared up.

This task includes the disposal of waste, the packing of equipment and the removal of raw material that was not needed. Finally, a **final quality check**, especially considering the water proofing issues, is conducted. When the quality check was successfully, the roof improvement can be completed, which is indicated by an end event in the process.

Notice, that the scaffold is not removed at the end of this process, as it might be required for other renovation sub-processes after the outside roof improvement.

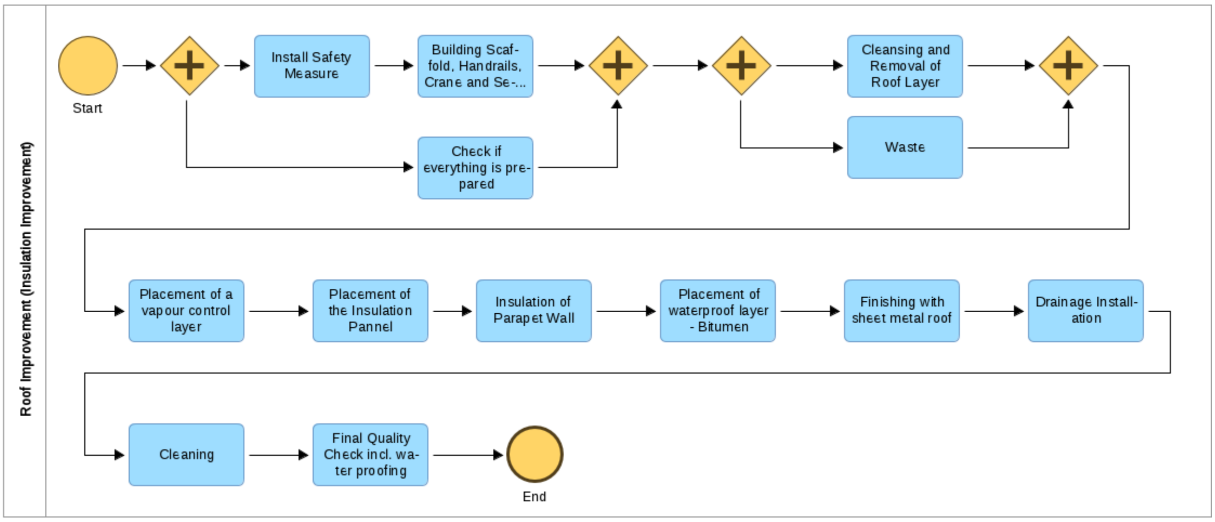

Figure 28: Roof Improvement Template – Outside

5.1.2 Roof Improvement – Inside

The roof improvement inside process, shown in Figure 29, describes the tasks required for internal insulation. The box around the process, also called pool, indicates that the process is fully conducted by one organization. In this case, a common construction company or an enterprise specialized in attic roof insulation may take over this part of the renovation.

The process start is shown by the start event. A preparation task follows. The reason for this task is to **check if everything is prepared**. For instance, the attic must be accessible, and anything stored in the attic must be relocated for the improvement period.

A decision follows after making sure that all required preparations are finished. It has to be decided whether the existing layers must be removed, or if their condition is good enough so that they can be kept. Following two tasks are conducted in case the existing layers must be removed, otherwise they are skipped.

First, the **existing roof layer is removed** and the surface, as well as the area around is cleansed. All broken elements are sorted out and parts in good condition might be recycled for other purposes. Secondly, the **waste** resulting from the cleansing task is separated and disposed in accordance with the regulations.

Afterwards, one more decision, which is based on the existing layers and their conditions, has to be taken. The question is, whether a vapor control layer is required or not. If yes, one additional task, explained in the following is conducted, otherwise this task is simply skipped. As the temperature inside the building and/or the attic is usually different compared to the outside temperature throughout the year, an installation for coping with vapor is required, if not available.

Therefore, the next task of the process is the **placement of a vapor layer**. Some characteristics should be fulfilled for classifying an attic as good insulated. For instance, the heat, produced by the heating inside of the building should not be given off through the attic. For this reason, an **insulation panel** is placed that should provide insulation.

In particular, in seasons with cold weather the insulation panel can save heating costs, as normally, the attic is only used for storing things and therefore not heated or cooled. A variety of insulation material, like fiberglass, mineral wool, cellulose, or foam, can be used for this task. However, not only the attic surface area must be insulated, but also the knee wall.

So, the next process task is the **insulation of the knee wall**. The knee wall is not higher than a meter and should support the roof construction, regarding stability. Normally knee walls can be found in older buildings, which rather require renovation compared to newer ones. These older buildings do often have an attic, which is the ceiling of the top floor.

The space emerging with the knee wall is quite small, so usually it is not high enough for a person to stand up there. There are two different tasks, which are one after the other, for the insulation, as the roof surface and the knee wall might require other insulation material, as well as different equipment. **Case specific finishing** is carried out after the insulation.

This might for instance include the dealing with special parts, as not every attic has a perfect rectangular or quadratic shape. Also, chimneys ranging from inside the building, over the attic to the roof, must be considered. Before ending the roof renovation in the attic, everything is **cleaned** and cleared up. This task includes the disposal of waste, the packing of equipment and the removal of raw material that was not needed.

Finally, a **final check**, especially considering the various layers and their attachment, is conducted. When the final check was successfully, the roof improvement of an unheated attic can be completed, which is indicated by an end event in the process. It should be noticed, that the scaffold is not removed at the end of this process, as it might be required for other renovation sub-processes after the outside roof improvement.

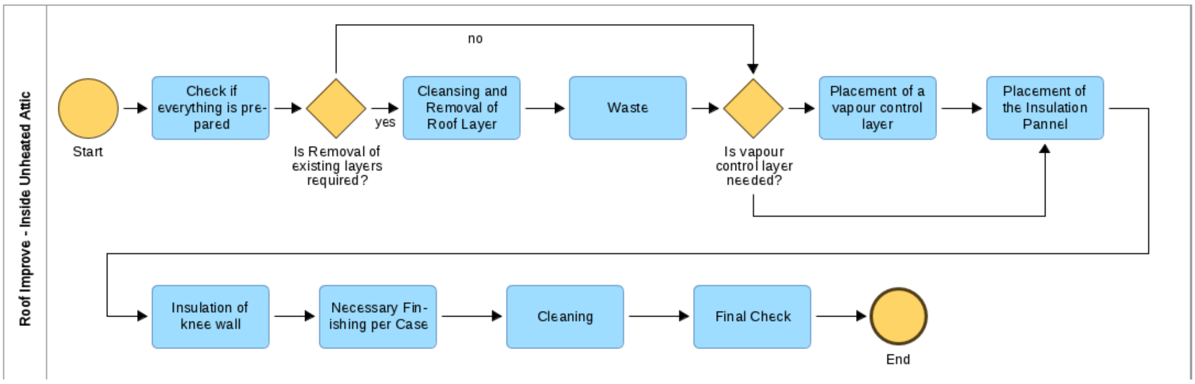

Figure 29: Roof Improvement Template – Inside

5.1.3 Facade Improvement – Outside

The facade improvement outside of the wall, as visualized in Figure 30, describes the required tasks for the renovation of the facade. The box around the process, also known as pool, indicates that the process is fully conducted by one organization.

In this case, a common construction company or an enterprise specialized in facade renovation may take over this part of the building improvements. A start event indicates the start of the improvement process. The first task that must be conducted is the **installation of a material lift or crane**. As most buildings are higher than a person, the required material for the renovation must be lifted. As both the material and the tools can be quite heavy, large, and impractical, a lift eases the job of the construction workers.

The next task is the **installation of safety measures**, which are essential for the construction workers as well as passers-by. This task might include blocking the street or sidewalks that are close-by. Also blocking the construction area might be reasonable that nobody is injured in case if anything falls down. As already mentioned, most buildings are higher than one story, so a supportive structure is needed. For this reason, a **scaffold** is built up.

The scaffold allows the construction workers to easily reach each story of the building from outside. The scaffold is usually standing till the end of the renovation process. After finishing the scaffold, a decision about the reorganization of gas, electricity of telecommunication must be taken. In loads of cases a reorganization is necessary, if not, the next task is simply skipped.

Various changes on the outside of the building might require the **reorganization of gas, electricity or telecommunication**. Also, if the condition of the existing installations is not the best, it might be more reasonable to exchange and reorganize them during the renovation, as to have another renovation project in the near future.

The **deinstallation of equipment covering on the facade** outside follows. This includes for example removing loose parts of the facade or protecting equipment from external influences. It is usually the case that the pre-processing steps resulted in some dirt and waste. For this reason, the next task is about **cleaning the facade**. The main dirt and dust are removed in this task. It is necessary that new layers and installations can be attached on the existing facade. It is often the case that the facade is not a hundred percent smooth and even. Therefore, the **facade is evened**.

After conducting this correction of the facade surface, the facade type must be chosen. There is either a **ventilated facade or a SATE system**. Only one of those two types can be chosen. The ventilated facade system is also known as double-skin facade. It consists of two layers that are separated by a hollow space filled with air, while the SATE is an insulation system composed of panels attached to the wall.

The main purpose of this space is to keep out rainwater and cope with the temperature differences. Benefits of the ventilated facade are that the amount of heat absorbed by the building is reduced in summer and heat inside is better retained in winter. In contrary, the SATE system is an exterior thermal insulation system that applies tiles on the outside of the facade. The panels can directly be mounted on the facade, so no supporting structure is needed. Another benefit is the low thermal conductivity of the tiles.

The panels are also tensile and resistant to compression. Some characteristics of the SATE system are the reduction of the building energy consumption, the elimination of thermal bridges or the simple installation for instance.

The next step is again not depending on the chosen surface, as it is required for all buildings. Not only the facade, but also the **window surface must be finished**. This might include the cleaning and smoothing the surface for further processing steps. Afterwards, the **final quality check** follows. In particular, the improved installations are checked with a check list. This is done before the removal of the scaffold, in case that any further actions must be taken. If everything was successful, the **deinstallation and uncovering of the equipment** follows.

The following task is only relevant, if the decision was to reorganize gas, electricity and telecommunication. If this was the case, **gas, electricity and telecommunication must be put back** again. Efficient processes normally reorganize gas, electricity of telecommunication directly in the beginning. This means that the disassembly and assembly are conducted in one step, which is beneficial as there is continuity in energy services for the residents. This task can be used to control the installations, or it is simply left out.

At this point, the facade renovation is nearly finished. For this reason, the scaffold is not needed anymore, so the **scaffold is disassembled**. Before ending the facade renovation on the outside, everything is **cleaned** and cleared up. This task includes the disposal of waste, the packing of equipment and the removal of raw material that was not needed. Finally, a **final check** is conducted. When this final check was successful, the outside facade improvement can be completed, which is indicated by an end event in the process.

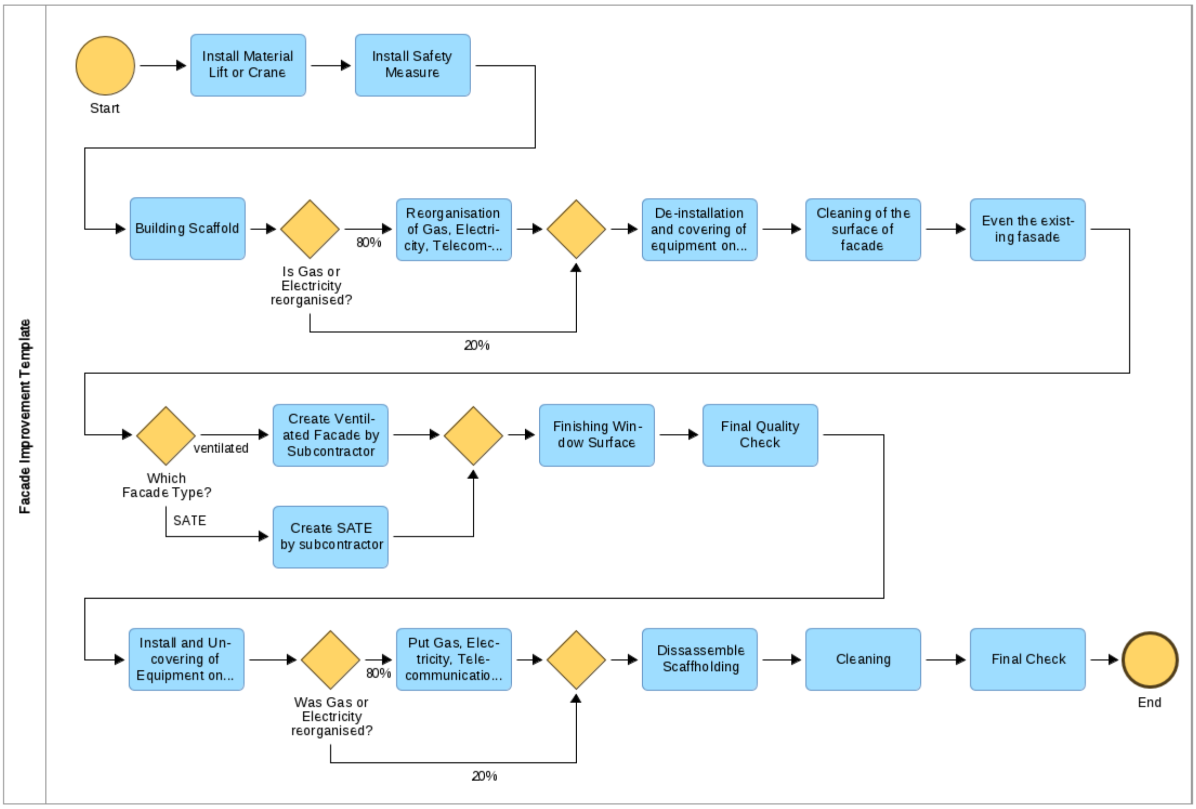

Figure 30: Facade Improvement Template – Outside

5.1.4 Facade Improvement – Inside

The facade improvement inside of the wall, as visualized in Figure 31, describes the required tasks for the renovation of the facade inside of the building. The box around the process, also known as pool, indicates that the process is fully conducted by one organization. In this case, a common construction company or an enterprise specialized in inside facade renovation may take over this part of the building improvements.

The start event is the start of the improvement process. First, a preparation task follows. The reason for this task is to **check if everything is prepared**. For instance, the rooms must be accessible, anything stored in the rooms must be relocated and wall decoration like pictures must be removed for the renovation period. Afterwards, all **covers must be**

unmounted. If they are in a good condition, they might be reused after the improvements, otherwise they are disposed and replaced with new components. For example, sockets, lights or sliding doors have to be unmounted for an easier processing of the facade renovation. A decision follows after making sure that all required preparations are finished. It has to be decided whether the existing indoor layers must be removed, or if their condition is good enough so that they can be kept.

Following three tasks are conducted in case the existing layers must be removed, otherwise they are skipped. First, a **waste removal system** is installed. This waste removal system can for instance include the delivery and setup of a waste container for bulky components. Normally a lot of rubble emerges, when the indoor layers are removed, so the waste system is absolutely necessary to keep the construction site well organized and safe.

The second and the third task required after the removal decision are conducted in parallel. Second, the **existing indoor layer is removed** and the surface, as well as the area around is cleansed. All broken elements are sorted out and parts in good condition might be recycled for other purposes. Third, the **waste** resulting from the removal of the existing indoor layer is separated and disposed in accordance with the regulations.

Not only on the outside, but also inside of the building, insulation is required. Therefore, the next task is to **apply insulation panels**. Lightweight mortar can be used for the insulation. Mortar is a mixture of sand, water and cement that can also be used to fix bricks or stones when building walls. The lightweight version can be fibre reinforced. The material has various benefits like breathability, compatibility with insulations systems and easy usage. It is important to notice that this task has to be checked with respect to the ventilated layer for electrical installations, as both depend on each other and have to go together.

Moreover, **screw anchors** are applied for further processing steps. The screw anchors allow the connection of structural elements and the reinforced concrete foundation. They can transfer the force based on concentrated pressure exchange between screw and concrete through pitches. To make the whole construction more stable, a **reinforcement**

mesh is applied by using mortar. This mesh is not only used for stability, but also for reinforcing the heating systems of the buildings' facade and the interior plaster and/or concrete works.

The mesh can be made of fiberglass, it has a high level of mechanical strength, a strong weaving and it is mostly resistant to alkali. Afterwards, the **plastering** is finished. Mostly a mixture of lime or gypsum, sand, water and fibre are used. It is applied in a pasty form to walls and hardens after drying.

A smooth and protected surface emerges with this wall coating. In the beginning of the process, covers were unmounted. Now it is time to **mount the covers**. For instance, sockets are installed, as well as switches or light. Also, an electrician should be involved in this task, as it must be clarified what happens with the electric installations. Finally, a **final quality check** is conducted. When this final check was successfully, the inside facade improvement can be completed, which is indicated by an end event in the process.

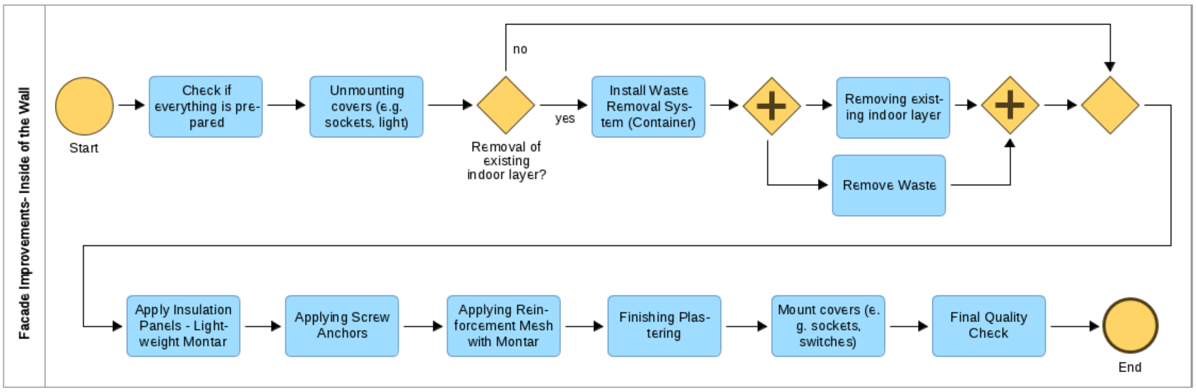

Figure 31: Facade Improvement Template – Inside

5.1.5 Window Exchange

The window exchange, as represented in Figure 32, describes the required tasks for the renovation of the windows of the building. The box around the process, also known as pool, indicates that the process is fully conducted by one organization. In this case, a common construction company or an enterprise specialized in window renovation may take over this part of the building improvements.

The start event is the start of the window exchange process. First, a preparation task follows. The reason for this task is to **check if everything is prepared**. For instance, the windows must be accessible, anything stored on the windowsills must be relocated and decoration elements like curtains must be removed for the renovation period. The next task is the **removal of the existing windows**. All broken elements are sorted out and parts in good condition might be recycled for other purposes. In most cases, the old windows are exchanged due to bad thermal characteristics.

The following tasks are then conducted in parallel. Where the first path holds a sequence of five tasks and the second path is responsible for the waste. The waste resulting from the window exchange is separated and disposed in accordance with the regulations. The first path contains tasks for the real window exchange. First, the **windows are positioned and fixed**. This means that the new components are inserted into the facade at the correct position and temporary fixed. For sure, the temporary fix is not enough, so the second task in this path is the **sealing with foam and/or silicone**. The sealing must be resistant to external influences like air and water. For this reason, PU foam and/or silicone are used here. The polyurethane foam has a variety of possible applications, as it can be highly flexible or rigid. Also, structures ranging from solid to open cellular structures are available.

One of the most important thermal characteristics is that they do not melt when they are heated. Silicone is a synthetic material that can have different viscosity. Silicones are usually heat-resistant, have a low thermal conductivity, are light resistant and have properties for electrical insulation.

After the sealing, **waiting time** emerges, as the sealing material needs some time dry. This time depends on the used material, as well as on external influences like the temperature. It may take only some hours to more than a day. Fourth, **the installation of the windowsills** follows. The shelves are formed by the bottom part to the frame of a window. They are on the outside and on the inside of the building.

They are not only used for decoration aspects, but also hold the window and the glass in place. Furthermore, on the outside of the building they keep rainwater away from the wall directly below the window. They can be made of masonry construction or in wood framing for instance. The path of exchanging the windows is finished by a **quality check and an inspection**.

For instance, it is inspected if the windows are waterproof, if they are fixed and their opening and closing mechanism works correctly. Finally, a **final quality check** is conducted. When this final check was successful, the window exchange process can be completed, which is indicated by an end even.

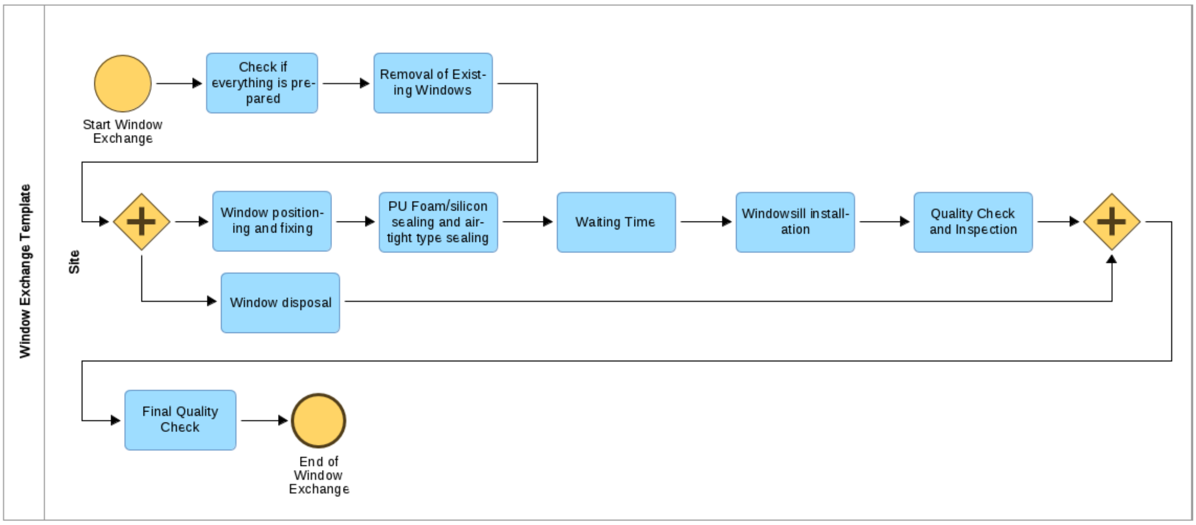

Figure 32: Window Exchange Template

5.2 Renovation Process KPI Models

KPIs can have various characteristics, ([1] Amor & Ghannouchi, 2017; [6] Florès, 2014) and in order to provide a catalogue of basic KPIs and key figures, their characteristics and foundations are described below[12]. The idea of such a catalogue is that the KPIs and their concepts can be used modularly. This means that the relevant figures are picked individually for each part of the renovation process. This kind of modular system enables easier usage and reduces the complexity for the overall renovation process. In specific, some of the use cases and process phases might require specific KPIs. For instance, if a subcontractor is involved in the process, an additional KPI for the subcontractor personnel costs makes sense. Also, the aggregation of estimations and assessments are eased through the implementation of KPI catalogue.

The following main characteristic for KPIs seem to be essential for differentiation, however there is a variety of other aspect. Notice, that the purpose and the context of the KPI might influence the characteristics and their manifestation.

1. **Limitation**: There are three main options on how KPIs can be limited. Firstly, they can be limited from top, which means that there is a set time limit or a maximum budget. Secondly, bottom limited KPIs indicate that there is an "at least" relationship between the KPI and its threshold. For instance, innovation and overall quality must be ensured, which can be supported by a minimum training and education budget for each employee. Thirdly, KPIs cannot only be limited from one side, but also from both. Research would be an appropriate example here. On the one hand, it is important to foster new developments, but in contrary, a limited number of resources is available for this topic.
2. **Tolerance**: There is a strict differentiation between KPIs with and without tolerance, as those two alternatives are mutually exclusive. If there is no tolerance, the KPI and the calculated measure can simply be compared. On the contrary, if there are KPIs with tolerance the level of tolerance must be defined in order to get a clear measure. For the definition of the tolerance level, statistical computations like standard deviation or confidence intervals might be used.
3. **Indicator**: Special thresholds are used as an indicator. Various stages are reasonable. The two most important stages are warning or critical. If an indicator points out that there is an early warning for a specific KPI, actions and plans can be adapted to meet the original goals. The critical indicator should pop up, in case of crucial risks or problems. The granularity for the indicators can be set as

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[12] https://www.brightgauge.com/blog/quick-guide-to-11-types-of-kpis

required. However, a threefold division with colour codes – red, yellow, green – like used for traffic lights might be reasonable. If the granularity is too deep, the system might get unnecessarily complex and the benefit of getting a fast overview might get lost.

4. **Range**: Especially key figures measuring opinions and subjective information must incorporate various possible answers. Ranges and categories might support the transformation of individual knowledge in measurable metrics. For instance, opinions and expectations can be categorized in positive, negative, or indifferent. In most cases, an even number of categories is more reasonable to find out at least a direction instead of getting stuck in the middle category.

In particular, the aggregation of the different KPIs and key figures offers a huge potential for improvements, as the exact calculations and rough estimations as well as the information from domain experts can be incorporated at one time. A variety of perspectives on the problem is considered, hence additional information that creates value for the renovation process is identified.

Qualitative KPIs

Qualitative KPIs are sometimes seen as no real measures, as they do not work with numbers, but with classifications. We consider qualitative KPIs as human-driven source of information and interpret them as knowledge and experience coming from domain experts. This in addition to simple assessments also support the overall analysis, based on the experience of domain experts. Question like "why" something is done this way as well as of "how" it is done are possible. Indicative measures include customer satisfaction, personnel time, personnel costs, experiences, productivity, resources, sub-contractors, machine down times, etc.

Quantitative KPIs

Quantitative measures can further be divided in continuous (decimal) or discrete (integer). Continuous measures can take any value, whereas discrete ones often use scales for rating something. As quantitative KPIs are measured by a number, they are straight forward.

- Quantitative continuous variables: kilograms, hours, euros, meters, …
- Quantitative continuous measures: average delivery time, average throughput time, average construction costs, average net profit, average personnel costs, average personnel time, …
- Quantitative discrete variables: satisfaction level, complaints, accidents, attitude, experience, productivity, …
- Quantitative discrete measures: average customer satisfaction, number of down times of the digger, percentage of projects completed on time, average number of ill employees, percentage of men in the renovation sector, percentage of full-time positions, …

Threshold/Tolerance – with or without

Thresholds for KPIs are set to enable the functionality of warning systems. They can either be set statically before the process execution or they can be set dynamically during the process execution. The selection of an appropriate threshold mostly depends on the seriousness of the influence of the related KPI. A balance between a realistic and a motivating threshold must be found. The KPI get reasonable through thresholds since they have to be compared to any reference value. As sometimes a strict threshold does not make sense, a tolerance level is introduced. For this tolerance level often statistical evaluations like variance or standard deviation are used. If there is a significant difference between the KPI and the threshold considering the tolerance, a problem might be indicated.

Indictors and Early Warning Systems

Indicators try to find out trends, which is very helpful for the identification of problems and risks. One main difference between indicators and KPIs is that indicators focus on identifying problems beforehand, whereas KPIs are often applied afterwards.

There are various types of indicators. For predicting an outcome, trends are analysed by using leading indicators. Most of the times using only leading indicators is not enough. Success or failure of the results are measured after a certain period of time by lagging indicators. Resources and their availability can be measured by input indicators. Efficient courses of the process can be measured by so called process indicators. Output indicators show success or failure of business process activities. Practical indicators are tailored to a specific business, company, or domain. Directional indicators are used to show trends like improvement, decline, maintaining or crash. A lot of indicators are of financial nature to ensure economic stability and growth.

5.2.1 Simple Cost Driver: Cover Sheeting Material Costs Sample

Cover sheeting material is used for various purposes in a renovation process. Basic applications would be the covering of the equipment or the covering of the construction site. The amount of needed cover sheet material is highly influenced by the environment, like the weather or the season (Figure 33). If there is a rainy season, much more cover sheeting material is required. However, the cover sheeting material is normally bought in reels. So, there is fixed price for each reel. For this reason, the number of reels matter as if there are two reels used half, both have to be paid, although there is something left. For the cover sheeting material this might not be critical, as the left cover sheeting can be reused on other construction sites.

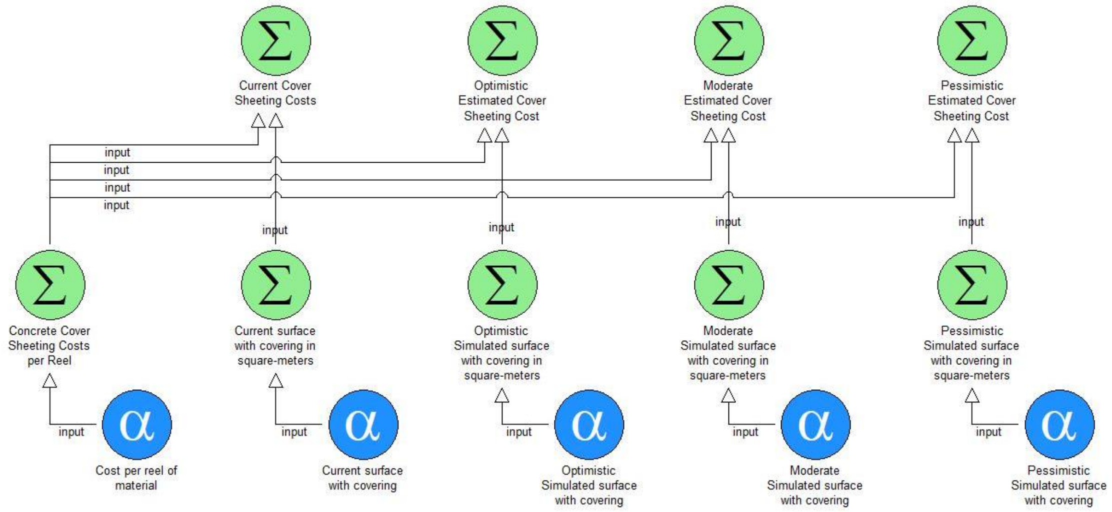

Figure 33: KPI Data Calculation Model - Cover Sheeting Material Costs Sample

5.2.2 Calculated Cost Driver: Subcontractor Personnel Costs Sample

Personnel costs are commonly calculated on an hourly basis according to categories. Subcontractors or own staff costs are therefore multiplied per category and per hourly rate. The different cost categories need to be defined, either per sub-contractor or by own staff and a continues reporting using time sheets are used to calculate the consumed budget. There are different ways to monitor the personnel costs, one way is to delegate the cost control to the sub-contractor, which is simpler but on the other hand, the project manager is not aware of any issues – possible over- or underspending. Therefore, it is advisable to at least estimate the working time with an average hourly rate. This sample is in the model in Figure 34.

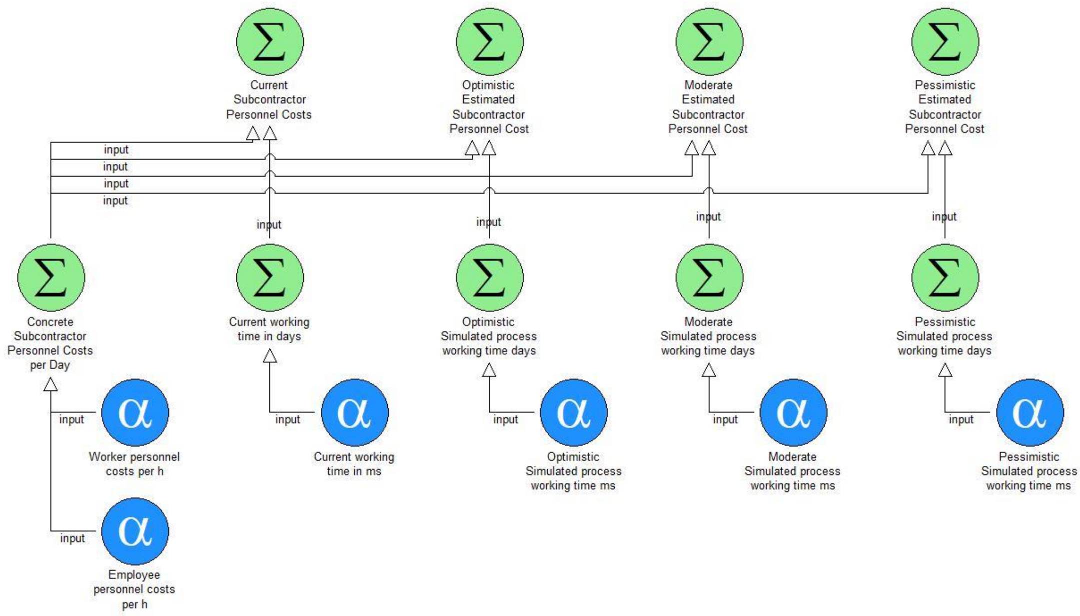

Figure 34: KPI Data Calculation Model – Subcontractor Personnel Costs Sample

5.2.3 Context-Dependent Cost Driver: Material Costs Sample

During a renovation process, two types of required material can be differentiated (a) basic material and (b) customized material. Basic material is used on a lot of constructions sites. For instance, bags of cement or expanding foam do belong to this category. More interesting is the customized material, as this is made upon order and is therefore, custom-built. This indicates that the parts can only be used for a specific renovation process. Windows and windowsills are an example of this category. They are built specifically for a concrete use case, where the customer can customize characteristics like glass thickness, shading, insolation, frame colour or insect protection. Unfortunately, once produced, it is very hard to find any other usage, except the planned one. Therefore, the risk of being left with the costs is much higher for customized material than for basic material. Tailored material may also be more error prone, as it deviates from the standard procedures.

Furthermore, it is mostly the case that this kind of material is more expensive, already in acquisition. However, the material costs are comprised of costs for basic material, which are rather low, and costs for customized material, which might be higher and increase the risks (reusability, sensitivity, …). The concept of the simulation works in the same way for all following sample models. Therefore, for explaining the overall principle and in order to focus on the relevant parts, the threefold simulation (optimistic, moderate and pessimistic) was accumulated to one simulation metric.

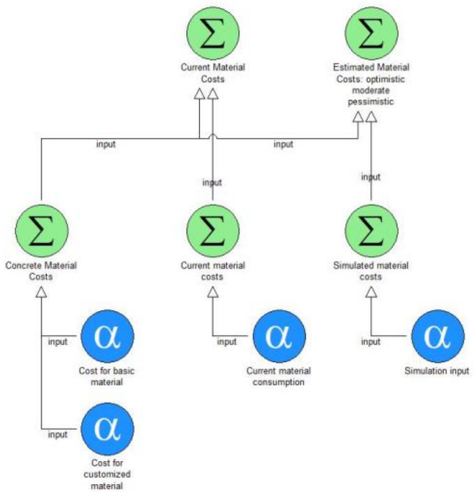

Figure 35: KPI Data Calculation Model - Material Costs Sample

5.2.4 *Dependent Cost Driver: Waste Costs Sample*

There are quite specific regulations for waste disposal. Following three main waste categories might be differentiated: (a) normal waste, (b) waste that can be recycled and (c) special waste. Normal waste can be disposed for free or at least at a very low price. On the contrary, it is not trivial to dispose special waste and to stick to the recycling rules. Special waste like asbestos can increase the costs of waste disposal. The material was used in the 1960s and 1970s. Today it is forbidden, as it came out that the dust is highly harmful. For this reason, it should not be broken during the disposal. Some parts of the waste might be recycled. For instance, wooden parts or brash can be rehashed and reused afterwards. However, it is important to consider the effort of waste separation for each type of waste (Figure 36). For instance, windows do consist of a frame and the window glass. Both parts might be separated as old window frames were made out of wood, which can be recycled, whereas the glass might have a crack and cannot be reused anymore.

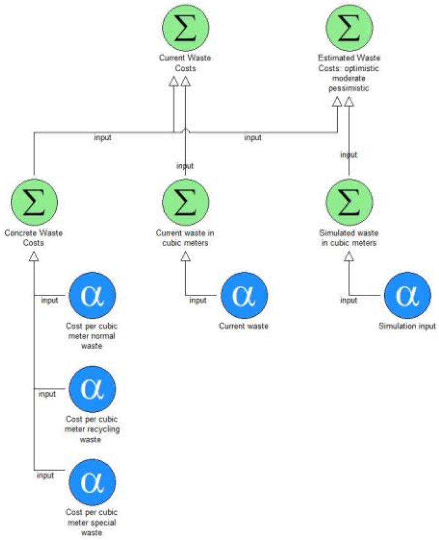

Figure 36: KPI Data Calculation Model – Waste Costs Sample

5.2.5 *Combined Cost Driver: Drilling Machine Costs Sample*

The rental fee for renovation equipment like a drilling machine mostly consists of two costs. There are the basic costs, which are for instance calculated in days. In particular, the delivery, the setup, the maintenance, and the pick-up are included here. Additionally, there is a cost for each hour of usage, as the value of the drilling machine decreases during the usage time, due to attrition (Figure 37). It is important to keep the downtime low in order to reduce the overall rental costs. However, if the surface is very soaked or dry, the drilling machine might not be used. Also, if the subcontractor cannot deliver as planned, some waiting time might increase the basic costs for the drilling machine.

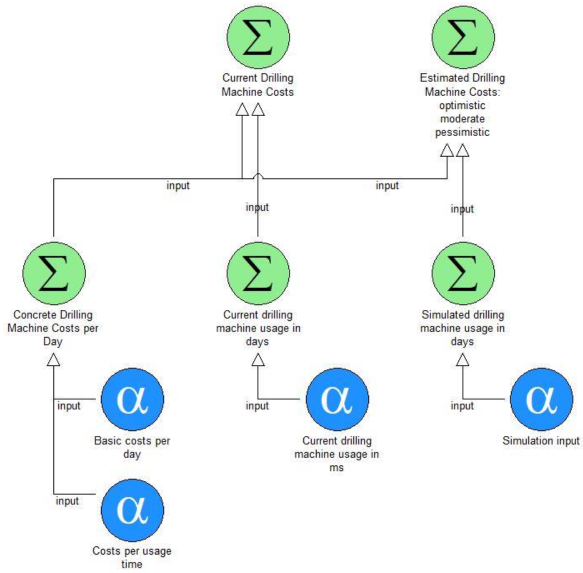

Figure 37: KPI Data Calculation Model – Drilling Machine Costs Sample

6. Facade Improvement Outside Sample as Use Case Outlook

The instantiated models for the different templates have been created for the Spanish pilot site in Bilbao for which the renovation measures have been already defined. The approach explained in section 2.2 has been followed and the template models have been refined for the specific needed renovations consisting of the insulation of the external facade and of the roof. In the following sections, we focus on the facade improvement outside process to describe the transformation of the template process into a concrete use case. In the first transformation step, all variations from the template process are excluded, as one of the options is defined for a concrete use case based on a specific construction site.

Characteristics of the concrete use case sample building (assumptions):

- built in the 1960s
- 15 stories high
- a sidewalk is close-by
- the last renovation was 30 years ago

6.1 Process Design

The facade improvement outside of the wall, as visualized in Figure 38, describes the required tasks for the renovation of the facade in a concrete use case, so it is a specific instantiation of the renovation process template described in section 5.1.3.

In this case, a specific construction company takes over this part of the building improvements. The construction company knows the building and its conditions. The start event indicates the start of the improvement process. The first task that must be conducted is the **installation of a material lift or crane**.

In our concrete use case, the building has seven stories. Therefore, the required material must be lifted during the renovation. As both the material and the tools can be quite heavy, large, and impractical, a lift eases the job of the construction workers. The facade of the use case building is in a bad condition, as the last renovation was a long time ago, therefore a grinder for removing the old exterior rendering is necessary as well as a facade milling machine, for instance.

The next task is the **installation of safety measures**, which are essential for the construction workers, as well as passers-by. As there is a sidewalk close-by the use case building, the construction area must be closed and a temporary redirection for the passers-by is installed as safety measure. They are redirected to the sidewalk of the other side of the street. As already mentioned, most buildings are higher than one story , therefore, a supportive structure is needed. For this reason, a **scaffold** is built up.

The scaffold allows the construction workers to easily reach each story of the building from outside. The scaffold is standing till the end of the renovation process. As the building is quite old and some installations are not fully conforming to current standards, it was already decided before starting the facade renovation, that a reorganization of gas, electricity and telecommunication is required. The reorganization is not only required to adapt to the regulations, but also to find the best-looking solution regarding the design of the new facade.

The **deinstallation and equipment covering on the facade** outside follows. This includes removing loose parts of the facade with a grinding tool. Furthermore, critical parts of the facade and the equipment is protected and covered with tarpaulins, as the weather forecast predicts rain and wind. It is usually the case that the pre-processing steps resulted in some dirt and waste. In our use case, the loose material from the facade was uninstalled. For this reason, the next task is about **cleaning the facade**. The main dirt and dust are removed in this task. This is necessary that new layers and installations can be attached on the existing facade. As our sample building is quite old and the condition could be better, the facade is not a hundred percent smooth and even. Therefore, the **facade is evened**.

Before starting the facade renovation on the outside, it was decided to choose the **SATE system**, as it offers various advantages at the concrete use case construction site. The

SATE system tiles for ensuring exterior thermal insulation are applied on the outside of the facade. No additional supporting structure is needed, as the panels can be mounted directly on the existing facade. The attachment on the facade is beneficial due to low thermal conductivity of the SATE system tiles. Also, tensile capacity and resistance to compression are ensured, as well as a reduction of the building energy consumption, the elimination of thermal bridges. One reason for choosing the SATE system at the concrete use case building was the simple installation and therefore lower personnel costs in this context. Not only the facade, but also the **window surface must be finished**. This task includes the cleaning and smoothing of the surface for further processing steps. The whole facade surface, especially sharp edges, are grinded.

Afterwards, the **final quality check** follows. In particular, the new installations for improved thermal capabilities are checked with a check list before the removal of the scaffold. If everything was successful, the **deinstallation and uncovering of the equipment** follows. As a reorganization of some installations (gas, ...) was conducted at this specific building, a final control of the disassembled and reassembled **gas, electricity and telecommunication** is reasonable. At this point, the facade renovation is nearly finished. For this reason, the scaffold is not needed anymore, so the **scaffold is disassembled**.

As the scaffold is rented for this concrete use case, the rental costs comprise the whole period between the scaffold assembly and the disassembly. In addition, the delivery, and some waiting time before the built up must be considered. Before ending the facade renovation on the outside, everything is **cleaned** and cleared up. This task includes the disposal of waste, the packing of equipment and the removal of raw material that was not needed. Finally, a **final check** is conducted. When this final check is successful, the outside facade improvement the sample building for our concrete use case can be completed, which is indicated by an end event in the process.

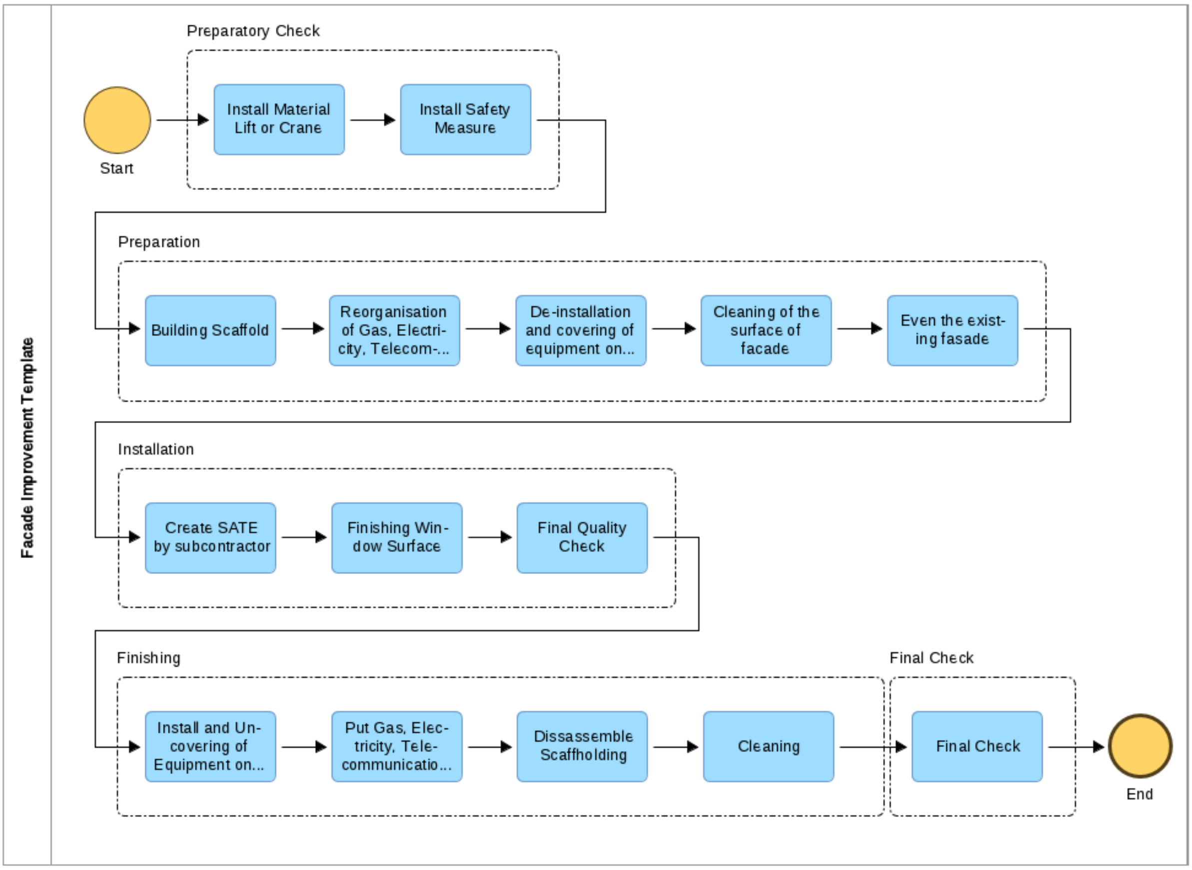

Figure 38: Facade Improvement Instance – Outside

6.2 Workflow Design

The workflow model (Figure 39) enriches the previously defined model instance by adding controlling and reporting activities about the renovation status and including connections with the KPIs model information and, when needed by automatic activities, also with services.

The main process activities are executed by the on-site workers and start with the installation of the crane and the related safety measures. After such activities, the scaffold can be built, and a first security check be performed. In case of problems the required corrective actions must be performed, otherwise the process can continue removing the equipment on the facade, including sills, cleaning and even the facade itself. After the facade is clean and even the SATE system installation can start.

The vapor barrier is first installed according to the manufacturers' instructions. Subsequently the insulation is placed, fixing first the brackets to the supporting wall and positioning then the rock wool panes on the brackets, by means of a mechanical fastening. Next step is the installation of the windproof membrane according to the manufacturers' instructions. After all the crevices and cracks have been fixed the exterior insulation system, composed of expanded polystyrene panels, can be placed in order to complete the SATE system. The facade will be then finalized installing new sells and covering with cement-free organic or silicone resin finish coat and equalizing paint.

After the quality checks succeed, the facade equipment can be reinstalled, the scaffold unmounted, the crane removed, and the site cleaned.

A weekly reporting process is started in parallel with the renovation activities and associated to the building surveyor user that will be responsible for filling the status report every week until the whole renovation process terminates. In this way we are able to handle reporting independently from the project duration.

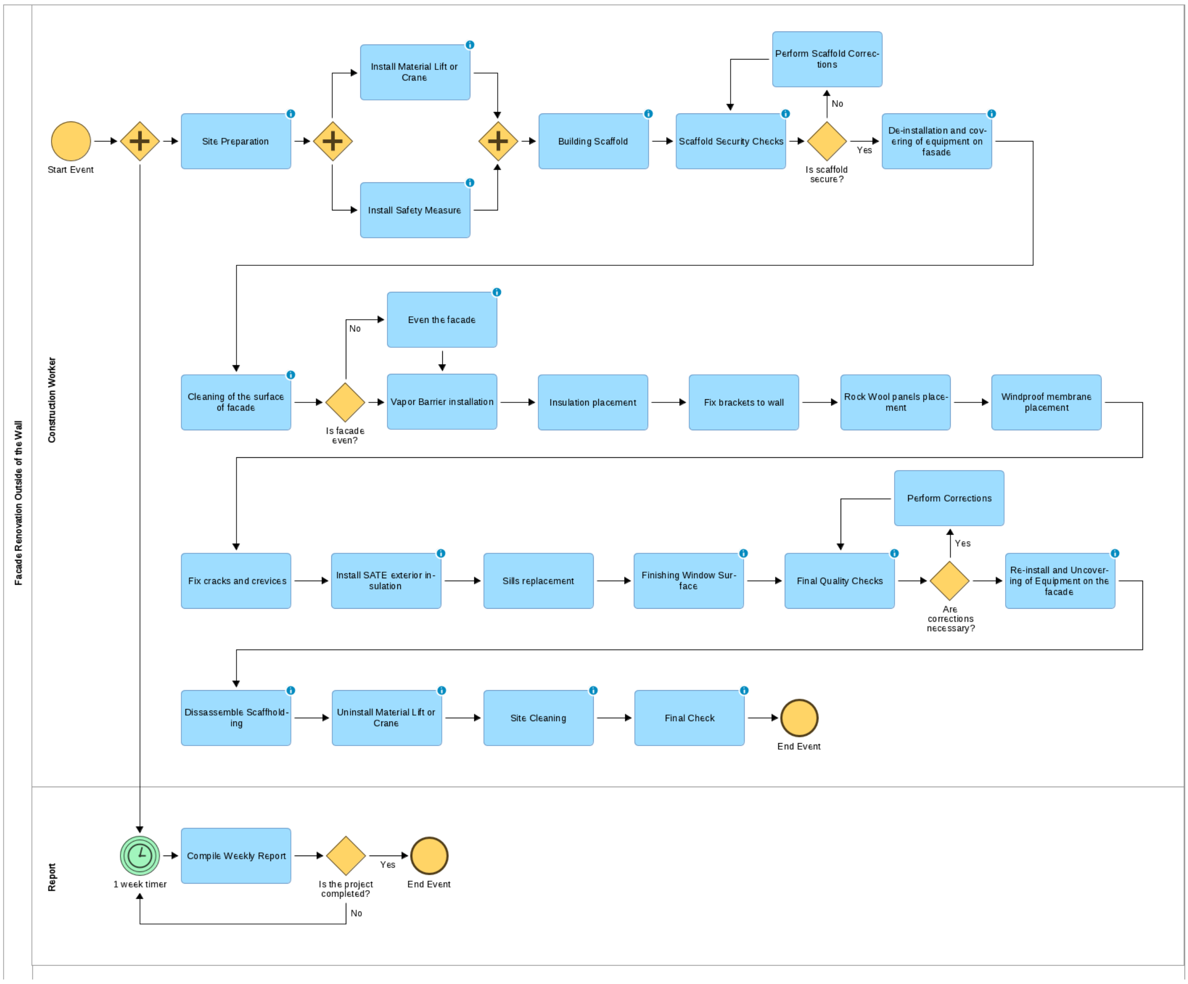

Figure 39: Facade Improvement Outside Workflow

6.3 EXTRACTION OF KPI RULES AND FORMULAS

For discussing the required costs, times, and resources of the facade improvement process (outside), an Excel table was set up. An overview of this table is shown in Table 1. As the facade improvement process has fifteen tasks (section 6.1), there is a row for each of those tasks. Additionally, the start element has its own row. The first column assigns a number to each task. The second column comprises the names equally to the BPMN facade improvement process tasks. In column three, the specific source of information for the correct monitoring of this activity is provided. Columns from four to height contains details on costs and times while column nine describe risks and column ten the goals.

The following questions are used suitable to the process tasks:

1. Are there dependencies with respect to start like Season, Weekday and Organization that influence the project?
2. How to calculate / estimate time and cost. Cost of rental or use, Cost of personnel resources, duration, execution time etc.?
3. Are additional influence factors possible - like in-house equipment, local regulations etc.?
4. Are additional influence factors possible - like who is performing the task?

Those questions helped to work through the process and identify that there are generic risks like (a) delay because of bad weather, (b) delay because of inadequate sub-contractors, (c) delay because of a problem with the customer, and (d) delay because of difficulties with the infrastructure like electricity or water. Some additional risks have been identified for some activities, like the delivery of insufficient or wrong material, quality issues, safety issues or wrong planning.

The times and costs have been split for monitoring.

Times are relevant with respect to:

(a) duration to indicate when to start with the next activity and
(b) execution time to calculate the costs raise – e.g. rental or staff costs.

Costs are split in:

(a) personnel costs that are both staff of sub-contractor costs which are paid per time,

(b) equipment costs that is also paid by time – either depending on the duration like a rent, depending on the usage like productive hours or a combination of a fixed rent an additional cost for usage,

(c) material costs that occur when material is used. Sometimes the material is covered by a sub-contractor and hence this does not need to be assessed by the project manager.

The trustworthiness and origin of the measures indicates, where the data to manage this particular activity comes from. This corresponds with the goal of assessment that is indicated in the last column.

	Task	Source and Trustworthiness of Measures	Duration Time	Execution Time	Cost on Person Resources	Cost on Equipment	Cost on Material	Risks	What needs to be assessed?
	Start		none	none	none	none	none	Delay based on weather Delay based on subcontractor Delay based on customer Availability of infrastructure (water, electricity, waste)	Pre-Conditions
1	Install Material Lift or Crane	Estimated	X	none	none	X	none	Delay based on weather Delay on supplier Wrong machine	Quality and safety of the equipment
2	Install Safety Measure	Expert Knowledge	X	X inspection time	X security agent	none	none	Delay based on weather Delay based on subcontractor Delay based on customer Non-Compliant Safety Measure	Quality and approval
3	Building Scaffold	Expert Knowledge	X	none	none	X usage of scaffold	none	Delay based on weather Delay based on subcontractor Delay based on customer Non-Compliant Safety Measure	Duration of using the scaffold
4	Provisionally reorganisation of Gas, Electricity, Tele-communication	Expert Knowledge	X	X time	X special agents	none	none	Delay based on weather Delay based on subcontractor Delay based on customer Non-Compliant Safety Measure	Duration and availability of special staff

5	De-installation and covering of equipment on facade	Expert Knowledge	X	X time	subcontractor or staff	none	none	Delay based on weather Delay based on subcontractor Delay based on customer Non-Compliant Safety Measure	Time and stock availability
6	Cleaning of the surface of facade	Calculated using standardised procedures	X	X	subcontractor or staff	none	higher costs on material	More material needed than expected Real material is different than expected Delay based on weather condition Delay based on subcontractor Delay based on customer Non-Compliant Safety Measure	Time, cost and quality
7	Even the existing facade	Calculated using standardised procedures	X	X	subcontractor or staff	none	higher costs on material	Delay based on weather Delay based on subcontractor Delay based on customer More material needed than expected Real material is different than expected Non-Compliant Safety Measure	Time, cost and quality
8	Create Ventilated Facade or SATE by	Calculated using standardised procedures	X	X	subcontractor	none	none	Delay based on weather Delay based on subcontractor Delay based on customer More material needed than expected	Time, cost and quality

	Subcontracto r							Real material is different than expected Non-Compliant Safety Measure	
9	Finishing Window Surface	Calculated using standardised procedures	X	X	subcontractor	none	none	Delay based on weather Delay based on subcontractor Delay based on customer More material needed than expected Real material is different than expected Non-Compliant Safety Measure	Time, cost and quality
10	Final Quality Check	Expert Knowledge	X	X	special staff (third party, subcontractor, staff)	none	none	Delay based on weather Delay based on subcontractor Delay based on customer Non-Compliant Safety Measure	Quality
11	Install and Uncovering of Equipment on the facade	Estimated	X	X time	subcontractor or staff	none	none	Delay based on weather Delay based on subcontractor Delay based on customer Non-Compliant Safety Measure	Time, cost and quality
12	Disassemble Scaffolding	Estimated	X	none	none	X	none	Delay based on weather Delay based on subcontractor Delay based on customer	Time
13	Cleaning	Estimated	X	X	subcontractor or staff	none	X	Delay based on weather Delay based on subcontractor	Time

								Delay based on customer Non-Compliant Safety Measure	
14	Final Check	Expert Knowledge	X	X	special staff (third party, subcontractor, staff)	none	none	Delay based on weather Delay based on subcontractor Delay based on customer	Quality

Table 1: Facade Improvement Template - Outside

With Table 1, each project manager can now work out a particular dashboard that fits the specific purpose. Once a KPI-model is generated, it serves as a KPI pool or as a template also for other processes.

We started to fill this KPI model pool with the “building scaffold” task.

In collaboration with a domain expert, we found out that there are three stages of planning involved:

1. Initial Plan: cost and time estimations.
2. Concrete Plan: signing of contracts.
3. Monitoring Plan: check if real world site is according to plan.

The initial plan is a rough estimation of the costs and the times, based on historical data as well as assumptions and in-house knowledge. Due to in-house knowledge, it might be suggested to estimate 15 EUR per m^2 for the scaffold budget. Furthermore, it is assumed that it takes 3 months to renovate a 1.000 m^2 facade. With these calculations, the way should be paved for understanding the importance of the simulation by learning from all project partners as well as the domain expert.

After the initial plan, the concrete plan is established. This includes the consideration of KPIs. The main questions in this context are what should be measured, why should it be measured, what is the tolerance and how can we get the data for the measure. The different building blocks of the contract can be parted in times and costs for instance. Another differentiation in measured costs and simulation can take place. In collaboration with the expert, we worked out a possible scenario for the building of the scaffold, considering the following parameters:

- Start time: t0
- End Time: t1
- Execution: not relevant
- Duration: 90 days (from start to end)
- Target cost estimation: 15 EUR per m^2
    - Measure:

        - Price per day = m^2 of facade * EUR per m^2 = 1.000 m^2 * 15 EUR = 15.000 EUR
        - Costs per period = Price per day * days = unknown as we do not know how many days the scaffold is actually needed.
    - Simulation:
        - likelihood of no payment of client (linear risk) – scaffold keeps staying.
        - likelihood of weather delays in next months (depends on demand forecast).
        - likelihood of subcontractor failure (depreciated risk).
        - likelihood of unforeseen problem (depreciated risk).

At first, the planned KPI value is estimated and stored. Second, the data source is identified that calculates the days the scaffold is in use. In addition to the cost calculation, the likelihood of weather-, sub-contractor -, customer- or other issue-based delay is estimated with normal distribution.

The result was the first configuration of the dashboard, where data services provided (a) the estimated planned figures using a manual entering of the data, (b) a data service that accesses a data source providing the number of days the scaffold is in use and (c) three excel sheets with an optimistic, a moderate and a pessimistic simulation scenario that is continuously triggered by the monitoring cockpit.

In order to get further insights on the importance and the principle of Table 1, another row is explained in more detail. Above we described the scaffold task. As there are quite varying requirements regarding times, costs, trustworthiness, and assessments, we also want to go into further detail for the "create ventilated facade or SATE by subcontractor" task.

For the initial plan, rough estimations of costs and times are taken. As a subcontractor is involved in the creation of the facade, it might be the case that there is no direct in-house knowledge available, except subcontractor contracts and details about past collaborations. This makes it even harder to set up the concrete plan, as the calculations and KPIs depend on external input. Again, the main questions in this context are what should be measured, why should it be measured, what is the tolerance and how can we get the data for the measure. For sure, the duration is of interest, as well as the execution time. In contrary to the scaffold task, the creation of the facade is taken over by a subcontractor. Hence, the personnel resource costs are important, whereas costs for material and equipment are not directly considered. In collaboration with the expert, following parameters are of peculiar interest:

- Start time: t0
- End Time: t1
- Execution Time: How long does the facade creation take in person hours? This measure is used to plan the further tasks.
- Duration: overall time from start to end
- Target cost estimation: 25 EUR per hour for one construction worker with one labourer
    - Measure:
        - Price per day = price per hour * hours per workday
        - Costs per period = Price per day * days
    - Simulation:
        - likelihood of no payment of client (linear risk) – interim solution for facade might be required to protect it against external influences like rain.
        - likelihood of weather delays in next months (depends on weather forecast).
        - likelihood of subcontractor failure (depreciated risk).
        - likelihood of unforeseen problem (depreciated risk).
            - more material is needed than expected.
            - real material is different than expected.
            - non-compliant safety measure.

After the planned KPI value is estimated and stored, the likelihoods of the risks are simulated. Since this task depends on a subcontractor, getting the figures might be more complex compared to a task conducted internally. Instead of relying on expert knowledge, standardised procedures for the calculations must be taken. Therefore, the combination and comparison of different figures and KPIs might be reasonable. For instance, it is reasonable to measure the progress on the construction site, have a look at the personnel time sheets in the reporting system and compare them to the subcontractor contract/invoice.

The creation of the facade has additional risks and different assessments compared to the scaffold task. Especially, the material can include some critical issues. For instance, the material delivery could go wrong, and more material is delivered. This requires a sophisticated decision about the further processing – store the remaining material, send it back or change the agreement with the supplier. It can also be the case that the delivered material is different than expected. This case might involve adapting the standard procedures or in worst case losing time by ordering new material. In contrary to the scaffold task, the facade creation does not focus on the duration. Not only times, but also costs and especially quality must be considered. In case of regular quality issues, it might be necessary to change the subcontractor, for instance. Concluding, Table 1 should show the interconnections of data measures, data sources, times, costs, risks, and assessments. By giving explanations for two samples – "building scaffold" and "create ventilated facade or SATE by subcontractor" – the importance of the mentioned issues should be obvious.

7. OVERALL COLLECTION OF DIGITAL TWINS FOR RENOVATION PROCESSES

This chapter describe the models related to the documentation of the entire BIMERR process. These models were initially extracted from BIMERR deliverable D3.1 and further elaborated to obtain, at the end, a detailed workflow representation that enables the digital twin. The proposed approach reflects the evolution of digital twins proposed by ([16] Tchana de Tchana et al., 2019) identifying three steps: (a) Digital Model, (b) Digital Shadow and (c) Digital Twin (Figure 40).

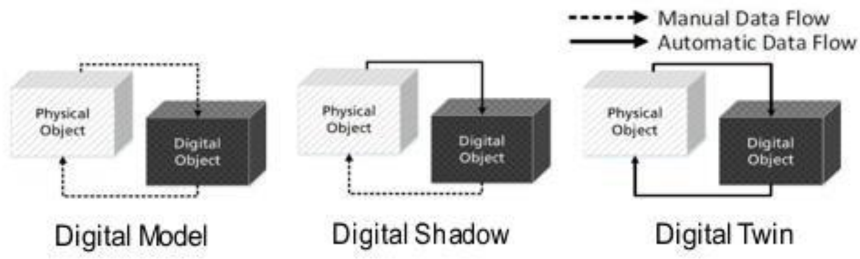

Figure 40: Digital Twin Evolution

As first step, the digital models representing the renovation process phases have been modelled, identifying the tools supporting each phase and the data requirements between them. After a refinement process, the models referring to the specific use case for each BIMERR specific tool have been defined and detailed enough to be executable as workflow from the BIMERR PWMA toolkit. In this “digital shadow” phase, such models are not focused on the steps to perform on the specific tool, but mainly to the interactions between each BIMERR specific tool and the BIMERR PWMA toolkit, responsible for executing the workflow and interact with the user. In this way, the workflow engine is able to track the status of each use case giving the user the flexibility to use the required BIMERR tool based on his/her specific expertise. The last step in order to have a complete digital twin, is the definition of the effective services used by the automatic activities in the workflows, and the modelling of the BIMERR related KPIs as described in the BIMERR deliverable D9.1, to monitor the effectiveness of the BIMERR approach compared to the baseline scenarios.

7.1 Digital Models

The overall renovation process in Figure 41 has been initially extracted from BIMERR deliverable D3.1 and subsequently divided in sub-processes for each renovation phase, identifying the tool required and data dependencies between tasks. Such digital models are detailed enough to be used as documentation for the BIMERR renovation process but too abstract in order to be executed as workflow.

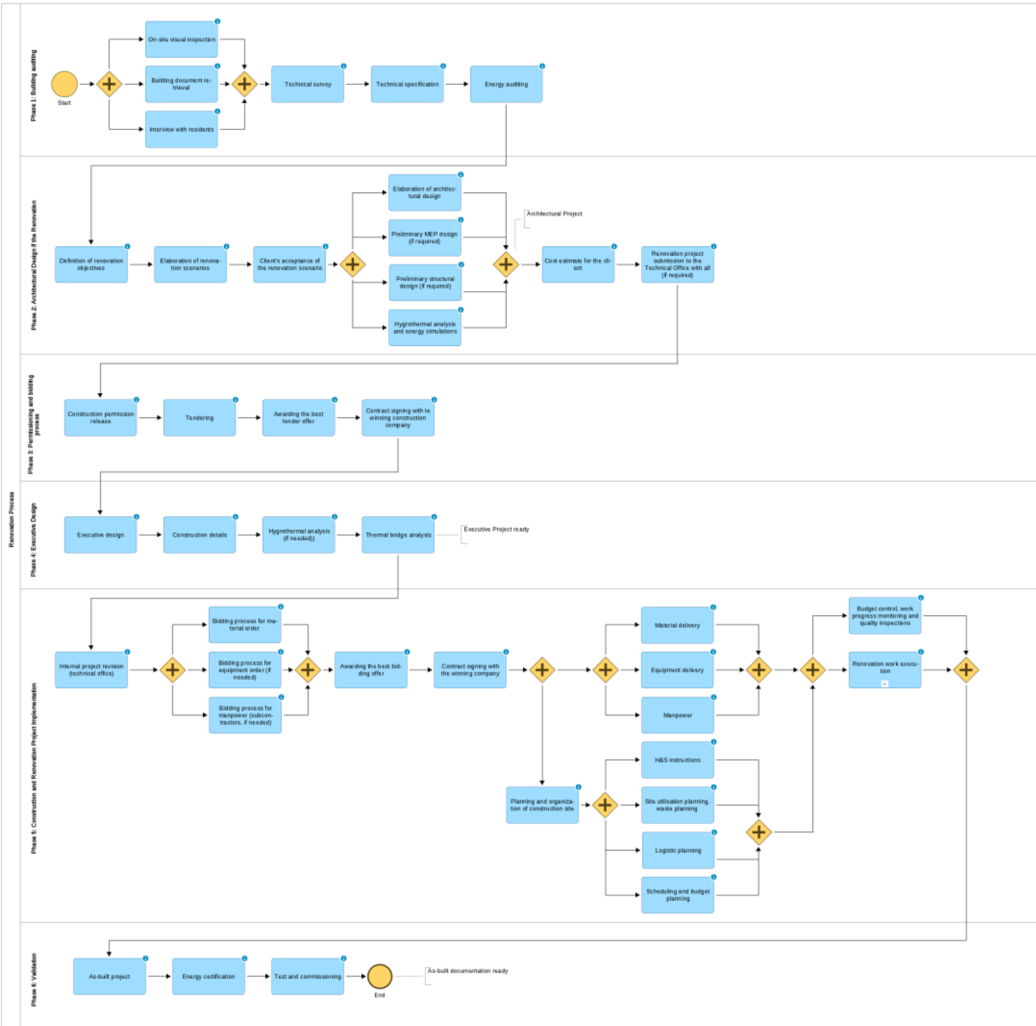

Figure 41: Digital Model of the BIMERR Renovation Process

In the following sections will be reported the sub-processes relative each phase of the renovation process that will clarify the details of the Figure 41.

7.1.1 *Phase 1 - Building auditing*

The building auditing is the first phase of the renovation process. It starts with the visual inspection of the building conditions, to identify the building problems and renovation strategies, done using the Scan-to-BIM BIMERR tool. In parallel residents' interviews are performed using the BICA BIMERR tool and such survey to identify their needs and expectations. The last activity in parallel is the identification of all the restrictions imposed by the Heritage Conservation and the retrieval of the official documentation of the building to be renovated.

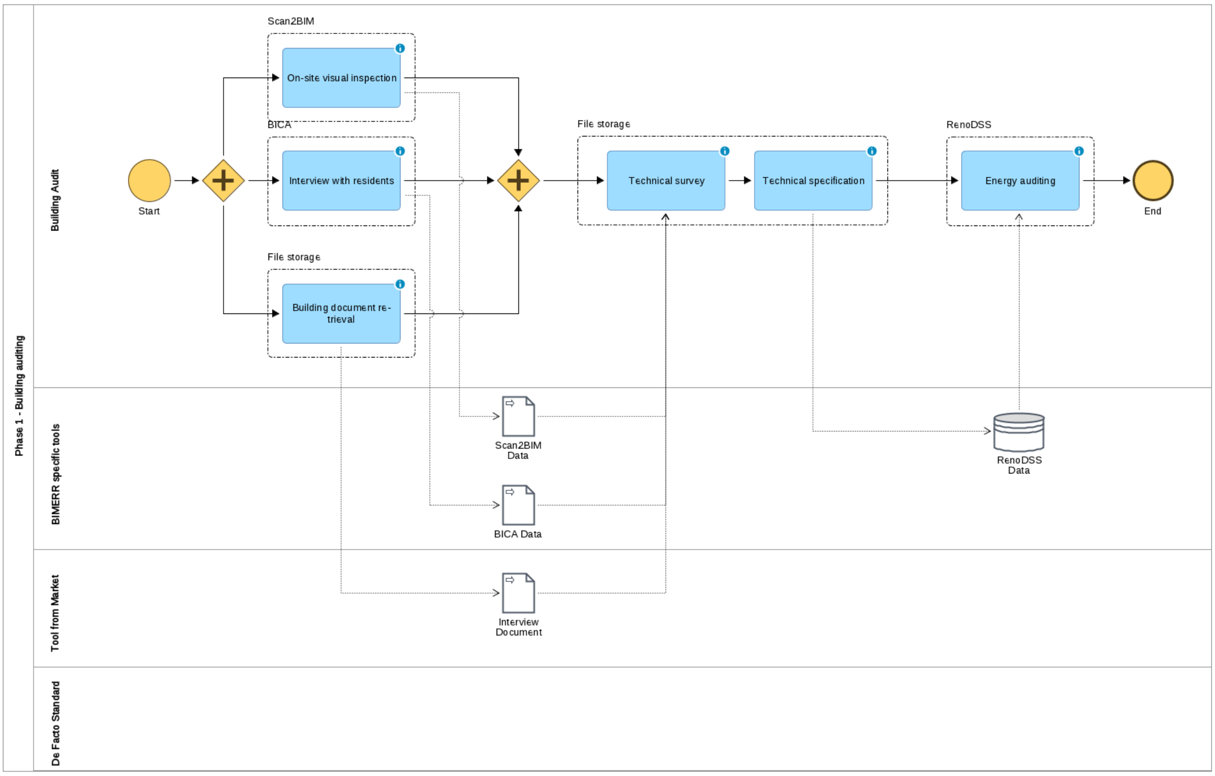

Figure 42: Phase 1 of the Digital Model of the BIMERR Renovation Process

After these initial activities, the technical survey and specification can take place, using the Scan-to-BIM, BICA and interviews data in order to create the BIM models, when not available, and enrich it with data regarding materials and components. At the end, the energy certification and auditing of the building is performed using the RenoDSS BIMERR toolkit.

7.1.2 Phase 2 –Architectural Design of the Renovation

In the second phase the architectural design of the renovations is targeted. The objectives of the renovation are defined, along with different renovation scenarios with their budget planning and the Return of Investment (ROI) and are proposed to clients for acceptance.

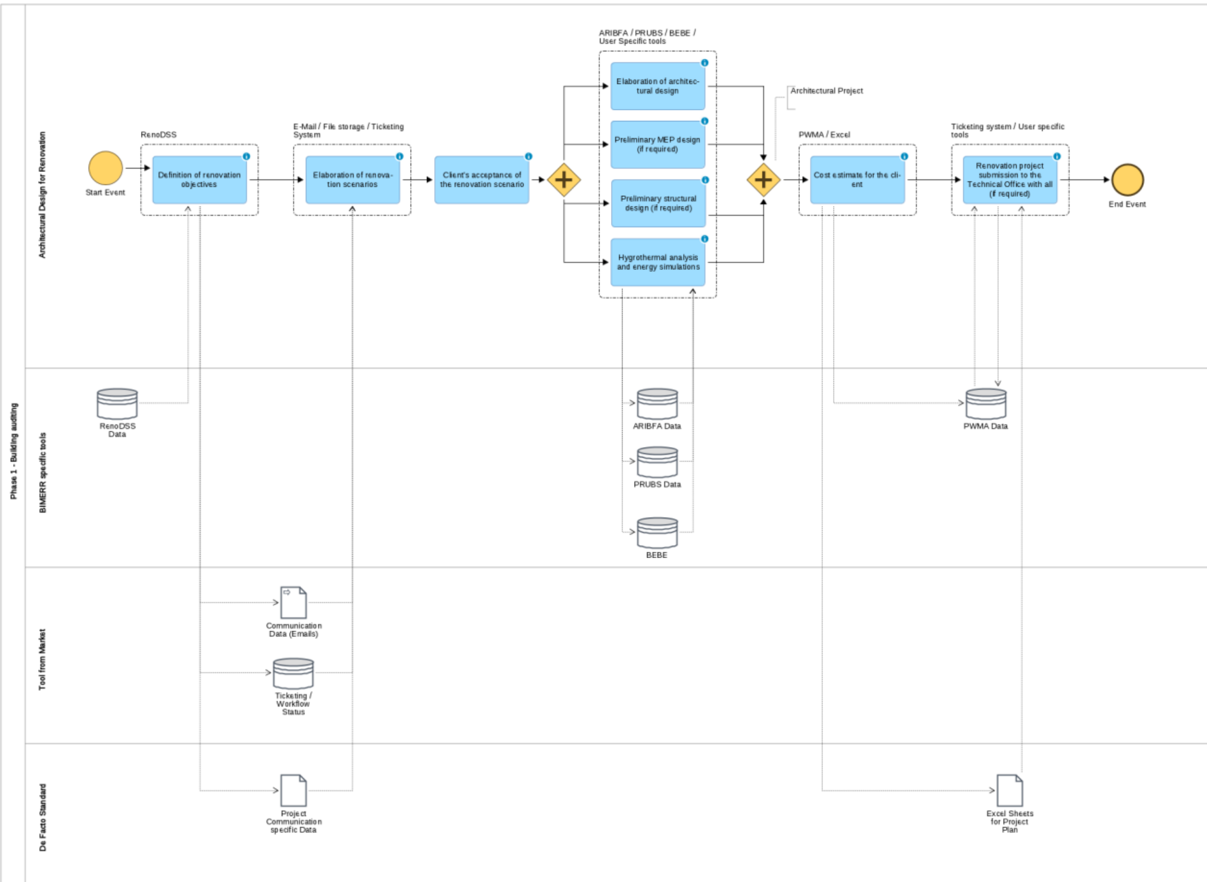

Figure 43: Phase 2 of the Digital Model of the BIMERR Renovation Process

After that, the effective architectural design can take place performing in parallel the CAD and BIM design of the renovation, the hygrothermal and energy analysis and, if required, the MEP and structural design. The use of the ARIBFA, PRUBS and BEBE BIMERR tools can help in this phase. The feasibility of the renovation is then evaluated through a simulation that estimate costs and times with the PWMA BIMERR Toolkit and when feasible, submitted to the technical office for the approval.

7.1.3 Phase 3 - Permissioning and bidding process

The Permissioning and bidding phase does not involve any BIMERR specific tools but rely on common office instruments for releasing the appropriate permissions and the bidding.

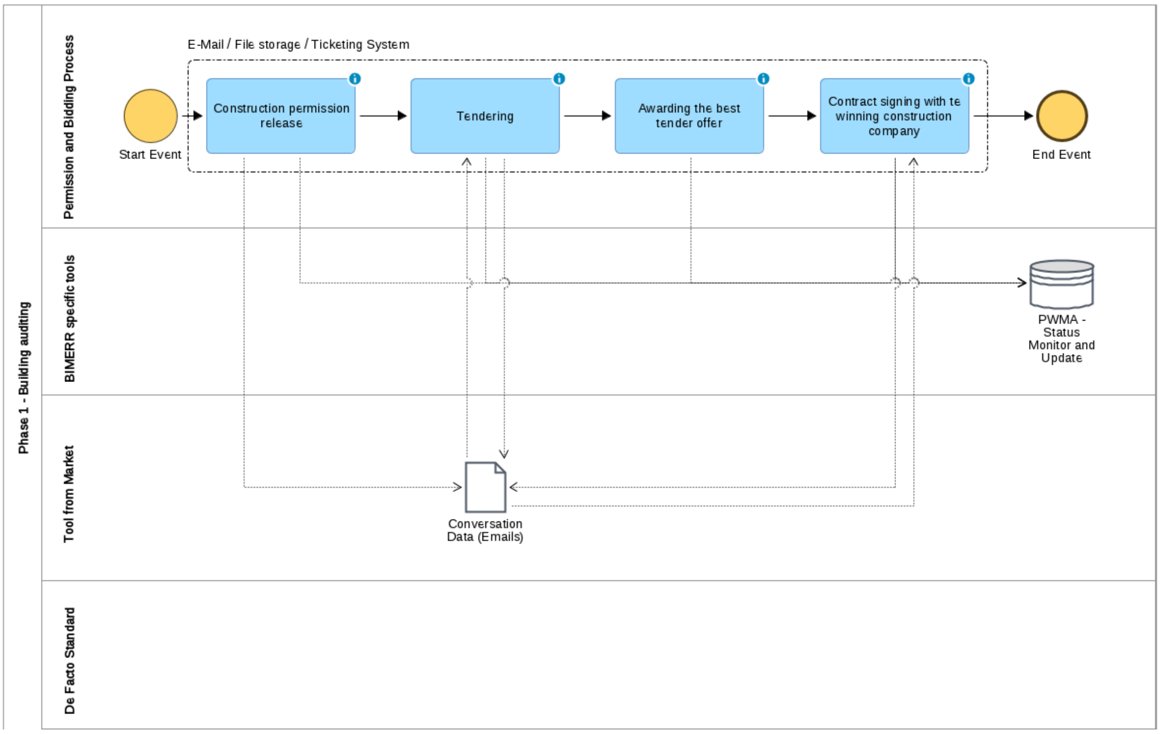

Figure 44: Phase 3 of the Digital Model of the BIMERR Renovation Process

The process starts with the identification of all the needed permissions, that vary from country to country and their fulfillments. After that, a tender is set and the company with the best offer will win and sign the construction contract.

7.1.4 *Phase 4 - Executive Design*

The executive design is a detailed design project, based on architectural one, but extended to add more construction details. Hygrothermal and thermal bridge analysis are also performed in this phase.

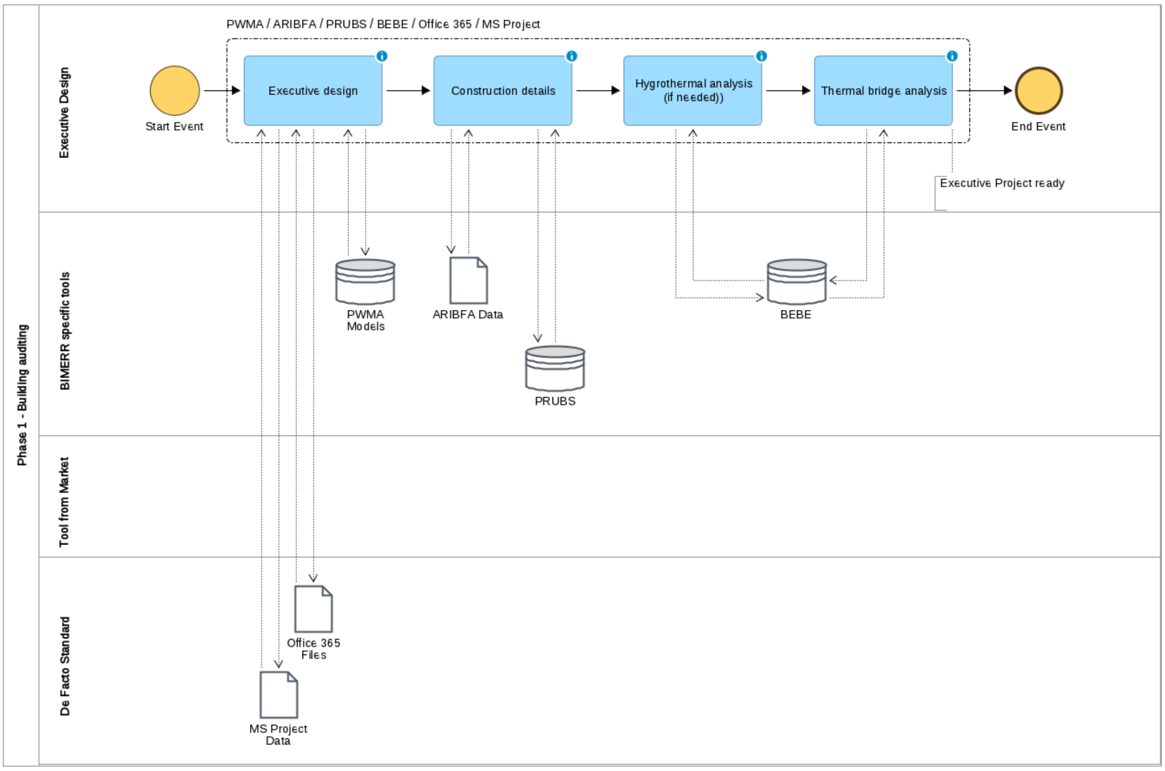

Figure 45: Phase 4 of the Digital Model of the BIMERR Renovation Process

The renovation templates defined in the PWMA toolkit are refined in this phase and BIM models are enriched with the help of the ARIBFA, PRUBS and BEBE toolkits.

7.1.5 Phase 5 - Construction and Renovation Project Implementation

The phase 5 is about the effective renovation execution on the working site. The only BIMERR tool involved is the PWMA workflow engine and app that track the proceeding of the works. Other office related tools are used here by the construction companies for planning logistic and scheduling manpower.

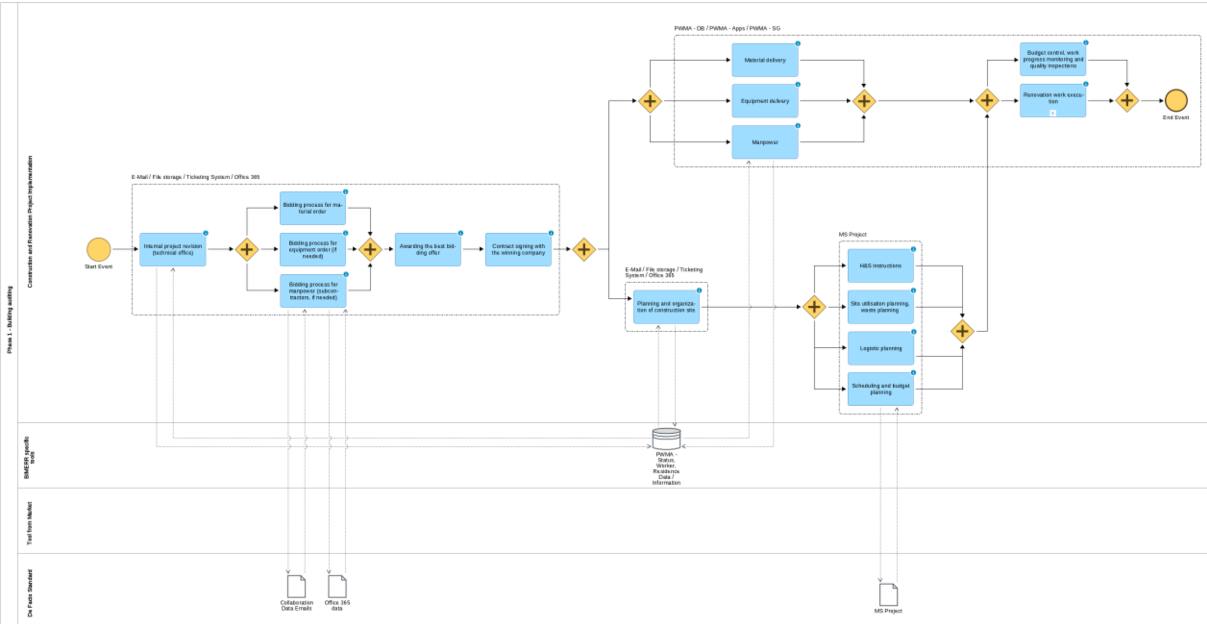

Figure 46: Phase 5 of the Digital Model of the BIMERR Renovation Process

Planning activities includes not only logistic, but also waste management, site utilization, health and safety protocols, material delivery and equipment delivery. The effective renovation can proceed after the planning, with a monitoring process that run in parallel for budget control and quality inspections.

7.1.6 *Phase 6 – Validation*

The validation of the renovation is the last phase. Here the new energy certification level is evaluated with the BEBE BIMERR tool and specific tools are used for testing the effectiveness of the other performed renovations.

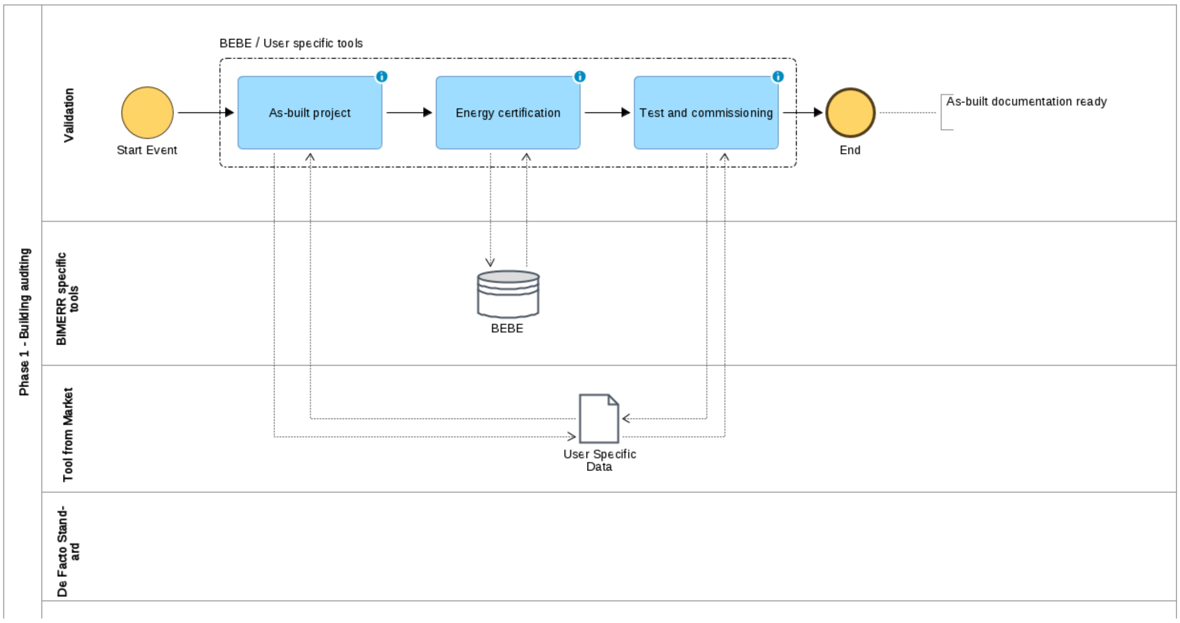

Figure 47: Phase 6 of the Digital Model of the BIMERR Renovation Process

7.2 DIGITAL SHADOW

The creation of the digital shadow of the renovation process involves the refinement of the previously defined digital models with enough details to be executed by the BIMERR PWMA workflow engine. With such workflows the user is guided in the usage of the BIMERR tools involved in each renovation phase. The goal here is to create a digital representation of the renovation process via workflow log files by managing the different interactions with BIMERR tools via the workflow engine as described in the use cases reported in BIMERR deliverable D3.1. Based on the tools' interactions expressed in the digital models, we were able here to organize the use cases in an overall workflow that, when required, execute as sub-processes the workflow specific for each use case. From the overall workflow in Figure 48 we can see that the use case ,3 where the PRUBs toolkit is required, can be executed in parallel with use cases 1, about the Scan-to-BIM tool, and use case 2 about the ARIBFA tool, because no dependencies are presents between the involved tools. After the use cases 2 and 3 are completed, we can proceed with the use case 4 where RenoDSS is required that also involve the use cases from 13 to 16. The PWMA simulation tools is then used in the use case 5 while the effective execution of the renovation on the site are described in the use cases 6 to 12 involving PWMA workflow related tools.

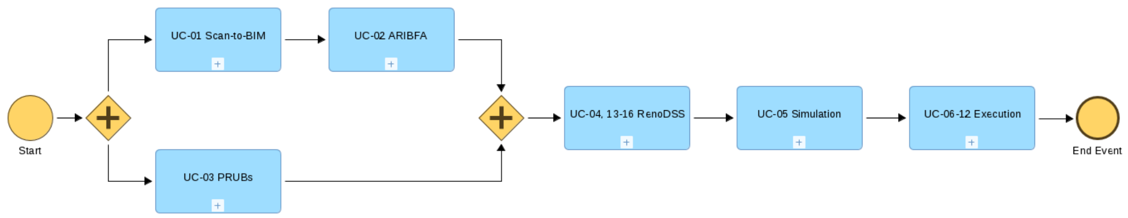

Figure 48: Overall Digital Shadow of the BIMERR Renovation Process

In the following sections the workflow of each use case will be introduced.

7.2.1 *UC01 Scan-to-BIM*

In the use case 01 the Scan-to-BIM BIMERR tool is used to perform a rapid scanning of the building and generate an accurate BIM model file that contain the building structure and building components of particular value to effective energy renovation design.

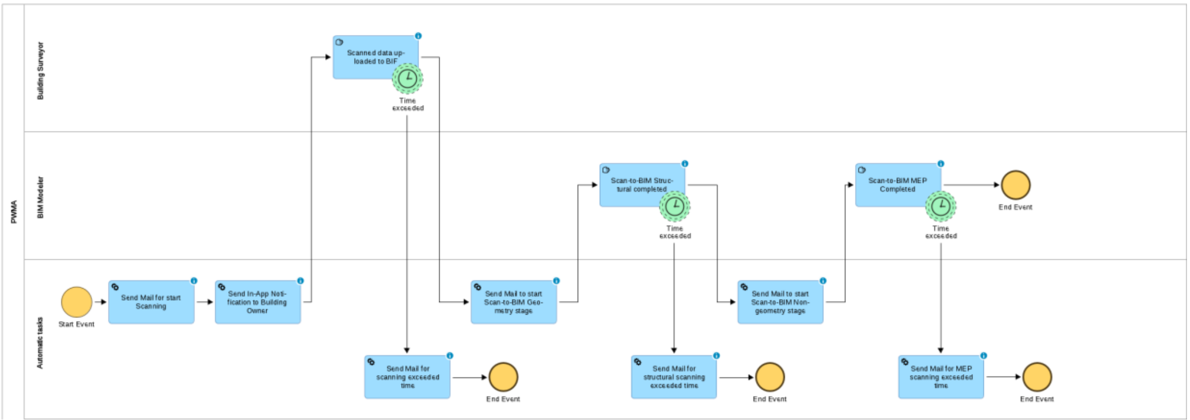

Figure 49: UC01 Digital Shadow of the BIMERR Renovation Process

The workflow is used to initialize the scanning procedure and report its status to track the progresses. The first activity is an automatic task executed by the workflow that will send a mail to the building surveyor, to notify the necessity to begin the scanning process. This automatic task, like all the other automatic and service tasks, will contain detailed information to instruct the workflow execution engine on which services to contact and with what parameters, to perform the requested action. The services information refers to the specific microservice definition model described in section 7.3.1. As soon as the notification is sent, also the resident is notified through the PWMA Resident App of the operations starting, to be aware that the Surveyor will sooner come to perform the scanning. The workflow engine then will wait for the building surveyor to perform the scan and to upload the generated BIM model to the BIF. The surveyor will use the workflow engine UI to notify the termination of the scanning procedure and, consequently, the possibility to continue with the next task. In case the building surveyor do not perform the scanning in 10 days a new notification is sent to alert a delay. The same process is repeated for the refinement of the BIM model performing the structural scanning first and the MEP scanning later.

7.2.2 UC02 ARIBFA

In the use case 02 the ARIBFA tool is used to enrich the BIM model generated in the use case 01, with building systems (heating, cooling, ventilation, etc.) and network (pipes, cables) that may be even hidden behind walls. In this process the building occupant can provide a useful contribution through the ARIBFA App that allow him to report supplementary data like photos, notes, etc.

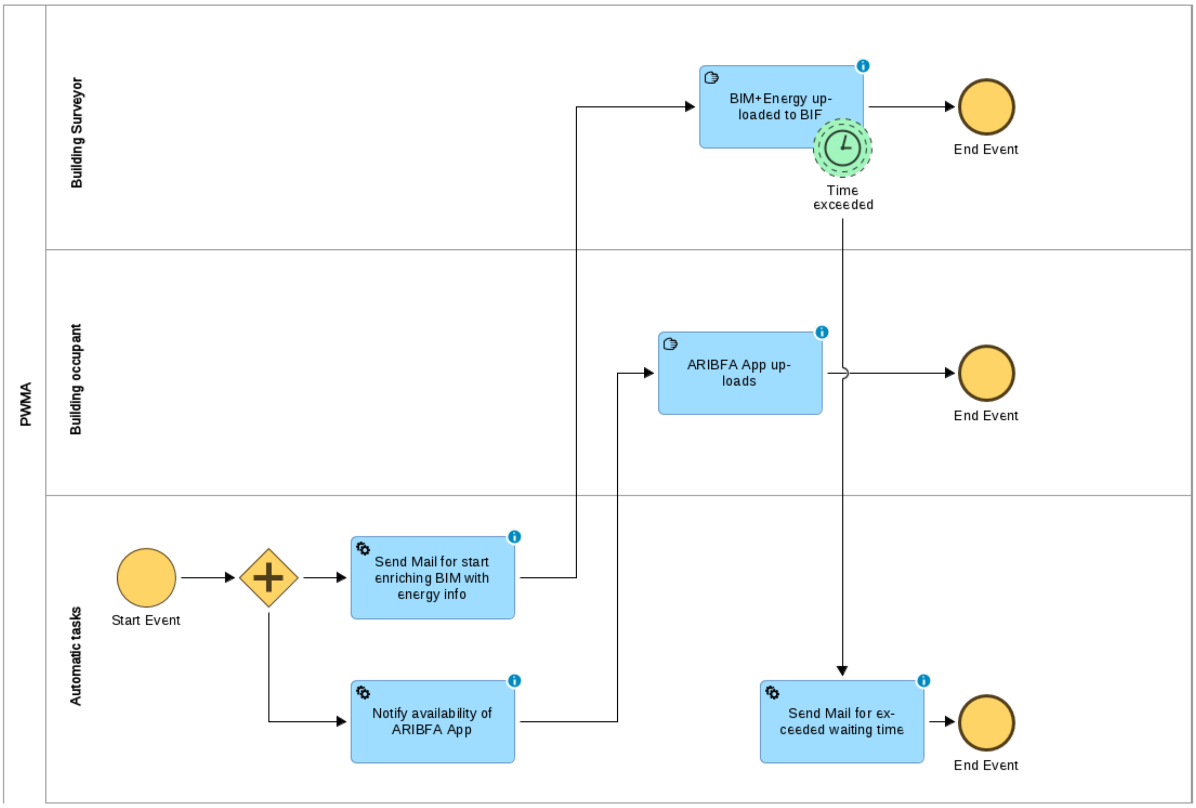

Figure 50: UC02 Digital Shadow of the BIMERR Renovation Process

Both the building surveyor and the occupant are notified by the workflow engine via a mail system. The surveyor is instructed on the modalities to acquire the additional data using the appropriate equipment (like HMD-AR glasses) of the ARIBFA toolkit, while the occupant is informed of the availability of the ARIBFA app for optional data reporting.

Also in this case, if the building surveyor do not perform the scanning in a predefined time frame, a notification of delay is sent.

7.2.3 UC03 PRUBs

In the use case 03 the energy profile of the building to renovate is detected using the BIMERR PRUBs toolkit, which will create a profile on the basis of the occupants' behaviours. Such profiles are then fed into a building energy performance simulation tool to provide a personalized estimation of expected post-renovation energy performance based on the occupants' profiles.

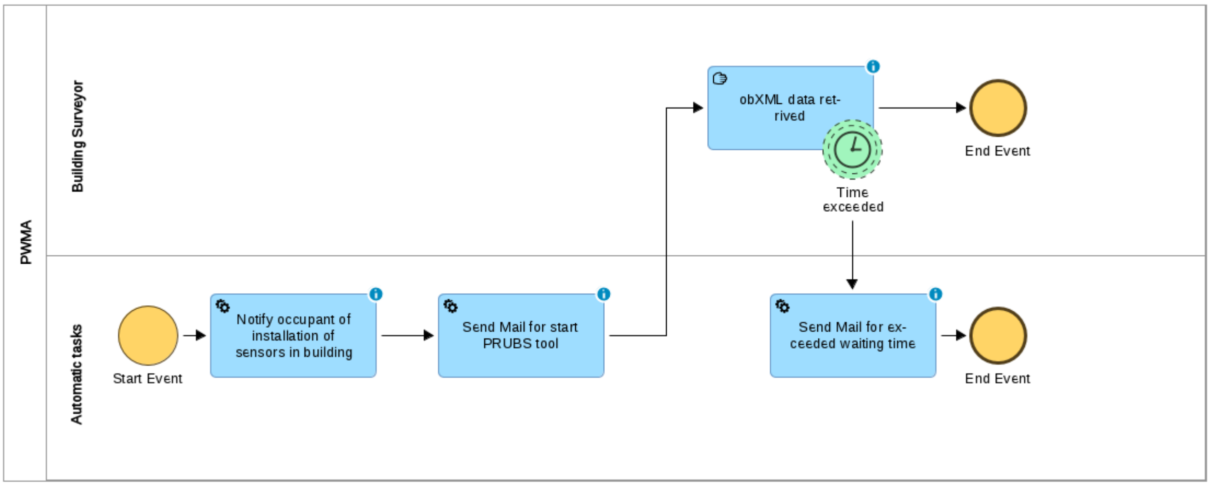

Figure 51: UC03 Digital Shadow of the BIMERR Renovation Process

To collect the occupant behaviors some IoT sensors will be installed in the building. The workflow will notify the occupants of such requirement to alert on the beginning of the profiling process. Also, the building surveyor will be notified automatically to begin the installation of sensors and data collections with PRUBs toolkits. On the conclusions of the activities an obXML[13] file is generated and uploaded to BIF and the building surveyor will use the workflow UI to notify it. Also in this case, a timeout exception will be raised if the operations will not terminate in a predefined time and a delay notification will be sent.

[13] https://behavior.lbl.gov/?q=obXML

7.2.4 UC04,13-16 RenoDSS

The RenoDSS toolkit is involved in the use cases 04, 13, 14, 15 and 16, all related to the finding of the optimal renovation scenario for the building. This application requires the BIM model resulting from use cases 01 and 02 and the energy profile of use case 03 for performing an energy performance simulation of the renovation measures. This is done first enriching the model with information of the materials used in the renovation and with their LCA-LCC attributes and with air quality information. Several simulations of different renovation options involving materials and components with their Life Cycle Cost/Assessment but also occupants' behaviours, are then performed in order to find the most efficient renovation in terms of energy and costs. In this simulation, also the interaction of the building with the surrounding urban system is considered, in order to support in future smart city scenarios, the decision-making and optimal urban planning towards enhanced sustainability and satisfaction of city commitments as documented in relevant SECAPs (Sustainable Energy and Climate Action Plans).

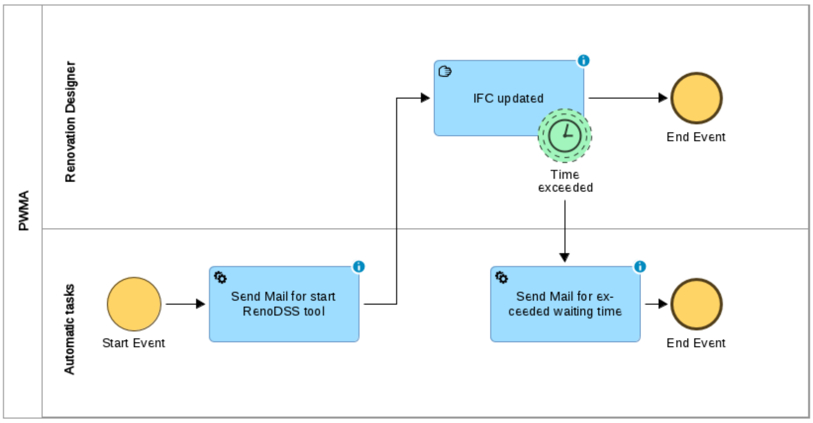

Figure 52: UC04 Digital Shadow of the BIMERR Renovation Process

All these actions are initialized by the workflow through an automatic message to the renovation designer that can use his/her knowledge to perform the required simulations in the RenoDSS toolkit. As the optimal renovation is identified, the renovation designer can notify the workflow of the updated IFC file in the BIF platform through an appropriate UI. In case the operations will not be performed on time, a notification is sent automatically by the engine.

7.2.5 UC05 Simulation

After the best renovation scenario has been identified the PWMA toolkit can be used to perform a simulation of the renovation process in order to identify times and costs considering different variables, like weather conditions, which may affect the renovation process. The PWMA toolkit will first allow to design the renovation process in a modelling environment starting from a predefined template and arriving after a refinement process to an executable workflow of the specific renovation process. In the middle of this process the simulation toolkit is used to optimize the process and identify bottleneck.

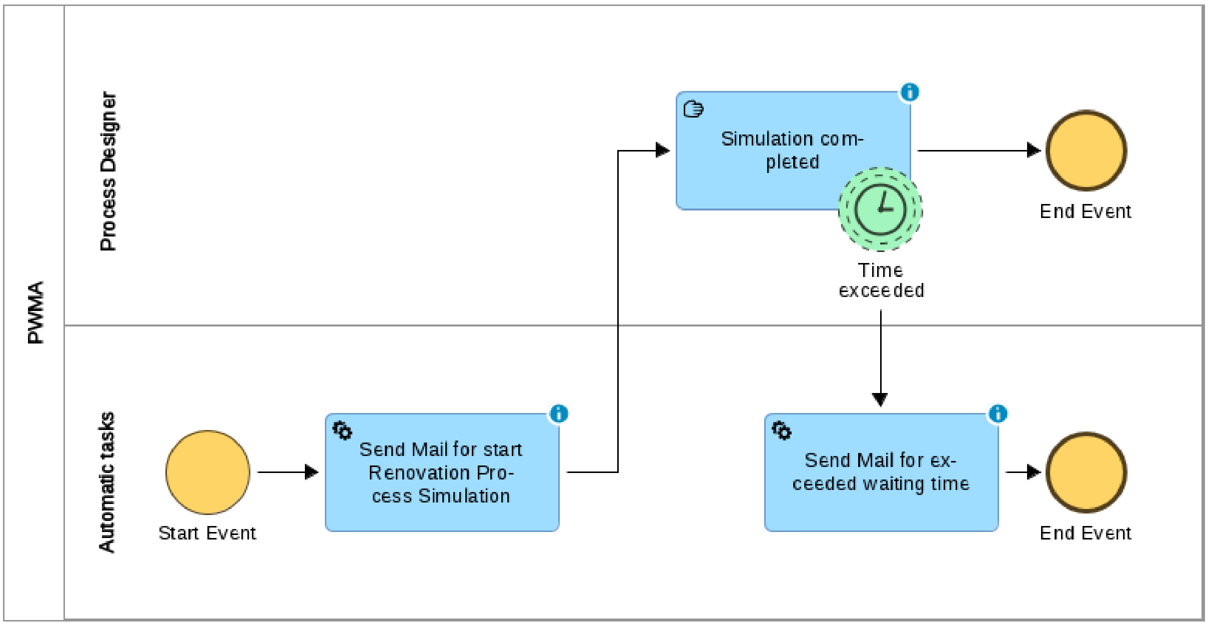

Figure 53: UC05 Digital Shadow of the BIMERR Renovation Process

The simulation activities are initialized by the workflow engine through a mail sent to the process designer, responsible to create the renovation process model, simulate it and iteratively refine and optimize till a detailed workflow model ready. As soon as such activities are completed, the designer notify the workflow engine that it can proceed with the next use case sub-process. Also in this case, a notification of delay is sent in case the modelling and simulation phase least more than expected.

7.2.6 UC06-12 Execution

The last step is the effective execution of the renovation activities. In this process the PWMA toolkit is used to refine the renovation process to an executable workflow and run it. In this phase the workflow is first also enriched with workers' schedule and BIM information. The workers on the building site will be guided in the renovation activities through smart glasses connected with the workflow engine that will display the steps to perform and site information (like BIM or health and safety training material) and allow to report anomalies that will trigger the improvement of the workflow model, also logging the activities for KPIs evaluation. During the renovation process the workflow engine is also responsible to notify the occupant about health and safety issues related to the current status of renovation via a specific app.

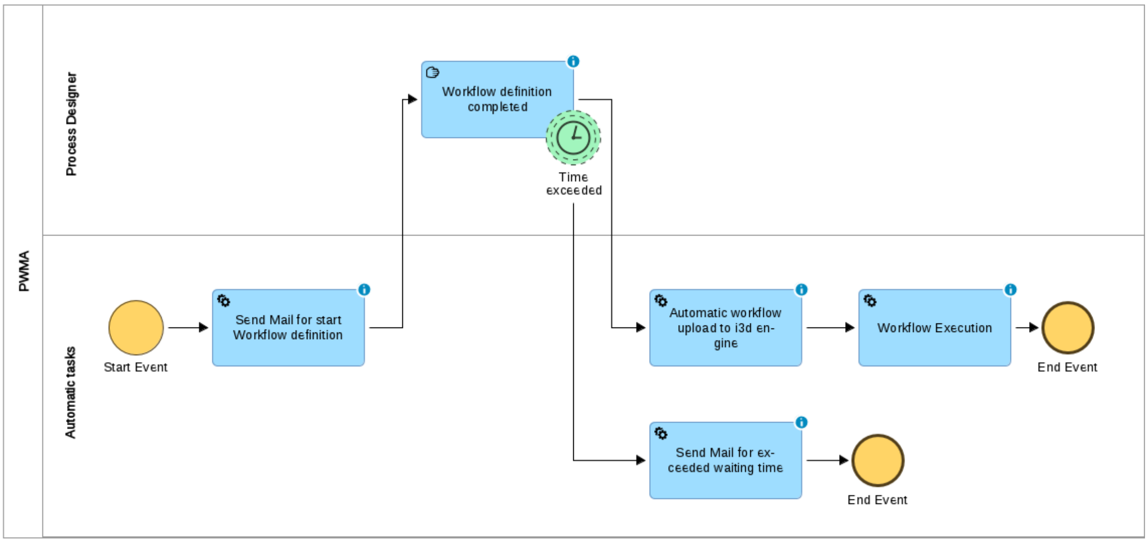

Figure 54: UC06 Digital Shadow of the BIMERR Renovation Process

The process designer is instructed to proceed with the workflow refinement activities through an automatic message from the workflow engine. As soon as the workflow is completed a service will automatically upload the model to the workflow execution engine of the PWMA and the execution start is triggered. Like in all the other use cases also here there are notification sent in case the process designer will not complete the workflow in a predefined time.

7.3 Digital Twin

The complete digital twin of the BIMERR renovation process is reached as soon as (a) we have defined the services that the workflow must use in order to perform the defined (semi-) automatic actions and (b) we are able to connect to the log of the execution workflow and services to calculate KPIs and calibrate the parameters of future simulations. In this way we are able to model all the aspects a workflow needs in order to run properly and close the cycle of model improvement through log mining.

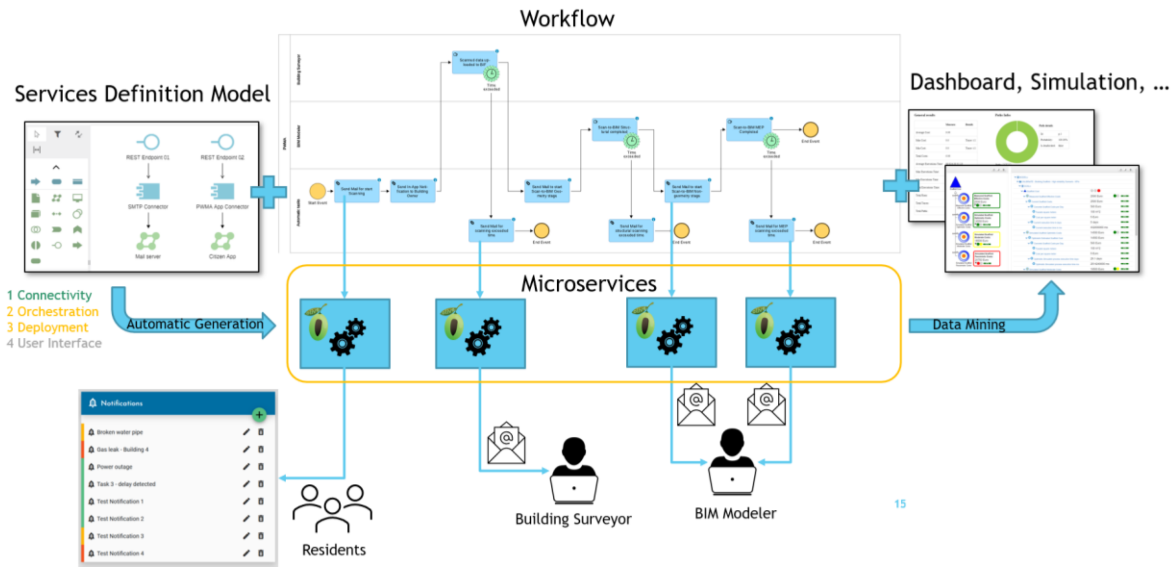

Figure 55: Digital Twin of the BIMERR Renovation Process

Using the microservice definition model, it is possible to model the behaviour of a microservice created with the Olive microservice framework, explained in detail in BIMERR deliverable D6.5, and automatically have a running service out of such models simply clicking a deploy button in the modelling environment. The KPI model instead connects with the microservices in order to retrieve the metrics' values required for the KPIs calculation. The KPI dashboard will use the information in this model to effectively call the services for retrieving the data and combine them to return the KPI values.

In the following sections will be presented the microservice definition models and the KPI models created.

7.3.1 Microservice Definition Models

For the BIMERR renovation process, a single microservice definition model has been created, dividing it in sections related to notification services, integration services and KPI data retrieval services.

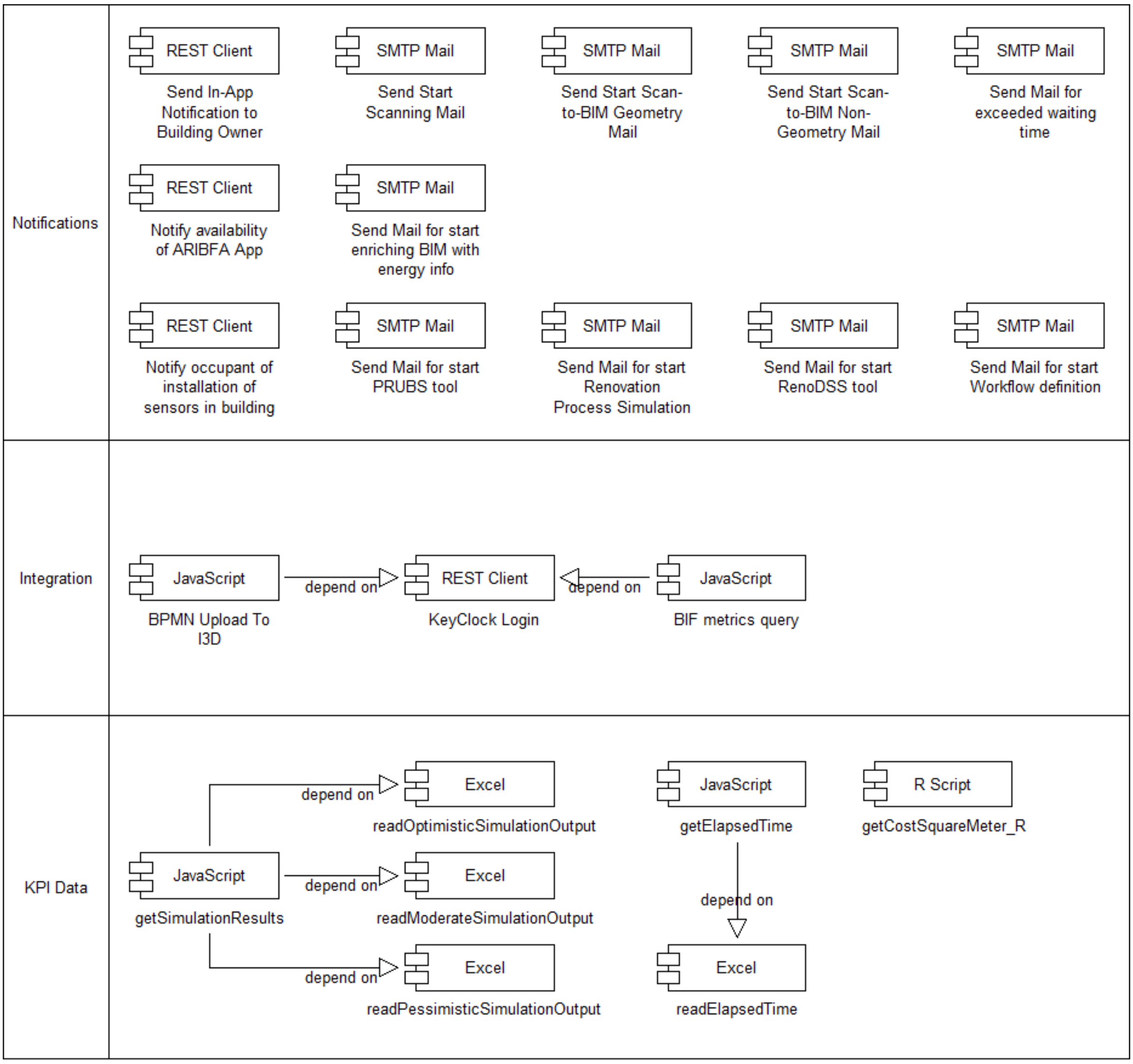

Figure 56: Microservice Definition Model of the Digital Twin

The notification services define the services that in every use case specific workflow are used to notify the respective stakeholder via mail or via the app for residents. Each mail sending service differs from the other for the template used containing the instructions on the specific process. In particular each mail describe which documents must be generated by the user performing the task, containing a description, a naming convention for the document, a deadline, etc. All such information will be provided as parameters for the services, using the data in the MIDP (Master Information Delivery Plan) associated to each process, at execution time by the workflow engine.

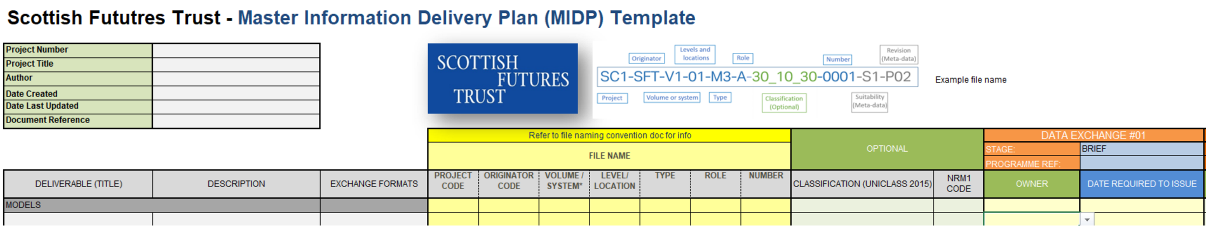

Figure 57: Master Information Delivery Plan

The integration services are related to the integration with the BIF platform and the workflow engine. The first one is used for querying some metrics related to the building structure available in the BIF and required for calculating some KPIs. The second is required to send the workflow to the I3D execution engine to be executed. Both services will depend on an authentication service that perform the login on the BIMERR KeyCloak identity provider to give the right access authorizations.

The last set of services are related to the extraction of data for KPI calculation. Such services in particular retrieve the results of the different simulations performed, and the logs of the workflow engine, to compare, in the same dashboard, the expected KPI values with the effective ones.

7.3.2 BIMERR KPIs

This section describes the model create to calculate Cost and Time KPIs of the BIMERR renovation process as defined in the D9.1 (Pilot renovation sites acquisition/selection process, ex-ante analysis and baseline definition). Each KPI related to cost and time has been categorized in a pool containing all the related metrics and data. As naming conventions (a) each KPI is named R_CT (Reduction for Cost and Time) followed by an identification number, (b) metrics data related to times start with T while quantities start with N and (c) baseline values contain BL while BIMERR enabled values contain BMR.

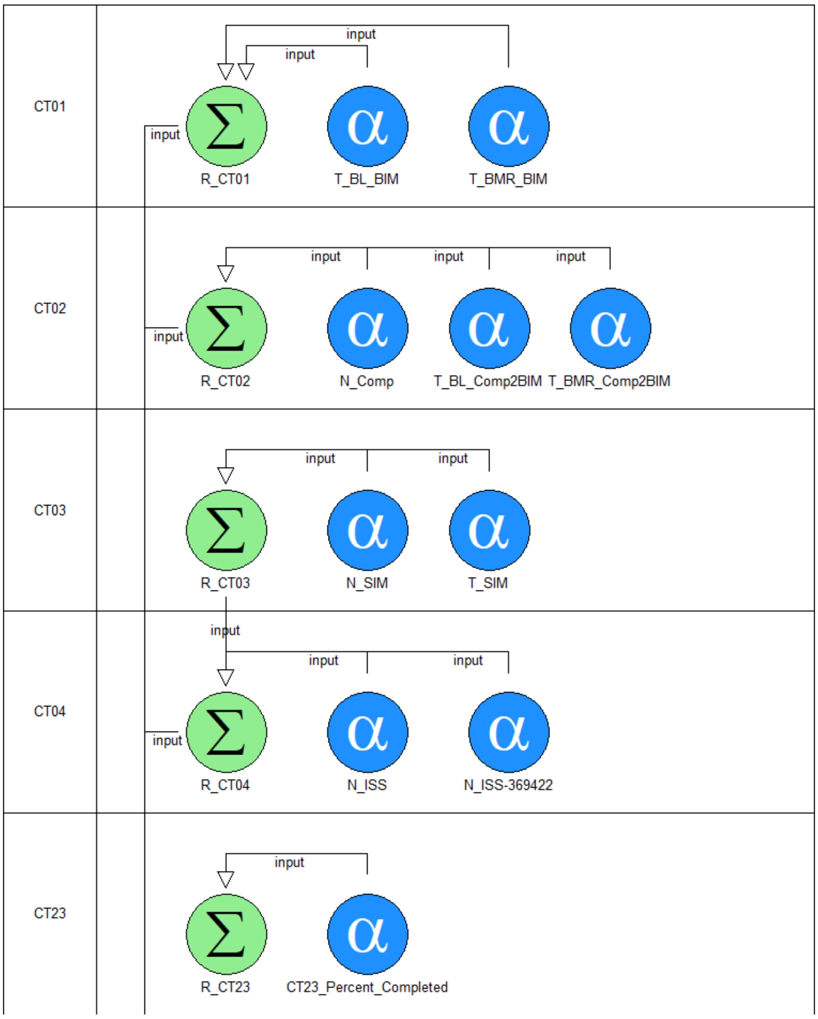

Figure 58: KPI model 1 of the Digital Twin

All the baseline values are collected directly from the pilot cases in form of Excel files with a specific template. The metrics data connectors (represented as blue circles in Figure 58, Figure 59, Figure 60, Figure 61, and Figure 62) related to the baseline values contain details about how to extract such data from the Excel through Olive microservices, while the ones related to the BIMERR enabled values are retrieved from specific BIMERR services when possible. Dependencies are specified using input sequence flows and the metric objects (represented as green circles in Figure 58, Figure 59, Figure 60, Figure 61, and Figure 62) use such information to calculate the KPI value implementing the formulas described in D9.1 for each Cost and Time KPI, combining the values of the data connectors objects and, when needed, of other KPI metrics.

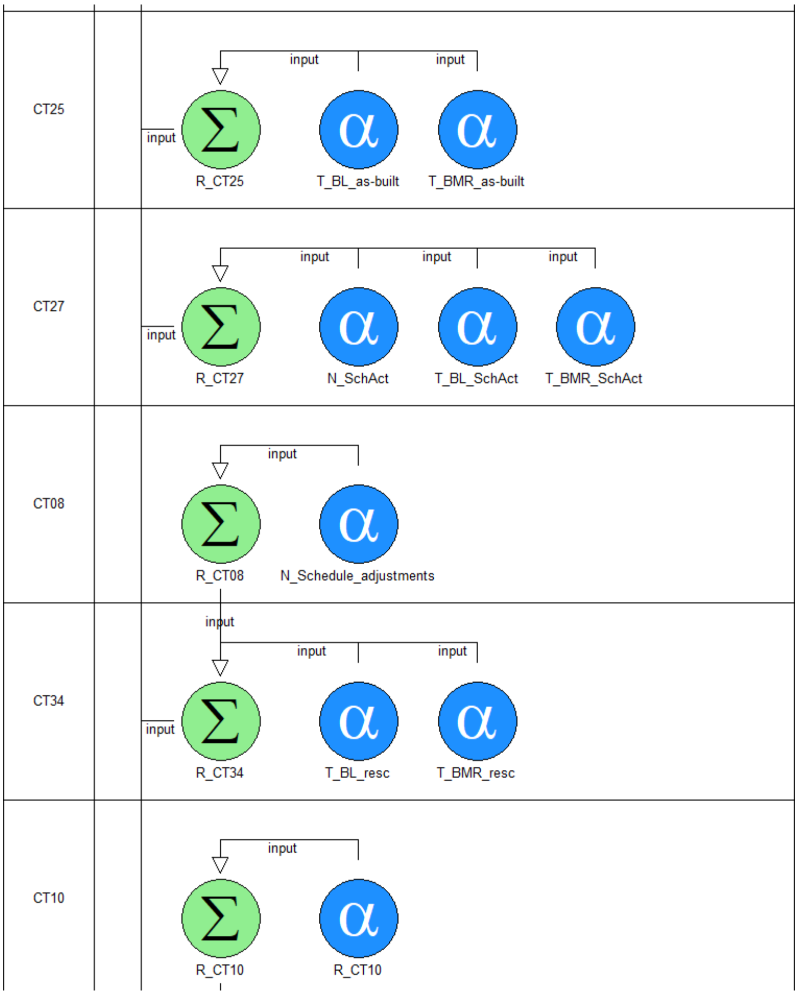

Figure 59: KPI model 2 of the Digital Twin

A sample of the first case is visible in KPIs like the CT01 about the time required to complete the as-is geometry model of the building to renovate, where the time reduction (R_CT01) is calculated as the difference between the time of creating the BIM model in the baseline scenario (T_BL_BIM) and the time of creating the same BIM model with the BIMERR tools (T_BMR_BIM).

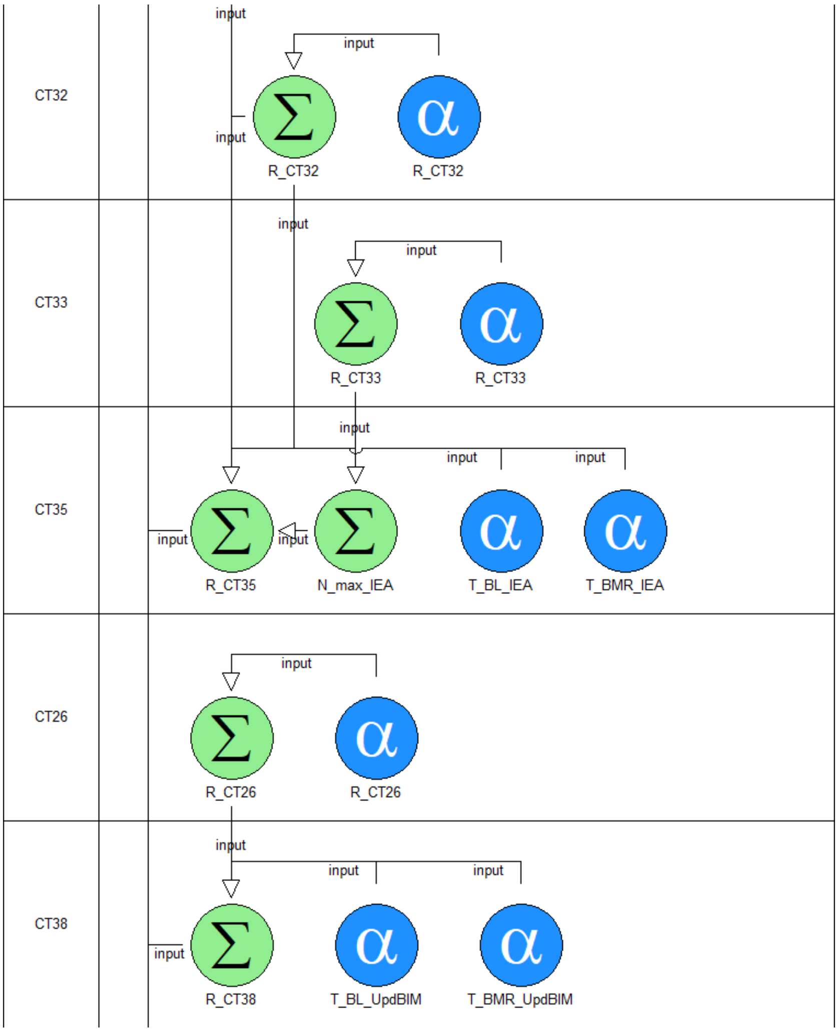

Figure 60: KPI model 3 of the Digital Twin

A sample of the second case, where the result of another KPI is used in the calculation, can be seen in the CT35 (Figure 60) about the time for information exchange between stakeholders during phases prior to construction. In this case the KPI is calculated using the formula “R_CT35 = N_max_IEA * (T_BL_IEA – T_BMR_IEA) – (R_CT32 * R_CT10)“ where

N_max_IEA is the maximum number of information exchange among CT32 project outputs and CT33 stakeholders, T_BL_IEA and T_BMR_IEA are the average times required for successful Information Exchange Action (IEA) respectively for the baseline and BIMERR scenarios and R_CT32 and R_CT10 are the results of previously calculated KPIs.

The KPI model is then exported in a JSON format in order to generate a dashboard for visualizing the calculated KPI values as described in more details in (BIMERR D6.5) where the BIMERR tools related to the PWMA are demonstrated.

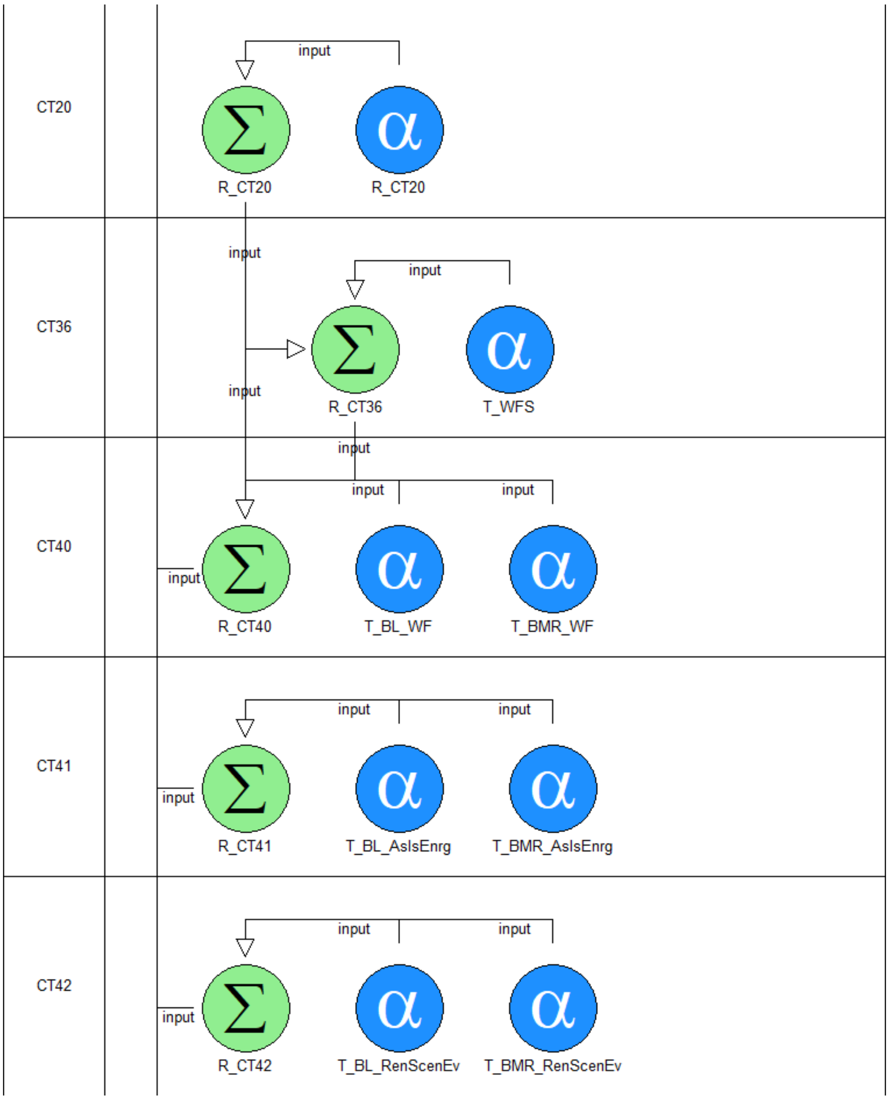

Figure 61: KPI model 4 of the Digital Twin

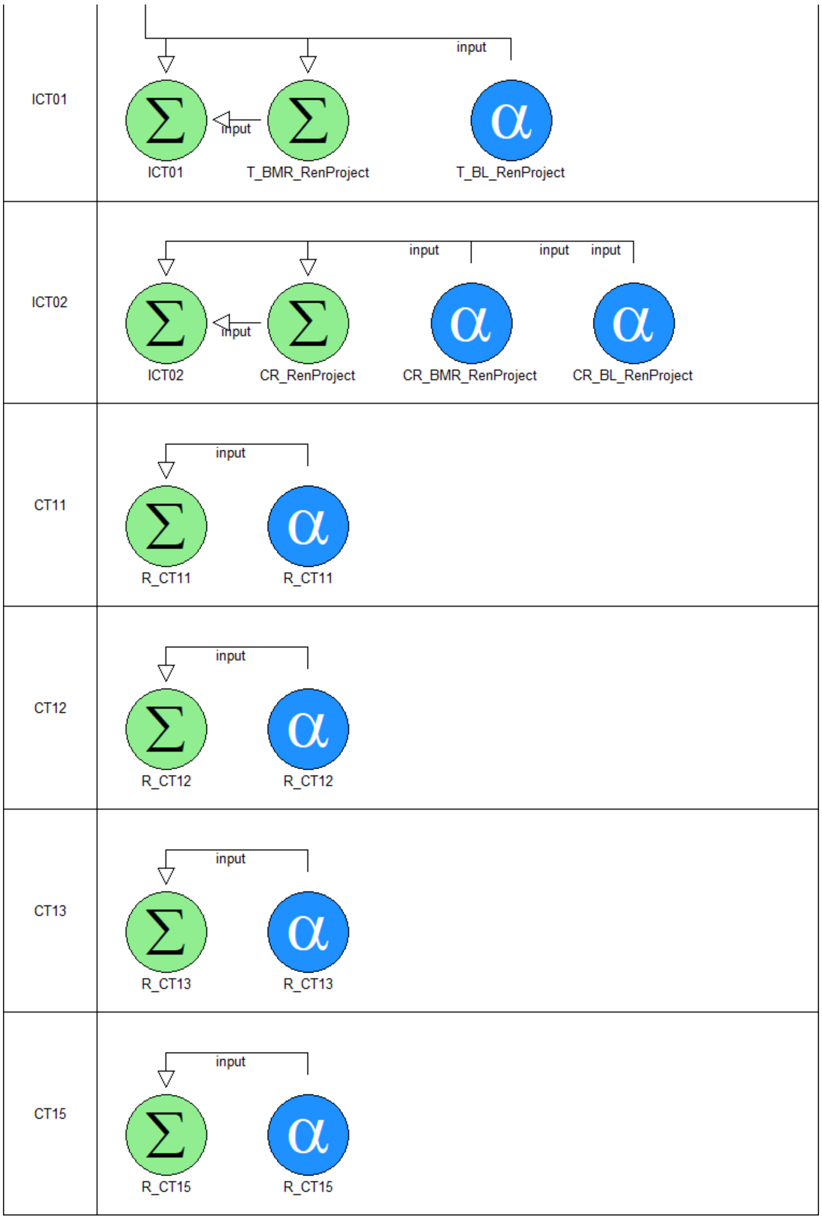

Figure 62: KPI model 5 of the Digital Twin

8. Conclusion and Outlook

8.1 Conclusion

In this deliverable we (a) introduced the principles of process management in the domain of renovation initiatives, (b) generated the set of templates with the domain experts, (c) exemplarily extracted knowledge for predictive simulation from domain experts and (d) technically set up the possibilities to create a digital twin for the renovation process, (e) transformed a renovation process template towards an executable renovation process and (f) applied the introduced digital twin creation concepts to the entire BIMERR renovation process.

The introduction of process management into the domain of renovation initiatives resulted in (I) the adaptation of the approach, as well as (II) the introduction of the approach to the domain experts. For (I) the adaptation of the approach the principles of "Industrial Business Process Management" have been considered since this approach also deals with physical business processes. As our approach currently only considers time and costs, the available BPMN standard and the corresponding tool family for Industrial Business Process Management were applicable. However, in specific cases, we proceed also to include more complex aspects like the management or sub-contractors, their contracting, material flow and similar aspects.

The tool family that was used, needed some configurations, in order to better enable the reflection of expert knowledge and address the individual characteristic of renovation initiatives. The Industrial Business Process Management is often applied in semi-automatic or automatic production environments, hence, a highly automatized and repetitive sequence of actions, whereas the renovation process is unique for each site and mainly performed manually. This phenomenon was addressed by introducing transformation layers between the different renovation process models – from template to instance and workflow – which is a domain specific characteristic.

Furthermore, the absence of massive data and the need to rely on domain-expert knowledge required changes in the way the KPIs are calculated and simulated. The heterogeneous influence factors and the different expert opinions have been reflected in the knowledge-based simulation environment that needs more domain-expert user-friendly possibilities to contribute with knowledge.

The (II) introduction of the process management approach to the domain experts was a very fruitful and positive experience. There are significant similarities between already existing project management and the here introduced process management. Hence, the identification of where existing project management leaves the room for complementary support as well as the fact that a thorough planning phase is needed before the process models can be used, was accepted, and positively received by the domain experts in the project.

The renovation process models quickly gained awareness between other partners, as the concrete sequence of actions, tool interactions and required data were mapped form existing approaches with the top-down process management that was driven by the domain experts. In that case, the process model acts as a moderation platform to bring high level domain experts on board of the project.

8.2 OUTLOOK

This document describes the set of renovation processes, which will be complemented by BIMERR deliverable D6.5 that describe the corresponding tools to apply the introduced process management of renovation processes. In the following we provide an outlook on:

(a) Introducing Artificial Intelligence for efficient Renovation Process Management

The challenge for renovation processes is the transformation of process templates into instances.

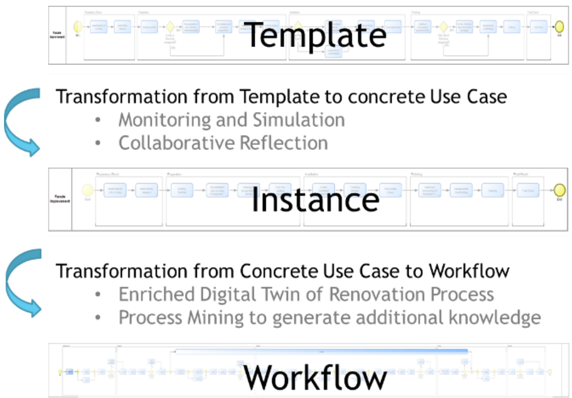

Figure 63: AI Techniques to support Model Transformation

Figure 63 indicates the three different levels of renovation processes, starting from the process template, the process instance for a concrete site and the workflow that creates a digital twin of the renovation process.

The transformation is currently exclusively performed in a manual and intellectual way from a process modeler. The goal is to introduce knowledge-based algorithms that support the transformation of process models to make process modelling more applicable.

(b) Introducing Marketplace model

In BIMERR deliverable D6.5 a new tool to simplify the fruition of the created models and functionalities has been introduced. The tool is based on the idea of exploiting the relations between the concepts of Model, Data, and Functionality to simplify the fruition of services to the user. This resulted from the experience of the final users that do not need to access the whole modelling environment to only use existing models, so a need to associate the model with data to provide a specific feature was needed. The resulting environment allows to define, at design phase, the model, associate it with a dataset accessing a data lake through microservices created in the Olive framework, and digitally sign the resulting model to certify the availability of a specific feature. An example is the renovation process simulation feature, that to run properly need an Excel, file specific for the model, where all the parameters for calibrating the simulation based on specific factors are specified. Using the Excel file of another model will result in a failure of the simulation or, even worst, a misleading simulation result. Signing the simulation feature for the model with the specific Excel data file will certify to future users that the feature is trustable. Another feature sample is the workflow execution. Here we can move from the top-down approach explained in this deliverable where first the renovation process template is created and refined to an executable workflow, to a situation where the user can choose between existing workflows to use, that fit the specific renovation scenario and adapt it for the needed case. The approach has been already successfully applied in the smart factory domain to proof the safety of robot operations and we want to explore in future projects the possibility of application the same concepts in the renovation process scenario.

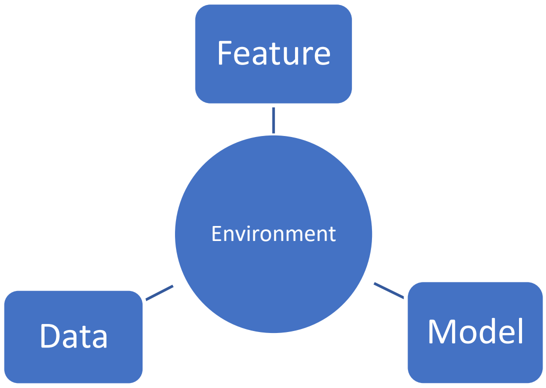

Figure 64 - Model Marketplace Idea

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