INTEGRATED WEB-BASED RETROFITTING SERVICES FOR ONSITE PROCESS MANAGEMENT

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Abstract

Because of the significant concerns about the rate and amount of renovation projects that need to be achieved to meet the European energy-saving and decarbonisation goals, the need for innovative and automated processes to streamline and facilitate the whole lifecycle of building renovation increases. This paper demonstrates the development of the RINNO Retrofitting Manager (RRM) with web service technologies and presents its numerous functionalities and components. The main purpose of the platform developed is to rationalise the onsite execution of the retrofitting process so as to enable optimising the delivery of renovation works, while making data easily accessible through an integrated set of role-based user interfaces. The RRM was co-defined and co-developed as a holistic web-based platform by implementing a collaborative Double Diamond approach. The proposed platform is expected to enhance collaboration, interoperability and data security, and avoid information loss and misunderstanding.

Introduction

Recent research showed 77% of European residential buildings were built prior to 1990 (EU Buildings, 2016), 35% of buildings are over 50 years old (EU Buildings, 2016), 75% of the existing built environment is energy-intensive and inefficient (Energy Efficient, 2022), and up to 80% of them will still be in use by the year 2050 (Menna et al., 2022). Inefficient existing buildings negatively impact both humans and the environment (UN, 2021). A renovation rate of at least 3% annually seems to be required to accomplish the EU's energy efficiency and environmental objectives in a cost-effective way (European Commission, 2022). However, following the current renovation rates, which range between 0.4 and 1.2% depending on the EU country, it would take more than 100 years to renovate all the EU buildings (European Commission, 2022).

Several works and studies have attempted to identify the main barriers and constraints that hinder building renovation in Europe (D'Oca et al., 2018; Palm and Reindl, 2018). They all highlighted (i) a lack of normalised and improved workflows, and practical software tools that facilitate renovation procedures, especially during the retrofitting phase when the space is shared between occupants and project teams (Amorocho and Hartmann, 2021); and (ii) the fact that issues, such as occupant disruption, that disturb onsite productivity and impact the overall efficiency of the project are usually neglected (Designing Buildings, 2022). To address these issues and enable the acceleration of renovation works, Killip et al. (Killip et al., 2013) proposed the consideration of three dimensions of innovation. First, innovative products or new technologies to enhance the performance of building components. Second, best practices which represent the most appropriate ways of achieving specific tasks and activities. Third, optimised processes that allow the renovation teams to plan, manage and execute efficiently the renovation tasks. The project participants need to use dedicated tools and methods to communicate and collaborate to enhance the performance of their activities and better control renovation projects in terms of cost, time, safety and quality (Amorocho and Hartmann, 2021; Caixeta and Fabricio, 2013; Egbu, 1997; Egbu et al., 1998; Naaranoja and Uden, 2007; Swan and Brown, 2013). Although innovative products are very important for the success of a renovation project, they should not be the main focus to solve the problem (Killip et al., 2013). Moreover, most project participants use specific software tools with proprietary file formats that cannot be directly processed outside of these tools. Such software and file types present significant obstacles to interoperability because data represented needs to be converted into other supportable file formats, which usually leads to information loss and misunderstanding.

Technological advancements, such as web technologies have provided a new way of representing and exchanging data between interoperable systems, and so uncovered opportunities to streamline and improve information project management processes in the AEC domains (Schraw, 1998). Due to the nature of a renovation project as an information-intensive process involving many stakeholders and systems as well as applications, web services present a real advantage to resolve the complex and multifaceted challenges faced. Web service technologies have been used by several researchers to improve interoperability between digital tools and optimise information exchange processes (Borgo et al., 2015; Pauwels and Terkaj, 2016; Terkaj and Šojić, 2015); facilitate linking and synchronising information across various AEC domains (Lima et al., 2012, 2005); and produce new information based on the knowledge explicitly gathered and represented (de Farias et al., 2016; Pauwels et al., 2011). However, to the best of our knowledge, none of the existing works have considered demonstrating the potential application of web service technologies as a comprehensive framework to seamlessly structure and manage retrofitting processes in order to accelerate the rate and amount of renovation projects.

This paper presents the development of the RINNO Retrofitting Manager (RRM) using web service technologies. The main purpose of the platform developed is to streamline the onsite execution of the retrofitting process, while making data easily accessible through an integrated set of role-based user interfaces. The RRM is designed and implemented as a common web-based retrofitting platform that helps optimise, execute, analyse and monitor the renovation process as well as guide and train onsite the workforce. Ultimately, the proposed platform is expected to enhance collaboration, interoperability and data security, and avoid information loss and misunderstanding among project stakeholders.

The remainder of the paper is structured into three main sections that follow this introduction. Section 2 presents the collaborative research and development method used to design and develop the RRM platform. Section 3 introduces the RRM platform and its different components and services. First, a general overview of the platform is presented, and then the RRM Engine is separately described. Second, the Onsite Monitoring component is detailed, including its main functionalities, the methodologies that enabled its development and integration as well as the Graphical User Interfaces (GUI) implemented. Section 4 discusses the added value of the RRM platform in the renovation process and potential advantages that such a management tool can provide to improve the onsite productivity for building renovation projects. Finally, conclusions and future extensions of the proposed framework are outlined in Section 5.

Research methodology

The RRM framework, including its services and components, was conceptualised and implemented within the context of a large European research project which is the RINNO project (Doukari et al., 2021). RINNO includes 19 partners from 10 different EU countries and aims to optimise and accelerate building renovation in Europe. To enable design innovation, while defining, developing and validating the RRM platform, the Double Diamond (DD) process (Design Council, 2022) was adopted as a Research & Development (R&D) methodology. The DD process has originally evolved as a framework for innovation and problem-solving to help practitioners, designers and non-designers, to overcome the most complex social, economic and environmental challenges. The DD process includes the following four steps: Discover, Define, Develop and Deliver. Since several multidisciplinary and distant research teams from across Europe were involved in this study and to enable concurrent and distributed R&D works, a collaborative DD (CoDD) approach was implemented (Figure 1). Thus, the original four steps were adapted as follows:

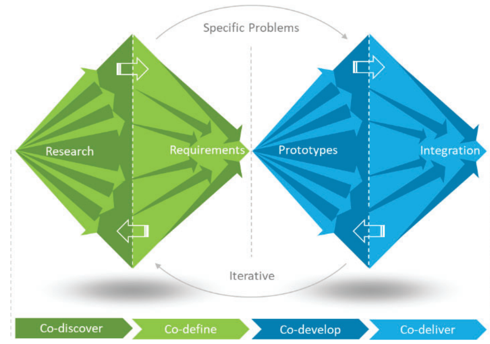

Figure 1: Collaborative Double Diamond R&D method

- Step 1 – Co-discover: several collaborative and parallel meetings and workshops were organised with the RINNO partners to understand, rather than simply assume, what the problem and objective were. It involved speaking to and spending time with partners, including large industrial companies, SMEs, social housing companies, and non-profit organisations from across Europe, who are affected by the problem. As highlighted in the introduction, the problem being addressed by this study is the lack of dedicated tools to streamline the onsite execution of the retrofitting process to enable accelerating renovation works.
- Step 2 – Co-define: based on the first step output, the second step required to collaboratively define a set of design requirements and high level functionalities and services that the future artefact must comply with to solve the problem identified. This step was particularly challenging as the objective was to enable simultaneous design and development and so implement a loose coupling between services. Also, some existing tools that had been developed by RINNO partners for the construction of new buildings, such as the Recommendation service, had to be reused and adapted to the renovation domain.
- Step 3 – Co-develop: once the second step was sufficiently detailed and a co-design of an artifact was co-defined, the third step consisted in co-constructing the artifact and all its services and components concurrently. Functional versions of the RRM platform services were co-developed and their integration was discussed and planed. Due to lack of space, only the development of the RRM Engine and its Onsite Monitoring component were detailed in this paper.
- Step 4 – Co-deliver: at this step, the RRM services and components were first integrated, then the result was tested and assessed whether it provided a satisfactory solution to the problem co-discovered and co-defined initially. As detailed in the next section, this was achieved during collaborativeworkshops by presenting and putting to the test the system developed to project and site managers, construction engineers and onsite workers and collecting their feedbacks and recommendations.

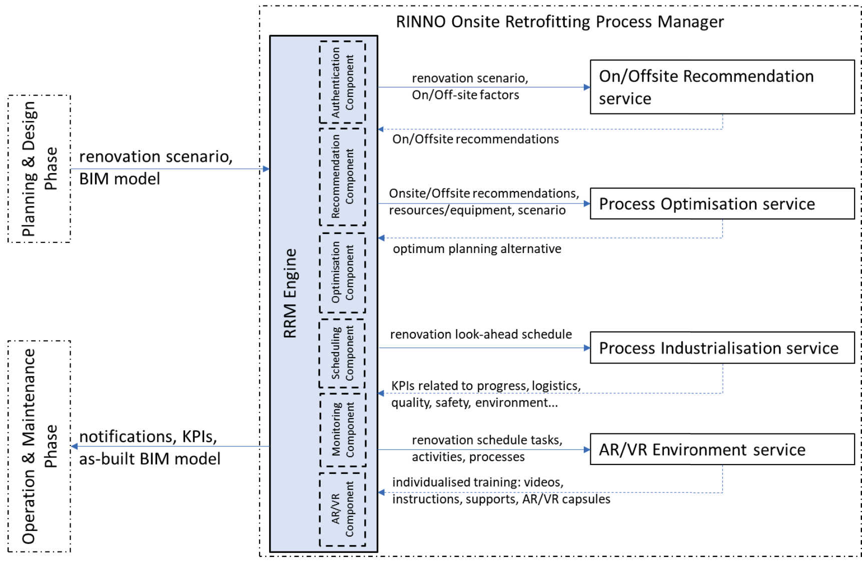

Figure 2: System architecture of the RINNO Onsite Retrofitting Process Manager (RRM)

RINNO retrofitting process manager

The RRM is an integrated platform that enables the orchestration and monitoring of information flows across all stages of the building renovation works. As illustrated in Figure 2, it enables four retrofitting services, namely: the On/Offsite Recommendation, the Process Optimisation, the Process Industrialisation, and the AR/VR Environment services, through the RRM Engine that implements a set of Application Programming Interfaces (API) and dedicated components. The RRM services were designed and developed collaboratively by different RINNO partners from different EU countries. The activities of the RRM platform are sequenced and coordinated through communication and information exchange between the RRM services. It starts with recommending the best On/Offsite renovation strategy and finishes with notifying stakeholders and displaying valuable information through several Key Performance Indicator (KPI) dimensions. The remainder of this paper only describes the development of the RRM Engine and its Onsite Monitoring component.

RRM Engine

Figure 3 shows the internal structure of the RRM Engine developed. As illustrated in this figure, the 'Retrofitting' class is a central unit of the RRM Engine that implements the main functionalities of the platform. On the one hand, it contains a set of 'Constraints', such as cost, duration, and material-related constraints, as well as a renovation 'Scenario' that should be identified in the Design & Planning phase, a recommended On/Offsite renovation 'Strategy' and a retrofitting 'Planning' class. On the other hand, the 'Retrofitting' class aggregates many project 'Stakeholders' that can be represented as a 'Person' or a 'Company'. This latter uses 'Resources' (such as equipment and workers), occupies 'Spaces', and submits or receives 'Information'.

The 'Planning' class enables the creation of retrofitting schedules, updates and optimisation. It allows retrofitting works to be visualised through AR/VR technologies in order to assist and train the workforce onsite using the 'Augmented Reality' class. This latter enables relevant web-based APIs to connect to the AR/VR Environment service and retrieve the required AR/VR data and contents.

Furthermore, the 'Planning' class is implemented based on Lean methodology principles (Womack et al., 2007) to enable integrating renovation-related information and constraints so as to ensure generating constraint-free commitment work schedules. The RRM platform implements three levels of Lean planning: 'Baseline', 'Look-ahead' and 'Commitment'. The first level consists of the retrofitting 'Scenario' which represents a project-level plan as received and parsed from the Design & Planning phase. The second, 'Look-ahead' level, represents further breakdown of the renovation 'Scenario' into renovation activities, assigned spaces, type of material to be mobilised as well as the number of workers required to execute the tasks. The last level, 'Commitment' planning, identifies retrofitting work quantities that are manageable at crew level, validated and achieved at a weekly basis by the Process Industrialisation service.

The main advantage of adopting Lean methodology is to be able to take into account the needs and constraints of each project actor by promoting and encouraging collaboration before tasks execution. Furthermore, this integrated architecture enables connecting downstream management systems, based on commitment plans that are executed at a weekly and daily basis, with upstream management systems and higher-level planning. This should ensure the consistency, quality and transparency of the whole retrofitting process.

The RRM platform was implemented using React (React, 2022), a free and open-source JavaScript library for building GUI components, to develop the front-end and C# programming language to develop the back-end of the platform.

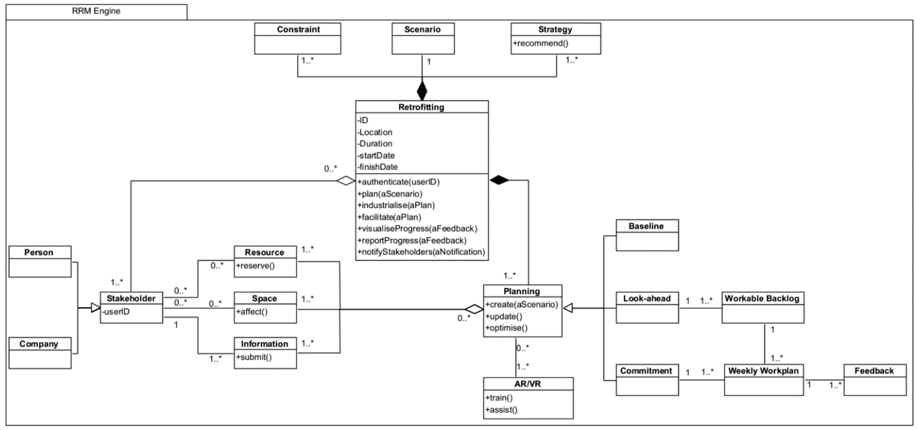

Figure 3: The RRM Engine structure – UML class diagram

Onsite Monitoring component

The Onsite Monitoring component of the RRM Engine (Figure 4) was developed to enable monitoring of the retrofitting progress and the provision of feedback to the project stakeholders. Its main role is to: (i) gather onsite

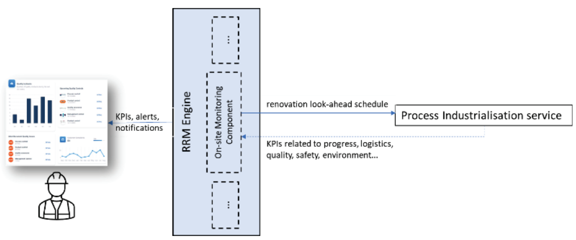

Figure 4: The Onsite Monitoring component

information about weekly project safety, quality, cost, completion of tasks and reasons for potential committed task delays, and information related to waste management and environmental aspects; and (ii) provide the project stakeholders with timely insights to take appropriate actions if needed.

To enable this, the following steps were implemented. First, workshops with onsite construction workers, project and site managers and engineers were organised in order to identify the most relevant information they need to be regularly reported during the retrofitting phase of a renovation project. For two days, fourteen participants from Bouygues Construction (BYC) company in France contributed to creating several "user stories", including renovation project stakeholders' needs and requirements in terms of onsite information and progress notification (Figure 5). Second, this input was categorised into different dimensions, including safety, quality, cost, scheduling, environmental, and services & benefits to facilitate KPIs identification. Third, for each data dimension a list of KPIs for onsite retrofitting process monitoring was defined, and their sources of data, calculation formulas, representation formats, and frequency of measurement were detailed. Table 1 presents an extract of the KPIs developed related to quality, cost and scheduling dimensions. Fourth, digital mock-ups were developed to clearly represent the project KPIs defined so as to enable their presentation and then validation with site managers and workers. Fifth, workshops were organised to demonstrate, discuss and validate the KPIs with BYC's teams. The participants showed interest in the structure, clarity and features implemented. However, based on the feedback received, the dimensions were reduced to only five dimensions, namely: safety, quality, cost, schedule, and environmental aspects, whilst the data related to services and benefits were integrated into the quality dimension. Finally, a set of friendly GUIs were designed and developed using React (React, 2022), CSS and HTML technologies (Figure 6). Particularly, MUI library (MUI, 2022) was used in order to ensure simplicity, clarity and responsiveness of the UI components implemented, and so enable visualisation on several device types with different hardware and software specifications, including smartphones, tablets and laptops.

Integration

The Onsite Monitoring component aims to implement two main functionalities. First, reporting onsite multi-disciplinary figures, including safety, quality, cost, scheduling and environmental KPIs presented in a simple yet easy way for comprehension using responsive, clear and color-coded UI components. Second, enabling linking a high-level planning system with low-level and commitment plannings managed through the Process Industrialisation service. To enable the second functionality, the Process Industrialisation service was integrated into the RRM platform. This particularly allowed managing GET requests and regular data retrieval through a loose coupling, using REST API, of the Onsite Monitoring component with the Process Industrialisation service. Information exchange between the two web services (i.e., the Onsite Monitoring and the Process Industrialisation) was enabled using JSON (JavaScript Object Notation) format which is, despite its name, language agnostic, humans and machines readable, in addition to be one of the most used file formats in web technologies. JSON templates were created to get and store information into the RRM platform database. For instance, the following schema shows how quality KPIs data were structured to be received and parsed by the Onsite Monitoring component:

[
  {
    "projectId": project_id_integer,
    "projectName": project_name_string,
    "qualityKPIInfo": [
      {
        "id": KPI_id_integer,
        "name": KPI_name_string,
        "value": [KPI_value1_integer, ..., KPI_value6_integer],
        "date": KPI_measurement_date_string,
        "unit": KPI_measurement_unit_string
      },
      {
        "id": KPI_id_integer,
        "name": KPI_name_string,
        "value": [KPI_value1_integer, ..., KPI_valueN_integer],
        "date": KPI_measurement_date_string,
        "unit": KPI_measurement_unit_string
      },
      {
        "id": KPI_id_integer,
        "name": KPI_name_string,
        "value": [KPI_value1_integer, ..., KPI_value5_integer],
        "date": KPI_measurement_date_string,
        "unit": KPI_measurement_unit_string
      },
      {
        "id": KPI_id_integer,
        "name": KPI_name_string,
        "value": [KPI_value1_integer, ..., KPI_valueN_integer],
        "date": KPI_measurement_date_string,
        "unit": KPI_measurement_unit_string
      },
    ]
  }
]

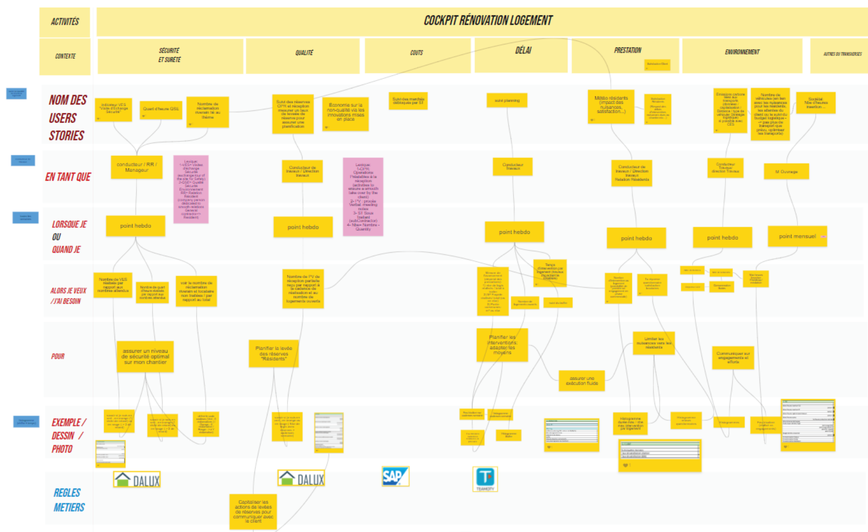

Figure 5: User stories defined during workshops with BYC operational site managers using Klaxoon platform

Figure 6. The RRM platform – KPIs for (A) Cost (B) Scheduling (C) Quality

Table 1: An extract of the RRM platform KPIs

Dimension	Description	Calculation	Representation
Quality	1- # of quality incidents 2- Monitoring the quality controls 3- Identification and alerts on recurring problems 4- # of customer complaints	1- # of opened 'quality incident forms' during the last 6 weeks 2- Quality controls to be done in the next 10 days 3- The 5 most recurrent quality issues 4- # of customer complaints	1- Bar chart 2- List 3- List 4- Line chart
Cost	5- Cost overruns 6- Cost savings	5- Sum of the registered overrun costs 6- Sum of the registered savings	5- Bar chart 6- Line chart
Scheduling	7- Delay monitoring 8- Duration for resolving issues 9- Milestones monitoring	7- Difference between days worked and days scheduled 8- Average duration between opening and closing issues 9- % of achieved, ongoing and upcoming tasks	7- Bar chart 8- Bar chart 9- Pie chart

Discussion

The RINNO Retrofitting Manager is an integrated platform composed of several services and components that complement each other. The RRM platform is crucial to the management of renovation projects during the retrofitting phase and presents numerous advantages and benefits to the project stakeholders compared to traditional ways of working. The following points summarise some of the significant value and benefits the RRM platform can offer during the retrofitting phase:

1. Retrofitting projects are known to be complex as witnessed by the variety of tools and processes that can be used to optimise and manage their execution. The RRM platform introduces a 'Common Process Environment' concept where all retrofitting processes and tools required are integrated in a one-stop-shop platform. Interoperability between tools is internally managed by the platform and there is no need to transform, import or export different file formats and deal with the issues related to data losses or formats that cannot be processed;
2. The RRM platform is developed based on Lean methodology aiming to constantly improve the added value of the construction tasks (in terms of performance, cost, quality and time), with the goal of enhancing the overall profitability and productivity of the project. This methodology ensures project actor needs are considered at the earliest stage of retrofitting and promotes and encourages collaboration before the onsite execution of tasks begins. Furthermore, adopting Lean method will ensure the RRM platform can connect downstream management systems, based on commitment plans that are executed on a weekly and daily basis, with upstream management systems and higher level planning. This will clearly bring more consistency, quality and transparency of the retrofitting process;
3. The RRM platform also offers an attractive and user-friendly GUI which, by simplifying some concepts, permits easy communication and better collaboration between the project stakeholders. In addition, the RRM platform manages, via REST APIs, complex communications and connections to remote services and modules deployed on distant servers. It also ensures the processing of data gathered from the Planning & Design phase and provides outputs and results to the Operation & Maintenance phase to streamline the project lifecycle management process;
4. Renovation projects consist of many mandatory decision-making actions for selecting the best strategies and adopting the optimal processes. To enable an informed and smart decision-making process, the RRM platform implements two AI-based algorithms using both the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method for solving multi-criteria problems (Chakraborty, 2022) and the PSO (Particle Swarm Optimisation) algorithm (Sahib and Hussein, 2019). The former helps select the appropriate mode of renovation, whether it is On or Offsite approach, while the latter is a bio-inspired algorithm used to accelerate the process of identifying the optimal retrofitting schedule that will be industrialised;
5. The success of a retrofitting project closely depends on the fulfilment of the project objectives and the compliance with client needs. For this, the RRM platform ensures gathering all project information required for organisational and sequence optimisation of renovation works onsite. This information includes data about logistics (e.g., materials, equipment, workers) as well as project specifications and needs, such as duration, cost and recommendations on the best renovation strategy to be adopted. In addition, while planning retrofitting works, the RRM platform allows the management team to capture and take into account, four different project constraints: i.e., physical (e.g., space), contractual (e.g., duration and cost), resource (e.g., availability and relevancy), and informational constraints;
6. To keep project stakeholders informed during the whole retrofitting phase, the developed RRM platform is site connected. Therefore, it enables onsite multi-disciplinary reports and feedback related to retrofitting process safety, quality, cost, scheduling and environmental aspects using relevant dashboards and KPIs presented in a clear and simple way. The dashboards developed integrate adaptive UI components that can be displayed on all types of devices with different screen sizes, such as smartphones, tablets and laptops to enable connectivity and accessibility either onsite or from the office.

Conclusion & perspectives

This paper presented the design and development of the RINNO Retrofitting Manager platform as part of a large European research project: the RINNO project. The RRM platform addresses the critical problem of the fragmentation of retrofitting tools and processes, and avoids separation between the Design & Planning phase and the Retrofitting phase of a renovation project. It was implemented as an integrated web-based platform to streamline the processes, enhance accessibility and enable better interoperability between software tools and file formats while conducting retrofitting works. The RRM platform integrates six components so as to ensure (i) project participants authentication; (ii) On/Offsite recommendation; (iii) renovation process optimisation; (iv) project scheduling; (v) retrofitting works industrialisation; and (vii) guidance as well as training for the workforce onsite and/or offsite. These web-based components and services run concurrently on the same platform to help the project participants to better collaborate, optimise, execute and monitor renovation works and processes.

The Authentication component helps make data accessible to all project stakeholders by providing a role-based authorisation for each stakeholder to access, input and retrieve relevant data from the RRM platform, while avoiding information losses and accidental data removal. This assigns responsibility for project data protection and ensures users have the required rights to access and update data. The On/Offsite Recommendation component helps select the best retrofitting strategy using the TOPSIS algorithm and a set of project factors and parameters relevant to onsite and offsite approaches. When this information is completed by the project manager, a decision-making process is triggered, and results are sent to the Optimisation component to generate the best renovation strategy to be adopted. The Optimisation component helps optimise the retrofitting process and define an optimal look-ahead schedule using one of the AI-based tools which is the PSO algorithm. Through different tables, it ensures the collection of all relevant project information required to optimise the retrofitting process onsite. This information includes data related to the project materials, equipment, workers needed, zones targeted, renovation activities, and project constraints and objectives, such as time and cost. This component can accommodate renovation activities that have been identified in the Design & Planning phase. The Scheduling component helps visualise and represent in a clear and simple way the look-ahead retrofitting schedule calculated and optimised using the Optimisation component. This will enable the project manager to check, validate and if necessary, update the retrofitting schedule before its automatic generation. The Onsite Monitoring component aims to enable high level project monitoring, via multi-disciplinary KPIs, and provide useful feedback and in-time information to the project participants. Its main functionality is to regularly collect onsite information about the project safety, quality, cost, completion of tasks and potential delays, and waste management, to be able to notify relevant stakeholders. Thus, offering an objective, synchronous, and shared assessment of the renovation process executed to enable adjusting accordingly stakeholders' strategies and efforts. Finally, the AR/VR component aims to ensure effective communication with the workforce to provide them with appropriate and requisite onsite and/or offsite assistance and training.

As illustrated in Figure 1, the RRM platform receives as input the as-designed BIM model from the Design & Planning phase. In future works, a BIM-based viewer will be integrated to enable more suitable 3D-based project monitoring using BIM along with the set of KPIs defined and Forge APIs. This will allow project and site managers to visualise historical data, simulate and/or monitor project onsite progress using 4D BIM, and automatically detect and process project anomalies and potential issues. The as-built BIM model will be amended accordingly and then provided to be integrated and connected to the Operation & Maintenance phase processes and tools.

Acknowledgments

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