INTEGRATION BETWEEN ENTERPRISE RESOURCE PLANNING AND BUILDING INFORMATION MODELLING

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ABSTRACT: *Enterprise resource planning (ERP) is an integrated business management system aimed at monitoring and maximizing resources and efficiency; on the other hand, Building Information Modelling (BIM) represents a broad series of approaches to design, based on the development of virtual models that cover the building's whole lifecycle. The integration of ERP systems within the Architecture, Engineering and Construction industry, while promising, has yet to reach the same results that its use has achieved in other fields. Although BIM and ERP are traditionally systems employed in different disciplines, they both deal with data integration and customization, and are designed to reconcile varied and scattered information. A mutual incorporation could allow for a more comprehensive understanding of the project starting from the initial phases, while also granting a more streamlined construction process and a reduction in errors and complications later on. The aim of this paper is to identify the possible connections between the two systems examining a case study, starting from an analysis of the current state of the art regarding this implementation, and by evaluating both the existing limits and the future possibilities of this implementation, for both small and medium enterprises (SMEs) and the industry at large.*

KEYWORDS: *Enterprise Resource Planning (ERP), Building Information Modelling (BIM), Small Medium Enterprises (SMEs), AEC, Construction, Data integration*

1. MANAGEMENT INFORMATION SYSTEM AND ENTERPRISE RESOURCE PLANNING

1.1 Brief history of ERP

Enterprise Resource Planning is a type of business information system meant to manage and monitor all the resources within an organization. Introduced in the 60s within the manufacturing industry as Material Requirement Planning (MRP) (Lee, Arif, & Halpin, 2002), the system mainly focused on the storage and allocation of materials. In 1975 IMB then developed the Manufacturing Management and Account System (MMAS), now considered the true precursor to ERP (Jacobs, 2007): the system was aimed at creating ledger postings, job costings and related forecasting updates based on the inventory status and order transactions, while also generating orders using a standard Bill Of Material (BOM).

The consequent technological growth enabled, during the 80s, the development of the Manufacturing Resource Planning (MRP II) system, which allowed the integration of functions related to human resources and marketing, as well as the management of all financial and accounting information (Kumar, & Van Hillegersberg, 2000). The ability to manage and update orders, inventory and financial transactions in a single system, allowed the companies to replace and centralize multiple typically stand-alone systems with a single software, resulting in easier communication between different areas and the automatization of data sharing.

However, the term ERP wasn't coined until 1990 by Gartner (Katuu, S. 2020), in order to describe a new generation of unified systems that could manage different departments within the same company, and that were based on the standardization and integration of processes within a single, shared database. This new type of management software also dealt with back-office data, financial transaction, marketing, and all the information related to all the different production stages, from planning and procurement to transportation and delivery. A rapidly growing business, ERP sales crossed the $10 billion mark in 1998 (Shi, & Halpin, 2003), with companies like J.D. Edward, Oracle, PeopleSoft, Baan and SAP surpassing IBM and positioning themselves as leaders in the ERP market. A critical factor in the success and spread of the software was also the so called Millennial Bug, or Y2K Problem, which was thought to cause global electronic damage due to how programs used to format year dates; in order to prevent possible informatic problems at the switch of the millennium, many companies took advantage of the

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necessity to update their own software and implemented ERP systems, cementing the software's consolidation in the industry.

Despite a promising start and initial accounts reporting a Return On Investment ranging from 30 to 300% within a year after installation (Shi, & Halpin, 2003), many failures were also accounted: the main problems were mostly related to the initial costs of purchase and installation - which, at the time, varied from $2 million to $130 million (Ross, 1999), and the time needed for full implementation, as well as the likelihood of a performance dip during the stabilization phase of the software, which was expected to typically lasts for four to 12 months. By 2002 all main ERP distributors faced a significant stock plummet: Baan had fallen off by then, and J.D. Edwards and PeopleSoft opted for a merger between the two companies, since there was very little overlap between what the two software offered and the joint venture was thought to, in this way, manage to exceed SAP and Oracle (Jacobs, 2007); nevertheless, Oracle itself took over the merger after a few days with an hostile takeover, leaving itself and SAP as the main distributors.

In the meantime, a new system was being developed: Extended ERP, or ERP II, not only allowed for real time access to information and immediate data sharing between members of the company, but also had managed to integrate two other software, Supply Chain Management (SCM) and Customer Relationship Manager (CRM), which could manage interactions with suppliers regarding procurement and transportation, while also handling clients' data (Al-Amin, Hossain, Islam, & Biwas, 2023). The advent of the digital era, paired with the difficulty for Small and Medium Enterprises (SMEs) to bear the software's implementation and managing costs, resulted in the development of Cloud-based ERP systems: in this case, the system runs on the provider's cloud platform as opposed to an on-premises hardware that needs to be handled by a IT team employed by the company. Traditional ERP software, developed for an easier but less flexible management than what the market requires today, have been proven to be insufficient in handling the complex internal processes required within an enterprise, as they are not able to grant the same streamlined integration that a cloud system can offer.

Many possibilities are viable today considering the advancements of technologies within the 4.0 Industry, one of which could be the development of ERP Mobile platforms, accessible from smartphones through internet connection, and that could allow for easier and instant access to information and more customization possibilities. The introduction of AI and Machine Learning could also quicken processes, thanks to the prediction of inventory status and the atomization of repetitive processes, as well as error predictability; the integration of IoT solutions, such as smart sensors, could, too, facilitate the monitoring of materials and equipment within the supply chain.

1.2 ERP within the construction industry

1.2.1 State of the art

ERP systems are currently used by construction companies in order to:

- Improve customer response time;
- Improve relationship with suppliers while also strengthening the supply chain all together;
- Increase organizing flexibility;
- Reduce time related to decision making processes, as well as the competition times and related costs.

Considering the great level of customization that this kind of management system can offer, it might seem impossible to define a standard ERP software for an industry like the AEC (Architectural, Engineering and Construction) one, which is incredibly fragmented and characterized by different areas of work, each one of which has its own particular needs, usually related to the specific project currently being worked on. As Helo and Szekely (2005) mention, many are, in fact, the benefits that an ERP system can provide, such as the possibility to immediately develop a Master Production Schedule which allows sales orders and forecasts, the creation of purchasing orders for suppliers and production orders for plants, the constant update of inventory statuses updated depending on procurement and delivery status, and tracking of financial records of both the customers' orders and the company's internal status regarding payroll and suppliers payments. Integrating an ERP system inside the company can help manage all this information within one single centralized software, allowing for a more streamlined sharing of data, which can prevent errors or duplicated records during the various stages. This implies a sort of standardization of processes that, while it can result in more transparency and rapidity during the processes and, all around, a general improvement of performance, clashes with the nature of the construction industry.

Multiple attempts have been made in order to push the industry towards the same levels of efficiency that this kind of implementation brought to other branches, while failing to get the same results (Gavali, & Halder, 2020): the outcomes achieved by sectors that rely on standardized mass production such as the production and manufacturing industry – industries ERP systems where developed by and for (Kumar, & Van Hillegersberg, 2000) – seem to be unrealistic for construction companies, which work instead on a project by project basis and where every case is characterized by specific needs related to not only the requests of the client, but also are dependent on the different and multiple teams working on the project itself, which vary often and might end up working together for the first time. As Yang et al (2007) noted, the Construction Managements packages offered by commercial ERPs cannot provide a once-and-for all model for all industries, much less for construction firms, especially considering how the level of digitalization and use of IT solutions within the industry is still very low and far from the rationalized and mechanical nature of other sectors.

Though, as of today, this type of technology cannot manage a reality so fragmented and unpredictable nor the increment of complexity within projects, the flexibility required by 4.0 Industry, and the recent development of technological advancements, require the establishment of a new type of interoperability between systems and a new way of designing and planning.

1.2.2 Construction Enterprise Resource Planning

According to Augenbroe (2006), an ERP system can be divided in two interfaces, one related to the project and one to the financial aspects: the development of a stable and clear link between the two – granted by a common access to the financial data, project data and customer data - is essential in order to allow a more streamlined planning and decisional process. In the construction industry in particular, the system should be project-oriented, since the project itself is the cornerstone of the financial activities: in order to ensure the handover of the construction within the established timeframe and costs, an efficient organization of the ERP system is needed.

As explained by Dudgikar et al (2012), the software allows the company to manage its own resources, split into:

- Manpower, meaning the definition and planning of the workforce, as well as identifying the teams and the skills required, especially if the work requires the introduction of subcontractors and their crews within the project;
- Materials, which groups all processes aimed at materials planning, programming, and their purchase, inventory control, materials transportation and handling on site;
- Machines, which handles, for example, the acquisition and management of all the equipment, and the identification of the tasks to be undertaken by said mechanical equipment;
- Money, including financial forecasts, project budget and cost control measures.

The company, then, needs to coordinate not only internal resources (workforce, equipment, inventory …) which can be handled directly, but also various external influences (suppliers' transactions, subcontractor relationships, market situation …) from which it depends on. Whoever is tasked with the decision-making process has then to manage a vast quantity of information that belongs to different areas, and that must also be properly recorded and shared.

Shi & Halpin (2003) developed the so called Construction Enterprise Resource Planning (CERP) system, an internet-based framework that develops in three tiers: one related to the User Interface, related to clients' management and data, one related to the Management Servers, which provides administration and the link between the other two levels, and one related to Applications, which includes the database of the system and all the project and materials information. This type of system can offer immediate access to all the data, granting better performance and quickness within the decisional stage; by being a cloud-based system, this system also supports a more transparent and collaborative process, as all information is stored within the system itself and is readily available to everyone, and can be traced to the person tasked with the transaction or the decision made.

The main obstacles of these applications can still be ascribed to the costs and time required for implementation and development of the systems, and the lack of software and modules that can handle the complexity of the processes typical of the construction industry. While the aim of these systems is to standardize and automate the workflow, so that every individual can access and use them easily, the landscape of this industry is still too fragmented and requires a level of specificity often incompatible with these goals.

1.3 ERP-BIM Integration

A potential integration between ERP software and BIM models could be one of the viable solutions aimed at facilitating the implementation of ERP system in construction companies. The status of this integration is, nowadays, still at the embryonal stage: the first pursuits focused on the attempt to connect the manufacturing data to the information related to the construction processes by exploiting 2D CAD files, but failed to define an efficient information-centric approach that could establish a proper integrated work frame (Holzer, 2014).

Within the multiple causes of these undeveloped integrations between the two systems, the main one can be traced to the slowness of the AEC industry in implementing solution related to the digital management of the designing and planning stages: the creation of digital and parametric virtual BIM models is still too underdeveloped in many companies, and rarely this way of modelling also takes into consideration the procurement or the construction process. Particularly, SMEs are especially the ones struggling with the development of these systems, mostly because of the lack of properly developed IT systems, which would allow for a more digitized process. As Ghosh et al (2011) point out, the time and costs implementation and management of these software is, once again, the main cause, as well as the lack of investments in proper staff training. Considering also the typical traditional and conservative outlook still very present within the industry, and the very high rates of change of technology solutions (Andresen et al, 2002), it's easy to imagine why these kinds of processes are rarely pursued by SMEs.

In light of the potential developing a common platform or a direct integration between ERP and BIM systems, one of the fundamental traits must be full transparency between all the involved parts, and constant and clear communication. Considering the typology and the volume of data and information that would be managed in this scenario, this kind of communication and integration requires a properly defined planning process starting from the initial phases: basically, a preliminary planning stage should take place well before the designing process itself, so that complications and unexpected events can be prevented or properly handled beforehand.

This sort of reengineering process is described by Kahn (2021), who proposes a total reshuffling of the typical designing and planning processes, resulting in a shift of the stress of workload to the initial stages, and a better distribution of efforts all-around. In this case, the Operation Stage, which includes 3D Coordination, design review and site work, is given the most emphasis, allowing for a better organization between the teams, a consequent reduction of designing and construction times. A transparent and well-developed coordination since the initial stages is therefore needed and the solution can be the connection between the ERP system and the BIM model.

2. CASE STUDY

For the purpose of achieving an integration between the ERP system and the BIM model, a real case study was analyzed. The following examination also takes into consideration the management system used by the construction company, in this case SAP, that was in charge of the construction of a building that covers an area of 1400 square meters. As part of this analysis, a first attempt was made to link the ERP software and the information model; ideally, the goal would be to directly integrate the two system so that changes within the model (in terms of 3D objects volumes and quantities, for example) could be automatically recorded by the ERP software, resulting in the update and correction of data and information related to material orders and scheduling.

2.1 Project content within the management and control software

In the initial stages of construction planning, a comprehensive preliminary Bill Of Quantities (BOQ) was compiled, which took into consideration the cost and pricing of materials, the need for equipment and workforce, taking into account not only the market average prices, but also personal agreements settled between the company and the suppliers or subcontractors. The structure used to define the BOQ during these initial exchanges between the construction company and the clients was therefore replicated in the ERP system, in order to consider every material, item and construction task, and their placement within the construction timeframe.

In order to translate and develop the construction timetable within the Project Builder of the software, a dedicated project profile was meticulously created. This project profile has been subdivided into discrete "Work Breakdown

Structure Elements," serving as a crucial classification system to effectively categorize the essential tasks for the comprehensive project plan. By using a top-down approach, the project structure branches out into multiple "networks", which represent the succession of activities that define the construction processes and that are characterized by start-to-end relationships and various interdependencies related to the time schedule of the task itself. These element profiles are used to plan, analyze and monitor time and resources during the whole construction timeframe: in this way, all the items present in the Bill Of Quantities are actually translated into the management system, each one representing a particular task on site and its related information.

These elements, that essentially represent every material used during the construction project and, in this way, its relative activity on site, are sorted with the following data:

- Milestones, which are required to proceed with payments;
- Information regarding the production centers related to the supply chain;
- Standard duration and minimum duration for each task (in terms of days); ideally, this kind of information should be the result of data obtained from the production center, however, it is often necessary to proceed with manual data entry of the durations, according to the schedule defined by the timetable;
- Deadlines: the start/end relationships between activities are determined in this section, as well as which task has the priority over the others within the construction process, and any time buffers that might need to be taken into account due to possible delays;
- Data relating to materials' orders, in the case of outsourced work. This section collects data referred to the identification of the supplier, its prices, cost items and planned delivery times, as well as data related to purchase requisitions managed by the accounting department.

2.2 ERP-BIM link

In order to develop a connection between the BIM model e the ERP system, only a small part of the whole project was taken into consideration. The work mainly concerned two categories of materials: concrete elements (exclusively focusing on the main structures, meaning the pillars and the load bearing walls on the main floor, the foundation slab, and roof) and drywall components. These elements were specifically chosen for a few reasons: firstly, these materials were enriched with the biggest volume of information - especially for the concrete, and therefore were considered ideal examples to test the potential transfer of data between the two system. Secondly, these are very different and partially antipode materials: on one hand, once arrived on site, the concrete cannot be stored, and has to be poured and used within a certain time frame; additionally, the concrete samples must go through a meticulous round of controls and checks, whose resulting documents can be collected and archived in the ERP system by connecting them to their relative object inside the project network. On the other hand, drywall elements, used here for vertical and slanted elements and for the false ceilings both, can be stored and stocked within the perimeter of the construction site for a long period of time, and have to undergo a less strict process of control and verification.

Considering the nature and the purpose of the ERP system, the time aspect and the possibility to whether to store or not the materials are especially crucial: delays in previous works, changes regarding the delivery dates of materials, or eventual changes in the project can influence the progress and continuation of the whole construction phase. Therefore, the possibility to track these changes directly and quickly, whether from variations in the BIM model or notification from the site, is essential in order to coordinate the work time schedule, the procurement and the delivery of materials and resources.

In order to then develop a proper connection, upon gathering all the pertinent data related to the tasks and materials taken into consideration for this analysis, links have been developed in order to establish a direct correlation between the ERP system and the information model. This connection was accomplished through the exportation of URL links related to the materials in each phase: each material is, in fact, within the project system, enriched with all the information collected from the accounting team (e.g. purchase orders, delivery dates, and all information previously mentioned), the project team (e.g. quantities, locations, construction phase…) and from site personnel (lab results and any type of documents collected on site). Once extracted (Fig 2.), the hyperlink can be sent by e-mail. Furthermore, the mail can be sent along with eventual notes or attachments from the operator, to other professionals who may need it (Fig. 3).

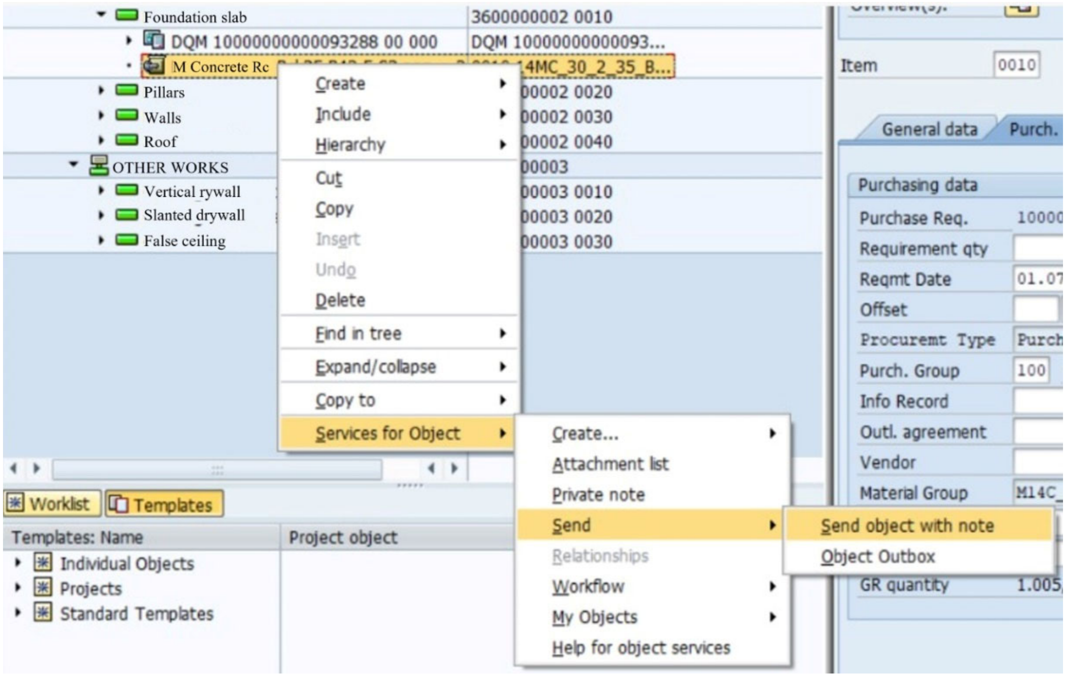

Figure 1. Procedure used to extract URL links related to the material; in this case, the concrete used for the foundation slab.

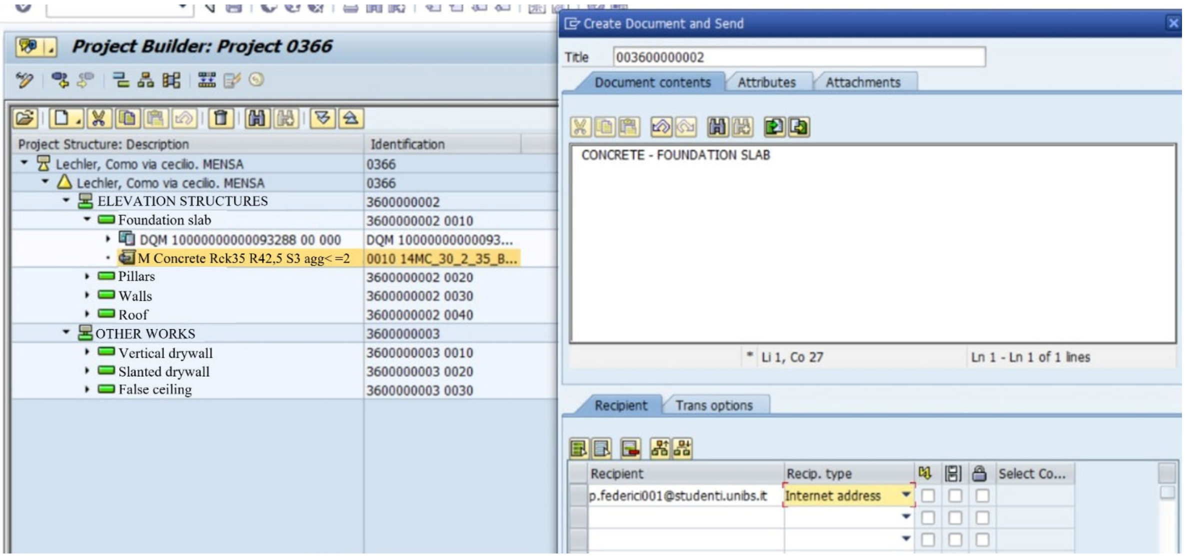

Figure 2. Creation of the URL link, related to the material, that can be sent via e-mail along with eventual notes and attachments.

The URL link provides direct access to the interface of the material, which collects and groups all the information related to the material itself and its construction activity on site, as previously mentioned. The hyperlink was then incorporated into the 3D object properties that belong to every object in the information model in the modelling software; by clicking it, the operator can directly access the ERP interface related to the material taken into account. In order for this connection to be operable, the personnel needs to, of course, have to access to the ERP system and the project at hand, and be familiar with the ERP interface and use. A basic run down of the system then would be needed for all the professionals within the work frame, in order to understand and make use of the connection.

The possibility to export a link that can directly bind an object inside the model to its material in the ERP system enables the association of the material with multiple objects at the same time, as they refer to a specific item rather than a task, effectively increasing the information and data strictly related to the object within the BIM model. For example, rather than extracting a single different link for each pillar built, which would consist realistically into a different activity each on site, a singular link to the specific type of concrete used was extracted: the link then brings up the related item in the ERP system, showcasing prices, deadline, schedules, orders and all the data related to that specific activity. In this way, an effective direct link was created between the BIM model and the ERP.

On the other hand, it is, again, necessary to point out that the access is limited to approved personnel since they are the only ones having the authority and responsibility to develop the project in the ERP system. Moreover, at stage of this case study, the linking system is not only manual, but also static, since it needs to be constantly updated.

3. AUGMENTED REALITY TOOLS AND PROCUREMENT

Another way to establish a link between the 3D BIM model and the ERP, concerns the use of the augmented reality (AR) tools. Through the AR technology it is in fact possible to overlap the BIM model containing the digital information, and the physical space of the construction site; thus, the data contained in the property set of the BIM model will be transposed to the matching objects in real life.

Thanks to this superimposition, AR is conventionally primarily used for project monitoring and control, but it can also be employed to implement the logistical aspects related to the procurement of materials and to their storage within the construction site. Through the use of an AR mobile app, by selecting each 3D BIM object, it is possible to notify its status in real life in terms of procurement information. In this way, every member of the construction and designer team gets to know in real time if a specific object is identified, ordered, delivered, checked, or installed, and the corresponding information can be recorded in the ERP system (Wang and Love, 2012). The planning of the supply and procurement of materials can be easily updated, allowing a more effective planning of subsequent orders. Similarly, it is possible to track the availability of materials by precisely defining the requirement for the consecutive period, guaranteeing an on-time supply approach.

3.1 Definition of status notification for the case study

Each status notification groups a potentially wide amount of information, therefore their selection based upon predefined criteria is fundamental. In the specific case study - in addition to the above-mentioned advisory of identification, order, delivery, check and installation - the information considered most significant to form this type of report (Fig. 4) are:

- Object of the notification and location in the construction site;
- Figure in charge: in order to fill out this field, one or more companies responsible for the procedure of supply and installation of the object must be selected;
- Expected date for delivery and installation of the object attending to the construction schedule;
- Properties of the BIM object: this field, unlike the others, cannot be filled in by the individual completing the status notification. The properties of the object are inherited from the BIM model and automatically entered in the field to avoid errors and to speed up the signaling procedure.

Considering the purpose of the object status notification, the most significant property concerns the Work Breakdown Structure (WBS) code which uniquely identifies the selected objects. These alphanumeric codes are also present in the ERP network and allow the operator to identify the corresponding purchase order and to update it by registering a delay.

Once all the fields have been completed, the final report will be visible on a web platform to which only specific members of the team have access to. The operator who is in charge of updating the orders on the ERP software will be notified via e-mail and will consequently look for the matching WBS code in the ERP network and act consequently.

As for now, the transfer of this kind of information from the construction site to the ERP takes place manually, due to the lack of interoperability between the software involved in the procedure; nevertheless, it is easy to imagine that the automatization of the process is the next achievement that needs to be accomplished in the future developments of the technologies and tools involved (AR, 3D BIM, 4D BIM-ERP).

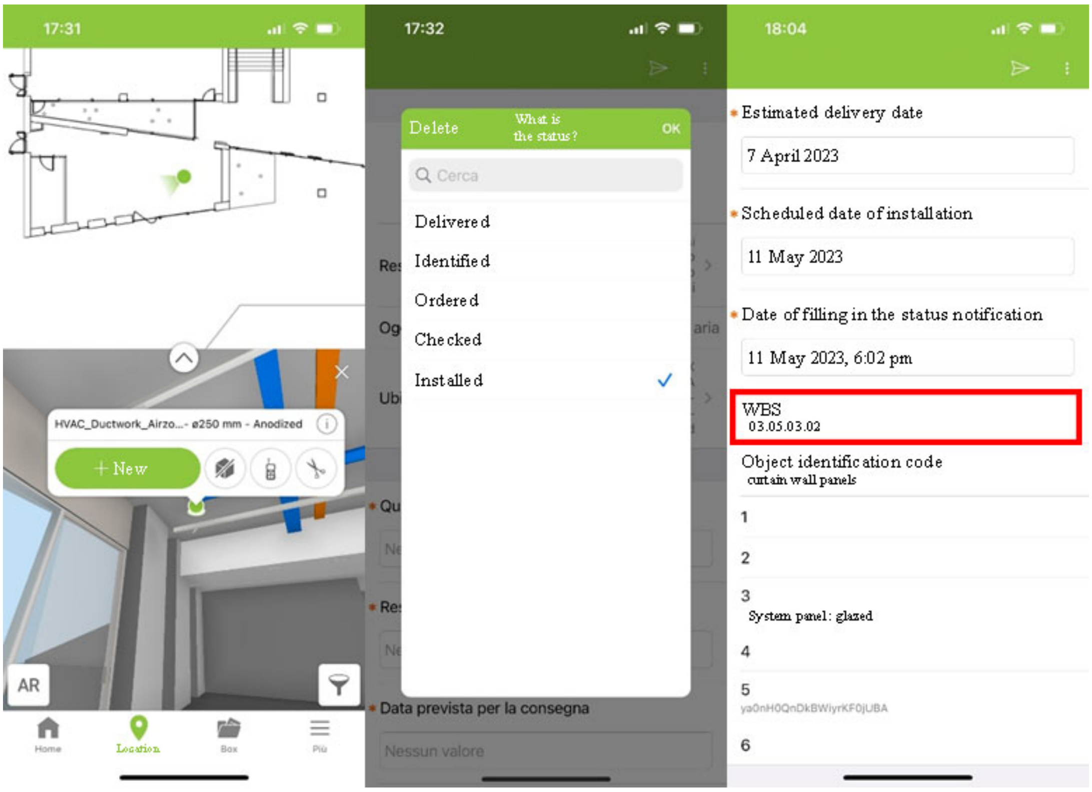

Figure 3. From left to right: (a) Selection of the object the completion of the Status Notification is referred to. (b) Multiple-choice responses to indicate the object's status. (c) Properties of the BIM object, automatically collected from the model: the WBS code is highlighted.

Ultimately, the two types of connections between the BIM model and the ERP system established operate in accordance with the diagram presented in fig.4 and necessitate a continuous update of information following the recording of new data obtained through the surveying of the construction site.

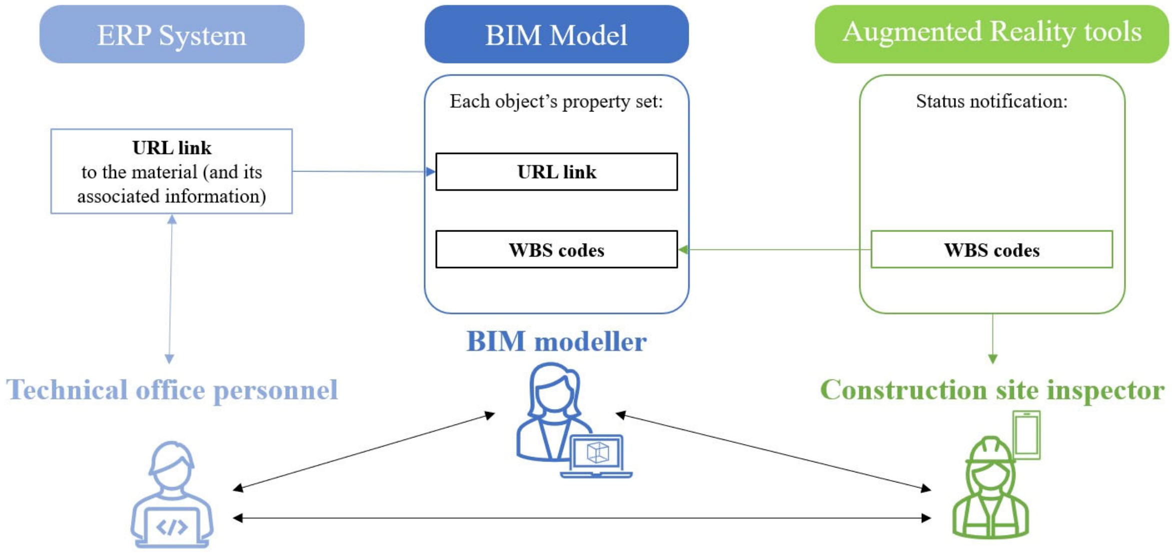

Figure 4. Schematic drawing of the procedure for establishing the ERP-BIM connection. An URL link is extracted from the ERP system and incorporated within the properties of objects in the BIM model, alongside WBS identification codes. Utilizing augmented reality tools, the Construction Site Inspector generates status notifications, which subsequently inform the BIM modelers and the Technical Office personnel of the current progress of the ongoing work. Both the BIM model and the information contained in the ERP system will be updated, and the flow will potentially start over again.

4. CONCLUSIONS

Through the process described, it was possible to develop a connection between the ERP system and the BIM model, both by the development of a hyperlink between the material stored in the management system and its own 3D object, and by the establishment of status notifications sent directly from the construction site to the company's system.

While effectively linking the two systems, the connection created remains, as mentioned, accessible only to those who have access to the company's management system, as the software access credentials are required to be able to view the system interface. Furthermore, the hypothetical idea of connecting the material in the ERP system to the 3D object belonging to the information model currently constitutes a manual and non-automated task, resulting in an exceedingly laborious process, especially considering the number of objects modeled and the materials used. Moreover, the link appears to be static and unidirectional: any change made to the BIM model, such as alterations in volume quantities or material types, are not directly perceived and recorded by the ERP system, and every modification has to be arranged manually. Similarly, item entries updates within the ERP system do not automatically update within the link, which would need to be exported again and consequently replaced in the 3D object properties.

As mentioned, it is still a very preliminary and underdeveloped connection, still manual for the most part, and far from the potential goal of streamlined automatization between the two systems.

To achieve a higher level of integration, the development of a potential plug-in bridging the gap between the modeling software and ERP software would be necessary: since these two systems were designed for different purposes and objectives, mostly due to the different industries they were developed for and by, establishing a direct connection between the two programs would entail the involvement of the respective software distribution companies. Their cooperation and a great amount of resources, both in terms of time and investments, would be required to generate a bidirectional linkage between the systems.

In the eventuality of such a development, it would become crucial to take into consideration the high level of variability that characterizes not only construction projects, but also the coordination and management of these projects by construction firms. The perspective of a full-scale ERP-BIM integration would imply the standardization of the designing, planning and managing processes within the AEC industry, so that the transaction developed within the software can be distributed and used universally. This would result in an adjustment of the management procedures between the companies, further facilitating collaboration and communication.

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