Towards BIM-integrated Labour Productivity Measurement

Inventory of Current Work Processes and Identification of User Needs

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Abstract— **This article marks the beginning of an innovative initiative aimed at integrating construction labour productivity measurements into the 3D Building Information Model / Modeling / Management (BIM) digital model, actively involving the workforce in real-time execution data encoding. Adopting a human-centered approach, the main objective is to ensure the tool's adoption and adaptation to the specificities of the existing processes and the construction site context. To achieve this, the article seeks to understand current performance tracking practices and identify emerging user needs through in-depth analysis of their activity. The research methodology combines field immersion with semi-structured interviews involving various stakeholders of a construction company. This approach helps to define the existing workflow of performance tracking and to identify three distinct typologies of use and their related characteristics. Additionally, the article highlights several challenges related to the integration of labour productivity into the BIM model by connecting it to the 3D objects. These include the need for a comprehensive definition of performance calculation, the accuracy of digital models to extract acceptable quantities, ease of encoding by foremen and stakeholders' perceptions of benefits in a context of major subcontracted activities. Finally, the initial development hypotheses are introduced, laying the groundwork for a new approach to improving performance monitoring practices in the construction sector.**

Keywords-construction sector; BIM, labour productivity; performance monitoring; human-centred approach.

I. Introduction

Despite the advent of new technologies, there is still a serious lack of effective and consistent tools to improve productivity and reduce losses on construction sites [1]. Field actors (whether they are workers, foremen, technicians, subcontractors, project managers or site managers) still often suffer from a lack of visibility over the tasks they perform. Currently, data related to performance are largely under-exploited in guiding companies' strategies [2] toward better project management for continuous improvement [3]. Construction labour productivity is calculated differently from one project to another, and even within the same company. The methods used are prone to approximations and errors; they are either archaic through paper-based notetaking or completely disconnected from the field through tools used by users who are external to the observed tasks. Moreover, they do not leverage Building Information Model / Modeling / Management (BIM) digital models, which are now perceived as an effective support for information management and digitization in the Architecture, Engineering and Construction (AEC) sector [4].

Starting from this observation, the project in which this article is embedded aims to develop a tool enabling construction site stakeholders to integrate directly and in real-time execution data into the building's 3D BIM model. The objective is to involve the workforce in this input process and data centralization for performance monitoring by providing innovative and sector-specific tools to workers (in this case, worker team leaders or foremen). Through this direct input by the concerned stakeholder, activity analysis would be more detailed, and process optimization would be more easily quantifiable. It is therefore appropriate to adopt a human-centered approach to ensure ownership and adaptation to the specificities of the process, the site context, and the Brussels ecosystem. This article constitutes the first phase of this process and aims to address the following questions:

- What is the current process for labour productivity monitoring on construction sites?
- What are the specific needs of the stakeholders involved in this process?
- What challenges are involved in developing an innovative tool that integrates labour productivity into BIM?

To address these questions, the article is organized as follows. Section 2 offers a review on construction labour productivity and its integration with BIM. Section 3 describes the objectives and research framework and Section 4 details the methodology employed in this investigation. The obtained results are described in Section 5. The article concludes with a summary of contributions, identified limitations, and future perspectives in Section 6.

II. State of the Art

A. Labour productivity

It is easy to find agreement in the literature regarding the primary goal of labour productivity monitoring, which is to analyze and evaluate performance on construction sites [3][5]. However, it is much more challenging to find a common definition and real performance measuring techniques. Usually, the discussion will center on the output of a specific task based on the resources used for it [3]. The resource is mostly taken as hours of manual labour, as it constitutes the largest source of variation in site productivity. The output refers to the amount of work completed, which is measured in various units depending on the performed task (e.g., kg for steel and m^3 for concrete). Gathe and Mind [6] thus define labour productivity as an output per work hour, as in (1). It can underpin most of the other productivity-related factors [5][6][7]. Labour productivity is measured in units of work accomplished per man-hour, but there is also discussion about unit rates; man-hours per unit of work [7].

$$Labour\ productivity = \frac{Output}{Work\ Hour} \qquad (1)$$

To optimize its performance, the goal of a construction company is therefore to maximize its labour productivity or to minimize its unit rates. This article seeks to explore the practice of this kind of performance measurement in the AEC sector as well as the existing tools used, with the aim of fostering continuous improvement on construction sites. In the next sections, the terms performance measurement and labour productivity will be used interchangeably.

B. Using BIM for labour productivity monitoring

Through methods and tools, BIM enables the centralization of all building data around a digital version to facilitate the sharing and efficient exploitation of data by the various project stakeholders throughout its lifecycle [8]. In order to better manage and optimize team work on construction sites, several authors propose to centralize data related to performance calculation in these BIM models, which are increasingly being utilized in large-scale projects. Cha and Kim [2] emphasize the relevance of associating performance measurement with 3D/BIM object-based technology to counter the inefficiency of conventional text-based systems. They propose a site performance measurement system that associates a 3D object with a spreadsheet. Katiyar and Kumar [9] propose a method to monitor real-time progress of prefabricated structure construction using Building Information Modeling (BIM) and Internet of Things (IoT) with sensors, to improve labour productivity factors. Matthews et al. [10] also proposed a BIM-based approach to track construction progress in real-time, using the BIM 360™ Field application to capture site data. Although these studies highlight the importance of combining performance calculation and BIM, none have yet resulted in a concrete application implemented on construction sites. Currently, no tool on the market directly integrates BIM with labour productivity calculation. Existing applications either focus on encoding execution data without connection to the digital model, or on BIM metadata without focusing on on-site performance and the underlying issues. To be closer to the needs of the sector, the following question arises: what is the best methodology to adopt in order to make it easier for these tools and apps to be implemented and tailored for the AEC sector?

C. Towards construction 4.0: adopting new technologies

Today, the construction industry is undergoing a digital revolution towards Construction 4.0. The main objectives of this transition include improving productivity, reducing environmental impact, increasing sector attractiveness, and cost control [11]. This evolution involves numerous challenges related to technology adoption, explained among others by the complexity of building projects, the diversity of actors involved, resistance to change, shortages of qualified labour, and interoperability issues between existing technologies and processes [12][13]. Among the social issues, the introduction of new technologies such as process automation or real-time monitoring of workers raises ethical concerns [14]. In addition, there is concern about the lack of skilled professionals capable of mastering the application of these technologies and the practical changes they entail [1]. To address the various challenges raised, some authors emphasize the importance of adopting a user-centered approach for implementing digital tools on construction sites [15][16]. A user-centered approach for the development of interactive tools, or human-centered design, aims to actively involve users in the design process [17][18]. This approach encourages optimization of performance and profitability, while enhancing user comfort, satisfaction levels, ease of access, and sustainability [17][18]. User-centered design is used in different fields but very few studies have been found in the construction industry. Thus, this article proposes a methodological contribution for defining and implementing such an approach for the development of innovative tools tailored to the AEC sector.

III. Objective and Scope

The previous paragraphs have highlighted the interest in developing an innovative application aimed at optimizing performance monitoring by integrating it with BIM, while exploring the effect of a human-centered methodology. This is the objective of the project in which this article is embedded. This project, named HARPO (Human-centered Application for the Resource and Productivity Optimization of buildings), is funded by the Brussels-Capital Region - Innoviris and consists of a consortium between a construction company (CIT Blaton), a start-up developing BIM technologies (Kabandy), the Belgian innovation center for the construction sector (Buildwise), and the Brussels Polytechnic School (AIA_BATir).

This article constitutes the first phase of the HARPO project and focuses on field immersion, understanding user profiles, and activity analysis. One of the fundamental principles of a human-centered approach is active user participation and a clear understanding of user needs and tasks [17][18]. In this perspective, the aim here is to thoroughly study current practices on construction sites regarding performance monitoring and to identify the

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different profiles involved. The objective is to understand the performance monitoring processes on-site, to identify specific issues related to these processes, and to address the challenges associated with their optimization through integration with BIM. To achieve this, we have implemented a two-stages methodology, based on a pragmatic epistemological stance carried out through action and practical problem-solving anchored in concrete situations [19][20].

IV. Methodology

Firstly, the analysis comprised a complete immersion on a construction site over a period of two months in a participatory-observational approach. This type of approach involves significant engagement from a researcher within a group, community, or organization, with active, concrete, and preponderant participation in fieldwork while aiming to accumulate knowledge through observation [21]. To maintain an objective distance and a continuous reflection, essential for implementing such an approach, a journal was completed during and after each day on the construction site [22]. Through this journal, a structure was well-defined to systematically capture the various actions taking place, the involved actors, the tools used, the site management methods implemented, etc. This immersion thus allowed for understanding the general workings of a typical construction site and the roles of actors within it. Although the preliminary immersion phase on the construction site only partially addressed the question of performance, it was fundamental for the subsequent steps. It continuously provided context for performance monitoring processes within the broader reality of the construction site, including a multitude of actors and various dynamic and complex processes.

Secondly, it was necessary to understand the specific processes related to performance monitoring. To do so, 15 semi-structured interviews were conducted with different profiles within the construction company. Initially, 3 interviews were conducted at the company's headquarters with 'office' type actors: a price study engineer, a quantity surveyor, and a financial engineer. These interviews allowed for a first interpretation of performance-related processes from the perspective of actors external to the construction site but engaged in anticipating performance before work execution, as well as in monitoring actual performance collected throughout the execution. Subsequently, 12 interviews were conducted on various types of construction sites, with 'field' type actors: 5 site managers, 3 project managers, and 4 foremen. These interviews enabled to understand labour productivity from perspectives related to on-site activity and to develop workflows specific to the construction company under study. To ensure clear interpretation of these processes, the workflows were created drawing inspiration from the Business Process Model and Notation (BPMN) method, a standardized way of modeling a business process [23]. Lastly, after the development of these specific workflows based on observation and interviews, they were compared to the sector to verify their alignment with on-site realities and project-specific requirements. The analysis of these workflows thus served to highlight current on-site needs and identify challenges in digitizing processes. Furthermore, the comparison of these workflows 1/ with future needs expressed by users and representatives of the AEC sector, and 2/ with purely technical and technological constraints regarding existing tools and their interoperability, framed the initial hypotheses necessary for the development of an application tailored to on-site usage and actor profiles.

V. Results

A. *Labour productivity monitoring process*

The general workflow for labour productivity monitoring is depicted in **Figure 1**, and was constructed and adapted progressively through the interviews and observations. It is subdivided into two 'lanes' representing two phases: the price study phase and the execution phase. It is important to clarify that terms like *performance measurement* and *labour productivity* will be used here because it is similarly used within the partner company, although it refers to *unit rates* as explained in the state of the art [5][7]. The first involvement of labour productivity measurement occurs during the preliminary phase to execution, namely the price study. This activity is carried out with the assistance of a software developed by the company itself, enabling the submission of a sales price and the tracking of site finances. Upon receiving a file from a potential client, the *price study engineer* imports the various workstations (or tasks) necessary for execution, applying quantities measured by the *quantity surveyor*. The software automatically calculates the sales price by incorporating reference budgets for each item. Behind these budgets lie those related to labour productivity, estimated based on company reference performances or the *price study engineer* expertise (e.g., 1h/m3 for pouring a concrete wall). Excel spreadsheets can be exported from the in-house software. If the submitted offer is accepted by the client, the project proceeds to the execution phase. Execution methods defined during the price study are often adjusted by the site team, leading to a redefinition of tasks and associated budgets (behind which lie the performance measures). The financial engineer adjusts the budgets on the same software, and work can then start.

After each working day, the *foreman* fills out a 'foreman report' on paper, summarizing the number of hours performed by each worker and for each type of task. These reports are transmitted to the *site manager*, who allocates the hours among a list of tasks in Excel. This item list must correspond to the budget spreadsheet item list, to compare planned and actual performances and assess the productivity of a workstation. Simultaneously, the *project manager* progressively enters executed quantities and expenses per task into the in-house company software already used during the price study phase. The software then compares the released quantities (and thus also the released hours) and

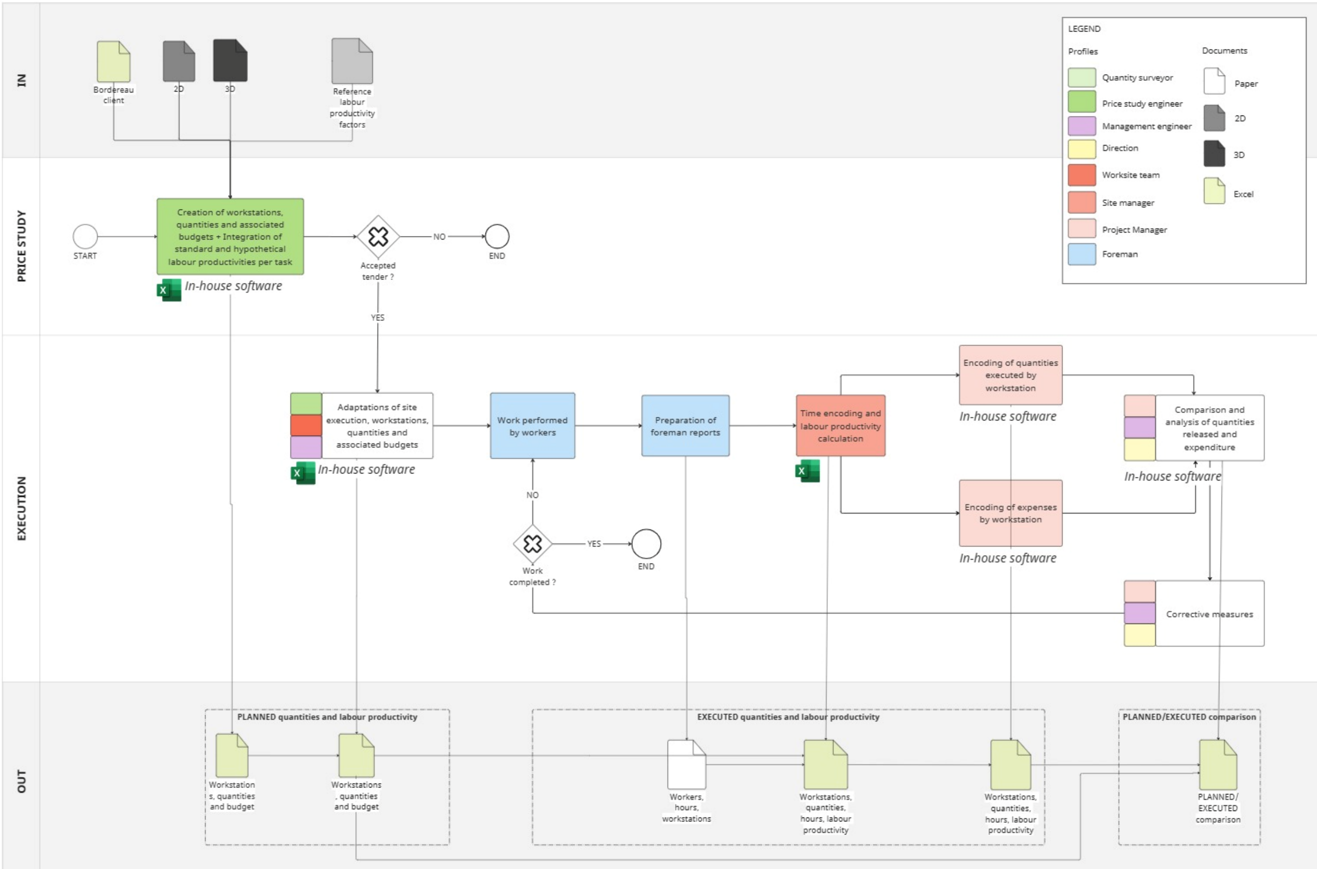

Figure 1. Labour Productivity Measurement Workflow.

expenses, enabling the *project manager* and the *financial engineer* to identify any budget deviations and their roots (which may be related to poor performance). If possible, corrective measures are then taken to reduce identified losses. The performance monitoring process by the *site manager* and budget monitoring by the *project manager* are continuous throughout the construction site progress.

Through this workflow it can be noticed that monitoring performances and assessing the productivity of items essentially involves comparing realized labour productivity with pre-planned labour productivity. The development of this workflow, combined with the multiple discourses and perceptions gathered during the 'office' and 'site' profile interviews, highlight the presence of a wide variety of uses and stakeholders in this process. More specifically, three typologies of performance assessments can be distinguished, which correspond to three different uses in short-, medium-, and long-term temporalities.

B. From a single workflow to three typologies of workflows

While each of the three typologies is relevant for the stakeholders involved in it, they are not all implemented in practice and present some shortcomings in their operations. This sub-section presents the three identified types along with their problematics.

The first use concerns the development of daily reports by the foreman and subsequent performance monitoring by the site manager. It can be considered from a short-term perspective as it involves real-time execution monitoring. Interviews revealed that these foremen reports are hardly ever used by site managers to monitor performances. Indeed, most works are performed by subcontractors who pay their workers per square meter, which means the site manager has no direct interest in optimizing performances since the risk of inefficiency lies with the subcontractor. Furthermore, the site manager must undertake a time-consuming task when allocating hours to a high number of items on an Excel spreadsheet that do not always correspond to the tasks listed by the foreman. Additionally, it is not always easy to find the right definition of labour productivity for a specific task and the 'hidden' tasks it should contain (e.g., preparing material before starting a work).

The second typology is manifested through budget monitoring and the identification of discrepancies between allocated hours and incurred expenses. This involves a medium-term analysis as it entails monthly meetings between the project manager and the financial engineer. Performance is not the essence of this process but is rather 'hidden' behind an analysis of budget gaps, which can sometimes be the consequence of poor performances. This process is perceived as optimal by the actors, although it is carried out on an old

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interface and sometimes requires the transfer of information from multiple stakeholders to the project manager. Unlike the first identified typology, this process is always achieved.

The third typology focuses on analyzing achieved performance on construction sites, in order to provide more accurate budget forecasts in a long-term perspective. Today, this feedback remains very limited, although it would optimize submission files and draw lessons from previous construction projects. Despite this perceived opportunity, several interviewed profiles emphasize the difficulty of labour productivity standardization due to the numerous factors that can influence them in a construction context that is never the same.

The analysis of these three typologies confirms the need for centralized executed data to exploit it in different ways and optimize the work of the stakeholders involved. To sum up, it would save time for the site manager and the project manager in the short and medium term and provide a performance database in the long run. The adaptability of data management is therefore central, relative to the needs of each profile, whether it concerns the specific construction site or in relation to other construction projects.

C. *The challenges of BIM-integrated labour productivity*

In addition to the importance of acquiring a flexible system, the analysis of the activity allowed to identify several key challenges to consider during software development.

Firstly, the very nature of performance measurement presents quite a challenge. Stakeholders struggle to define labour productivity calculation of items and its required sub-items. Interviews revealed the various possible approaches to interpreting performances, demonstrating the difficulty of standardizing them due to the lack of agreement on the tasks contained within a same item and the complexity of factors to consider on site. This is in line with the lack of a precise definitions found in the state of the art, pointing to the need for a deep investigation into the complex network of workstations on construction sites and their related labour productivities.

The second point concerns the accuracy of the 3D digital model. Since the goal is to use quantities from the BIM model and apply hours to calculate performances, it is crucial to rely on quantities representing reality in an acceptable way. However, this could be compromised by modeling errors or inaccuracies that do not faithfully reflect the reality of execution, especially at junctions between several objects.

Another point concerns the ease of digital encoding of execution data by foremen. Stakeholders emphasize the need for a straightforward tool and sufficient prior training to use it. While some worry about the possibility of mistakes due to the increasing shortage of skilled labour, others see it as a chance to empower and elevate them.

Finally, the last point concerns the predominant context of subcontracting in the construction sector. As mentioned earlier, this reality questions the future value perceived by actors studying their labour performance in a scenario where the inefficiency risks do not lie in their hands. The project partners seem to predict a future with decreasing use of subcontractors, or new forms of subcontracting with hourly wages where this problem would disappear. However, this needs to be verified and trends need to be carefully studied to make sure to align with the sector.

D. *Development hypotheses*

The identified existing processes and points of attention, when confronted with the first needs expressed by the users as well as the technical and technological constraints identified by the project partners, enabled to establishing initial development hypotheses. These hypotheses have been thoroughly built, discussed and revised in meetings with the partners. Some have been given priority, while others will be taken into consideration in a future iteration of the application, allowing for an initial primary focus on the essentials. They are still referred to as hypotheses to be confronted and re-questioned with end-users throughout the tests of mockups during Living Lab's.

These theories include, for instance, which profiles are best suited for which tasks based on their roles and skill sets, or what format is more appropriate and whether portability of the tool is required. Some hypotheses are more specific to the general workflow of the future application and the intervention of the 3D digital model in it. For example, two options are considered: starting from a 3D model and integrating tasks and hours, or starting from a list of tasks and integrating hours and a 3D model. The first option provides a familiar starting point for site actors but raises issues related to tasks not represented in the model. The second option offers technical simplicity but requires selecting from a large task list. A compromise is found by allowing foremen to choose from a limited task list, opening the 3D model only if this task is linked to it. To maintain track of decision-making processes, each hypothesis and its supporting evidence are purposefully documented.

VI. CONCLUSION

This article tries to comprehend the details of current performance tracking on construction sites in order to develop a digital application integrating this kind of data into the BIM digital model. The initial phase of the user-centered approach allowed to identify three current typologies for performance tracking, each benefiting different stakeholders. This has emphasized the importance of centralizing execution data for its multiple purposes and assisted in identifying the specific needs of each profile.

However, it is important to note that this study was conducted within the partner company, and further investigation among other general contractor companies is still required. Initial discussions with the Belgian construction research center already indicated that performance tracking is primarily integrated into site budget monitoring as highlighted in this article. However, it is still somewhat undefined to what extend the two other identified processes are present in the rest of the sector.

Furthermore, this article represents only the first step of a broader research endeavor. It has outlined a set of needs and specificities to consider in framing the initial hypotheses that will serve as the basis for the development of the future application. But, it does not yet offer a user-centered methodological contribution for the creation of other on-site technologies that considers factors like interoperability, appropriation and adaptability to the context.

Therefore, the next phase of the research will involve a more participatory ergonomic study involving future users in defining the front-end of the solution. This will be accomplished through the creation of mock-ups based on the hypotheses established through the methodology described in this article, then evaluated during living labs, and subsequently adapted to each identified profile and usage typology. The first use will involve testing data encoding methods by team leaders, which is a crucial aspect of the performance tracking process. To optimize this encoding and address identified challenges, considerable effort will be devoted to defining the most relevant definition of labour productivity. This process entails collecting numerous existing foremen reports and conducting an in-depth analysis of the tasks they contain.

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