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AN INNOVATIVE DIGITAL TWIN PROTOTYPES SYSTEM TO ENHANCE TENDER EVALUATION IN GREEN PUBLIC PROCUREMENT

Silvia Meschini[1], Lavinia Chiara Tagliabue[2], Giuseppe Martino Di Giuda[3], and Stefano Campi[1]
[1]Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Milan, Italy
[2]Department of Computer Science, University of Turin, Turin, Italy
[3]Department of Management, University of Turin, Turin, Italy

Abstract

Digital Twins (DTs) and process digitalization are promising to bridge the gap towards Product Lifecycle Management (PLM) in construction industry. In a PLM view, DTs should born in the early design as virtual Prototypes (DTPs) useful as the basis for future DT Instances (DTIs) to manage the whole lifecycle. DTPs could help to overcome a discrete project performances view and enable an holistic one, exploitable for bids evaluation besides performance and sustainability optimization. The research adopts a PLM view to define a methodology aimed at developing a DTPs System which could lead a disruptive change in tenders evaluation, enhancing Green Public Procurement adoption.

Introduction

Despite Architectural, Engineering, Construction and Operation (AECO) industry is one of the largest in the world, in the last twenty years suffered from a decrease in productivity and still performs bad. Such limited performances may be ascribable to the intrinsic complexity of construction projects as well as a huge fragmentation and strong risk aversion which discouraged new technologies uptake (Mc Kinsey, 2017). Although Building Information Modelling (BIM) is boosting collaborative approaches through Industry Foundation Classes (IFC) over cloud platforms (Afsari et al., 2017), its large-scale impact on the processes is still far. The main reason lie in the representation limits pointed out by IFC standard, with relevant information losses and lack of process data (Oraee et al., 2017). Other crucial factors to be considered are the diffused competitive rather than collaborative approach and the struggling information and process management due to the lack of actual interoperability (Afsari et al., 2017). In current BIM-based approaches, process and data models remain separated and parallel entities throughout the whole lifecycle, without updates as the project state changes and no recorded data change history. Recently, the digital transition of process management was identified as the solution to overcome existent gaps and to provide a significant breakthrough (Mc Kinsey, 2017). Nevertheless, the potential of digitalization is hard to realize without linking processes and data models, thus it could be useful a well-known approach adopted in other engineering fields, namely PLM (Gilz, 2014). It enables to manage complex processes characterized by an important amount of data and strong variability, supporting a systematic and multidisciplinary performance view along the whole lifecycle. Some studies identified a key role to BIM for bridging the gap towards PLM, but it was introduced mostly to enable collaboration, improve efficiency, lower omissions and errors during the design and construction phases. Thus there is an intrinsic difficulty in feeding models with always-updated needed information through the lifecycle. Moreover, due to the aforementioned interoperability and information transactions issues, the synchronization of data updating still remains a human task. Major limits consist in missing or uncontextualized process management information, in addition to the static nature of data stored in BIM models and the lack of a simultaneous and bidirectional relationship with the real world. Consequently, BIM by itself cannot effectively boost productivity throughout the whole lifecycle and many studies suggested its integration in the more complex perspective of PLM (Aram and Eastman, 2013.; Corneli et al., 2021). Processes should be normalized and stored together with data, enabling information contextualization and data and process models linking.

Concurrently, another emerging technology is promising to revolutionize Information Management (IM) and decision-making processes, namely DTs. The dynamic and interlinked nature of DTs could be the solution for the management of complex and variable systems such as those concerning building lifecycle. In particular, in the aim of filling the gap towards PLM and enhancing sustainability by promoting the adoption of Green Public Procurement (ISO 24000:2017) as required by EU directives and Italian Legislative Decree (L.D.) 50/2016. Tender evaluation phase is often under-valuated compared to the rest of lifecycle even though it still is poor digitalized and could have relevant impacts in the long-term (EU Commission, 2017). A unique definition of DT in AECO industry has not yet been formulated, but it should not be forgotten that its first formalization was in the field of PLM (Grieves and Vickers, 2016). By adopting Grieves perspective, the DTs could be developed starting from the early design phase as DT Prototypes (DTP), in the dual aim of optimizing project performance and to structure the basis for the future DT Instances (DTIs) for the subsequent lifecycle. As the major part of buildings is foreseen to have a virtual twin with added value due the easily information and process management through the lifecycle (Dornier R. et al., 2021), it is

advisable to develop the DT since the early design phase, optimizing the use of resources, production time and costs. In the aim of encouraging GPP adoption through the Most Economically Advantageous Tenders (MEAT) an innovative approach which integrates DTPs and process normalization through an open-source distributed platform based on Web of Linked Data (WoLD) principles is proposed. In this perspective, the semantically enriched digital representation of BIM models can be the suitable starting point to setup valuable DTs from the early design phase. Exploiting bidding IFC models to develop DTPs through the WoLD platform, could enable to extend actual approaches to a PLM perspective. During tendering phase, DTPs could be aggregate in a DTP System (DTPS) and exploited in a virtual ecosystem to evaluate different design proposals (Dornier R. et al., 2021) aiming at identifying the optimal option in a more sustainable lifecycle perspective. Therefore, DTPs are meant as "reusable" prototypes, useful to be enriched throughout other phases of the lifecycle with real-time input and data provided by sensors networks. Consequently, actual DTIs could be defined to manage the operational and maintenance (O&M) phase in a more sustainable and resilient perspective. The aforementioned DTPs enrichment, could be facilitated through the open-source collaborative platform exploiting Semantic Web (SW) and Linked Data (LD) principles with easily accessible information concerning the whole lifecycle. Thus, the paper presents a methodology aimed at the vertical implementation of DTPs and their horizontal integration in a DTP System (DTPS) for the automated criteria evaluation in a MEAT tender. A GPP approach is promoted and due to the lack of automated and user-friendly tools enabling sustainability criteria evaluation during the design and tendering phase, the developed methodology will be tested starting from such criteria evaluation. In particular, by the mandatory but yet not fully applied Minimum Environmental Criteria evaluation, namely CAM, (Lavagna et al, 2019) in the Design Build (DB) procurement context for the construction of a new school and a brownfield renovation in northern Italy, selected as case studies (Pellegrini et al. 2021). Assessed in comparison with previous developed approaches, the methodology could be extended to further criteria, until covering the complete bids evaluation and providing the full digitalization of tendering procedures.

Background and motivation

Towards an open-source, distributed, collaborative process-based framework

The research is conducted under the umbrella of an Italian Research of National Interest Project (PRIN) which promotes the digital transition of project management aiming at overcoming the afore illustrated limitations posed by current BIM-based collaborative approaches (MIUR, 2017). The goal is to overcome the current separation between data and process models throughout the whole lifecycle by integrating them in a collaborative process-based framework (Figure 1). Data and procedures will be jointly stored by means of typed links with a customized semantic. World Wide Web will be exploited as a support base through the emerging Blockchain and WoLD technologies (Törmä, 2015).

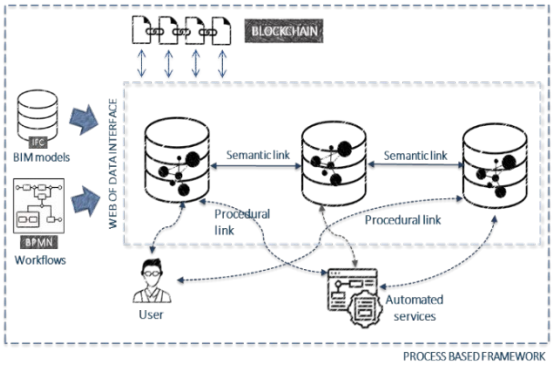

Figure 1- Open source, distributed, collaborative, process-based framework (i.e. WoLD platform)

In particular, the framework will exploit:

- SW to translate BIM models in graph format (i.e. RDF) through tailored ontologies;
- LD to enrich BIM models with missing data by interlinking them from different domains through customized typed links;
- Business Process Modelling Notation (BPMN 2.0) to define and formalize data generating processes in a machine-readable way, enabling external actions (i.e. from humans or micro services) to be called (Von Rosing et al., 2015).
- Blockchain at the top level aimed at the decentralized notarization of transactions and documents liability tracking (Li et al., 2019).

Accordingly, the major outcome of the PRIN project consists in an open-source, distributed, collaborative platform to enhance cooperation in an easy-to-use digital environment. The key potential lies in a strongly interconnected informative database, which represents the suitable starting point for developing valuable DTs through the building lifecycle. In Particular, BPMN will provide process models in a machine-readable format which enables the seamlessly integration between data and their generating processes through the lifecycle, in addition to tasks automation (Von Rosing et al., 2015). LD and SW combined with IFC provide a highly scalable and customizable approach for the DTs definition. As a result, IFC models are translated in graph format and missing parameters to generate DTPs could be linked through tailored typed links. These DTPs can be initially fed by bidders input and then can be incrementally enriched as the lifecycle of the building progresses. The involved research units should develop several Proof-of-Concept (PoC) use cases, covering all the development phases of a building lifecycle (i.e. pre-design, design, construction, operation, maintenance and disposal phases) to demonstrate the easy collaboration and information exchange by sharing on-demand granular information. The present research deals with the PoC use case for the design and compliance-checking, aimed to exhibit how checking procedures could be developed and automated throughout the open collaborative platform and how to

formalize links between design data, processes and system performances, depending on the evaluated criterion. This is key to maintain Information Requirements (IRs) consistency through the design phase and the whole lifecycle, avoiding shifting away from the original intent, especially in the evaluation of technical offers in competitive biddings.

Digital Twins and PLM

The first formal definition of a DT was provided by NASA, but the first general concept was given by (Grieves and Vickers, 2016) in PLM and included the fundamental elements of a twin model: the real part, the digital part and the information links between them (Brilakis et al., 2019). Grieves defined three types of DTs with a growing level of maturity, conceiving them as a dynamic model that changes over the lifecycle. At the early stage, the DTP emerges virtually, taking physical form during the production phase and going along with the operational phase as DTI, until its disposal. It is remarkable that at the early ideation stage, the physical system does not exist yet; rather, it takes place in a virtual space as a DTP, identifiable with the digital space of information models. In manufacturing, before the advent of computer design, the system had to be costly implemented in a physical prototype as it was just a thought with very limited understanding of both form and behaviour. Now, very complex shape and system can be quickly modelled and the same occurs in AECO industry. The DTP could be exploited to predict future behaviour and performance of the product (i.e. building) in order to check when it meets the proposed requirements and represents the optimal solution (Dornier R. et al., 2021). DTs are gaining attention also in the AECO industry, due to the constant increase of data to be managed throughout the building lifecycle, caused both by the increasing complexity of construction projects and by the widespread integration of digital tools. Nonetheless, there is no commonly agreed definition of a DT in AECO industry so far, but almost all the attempts to provide it include the three key features aforementioned (Jiang et al., 2021; Brilakis et al., 2019). Many studies agree that there is not and might never be a universal definition of DT, its meaning depends on the purpose for which it is developed. In fact, the value given from DTs lies in the ability to obtain the right information at the right moment. It should not be a mere replica of every part of the building; rather it should be tailor-made based on its scope of replicating some behaviour of the physical asset. On the contrary, its bidirectional link with the virtual world is fundamental as it enables simultaneous data updating as soon as a change occurs. Some studies already made a parallelism with the DT types defined by Grieves, in particular (Alonso et al., 2019) transposed the DTP definition to AECO industry and defined the Building DTP as: "*A Building Digital Twin describing the AECOO asset during its design and construction. It contains the informational sets necessary to describe and produce a physical version that duplicates or twins the virtual version.*" Adopting this definition, during the design and tendering phase, a Building DTP should be exploited in a virtual world evaluating different design proposals in the aim of identifying the optimal version (i.e. the most advantageous bid). This could be disruptive, since until now no prototype of the building with a holistic view of its performances was available; rather it was a siloed set of discrete project performances, evaluated through document-based approaches which prevented to estimate the impact that a change in input could have on the single and overall project performance. Until now, the comparison concerned just single project parameters disjointed from their impact on installation and maintenance costs and resources consumption. A well-structured DTP can provide a complete and valuable prototype, allowing to simulate multiple scenarios and visualize the holistic response to changeable input. This enables to evaluate the designed performances and choose the most sustainable solution also with respect to the expected savings. Nevertheless, although (Grieves and Vickers, 2016 and Alonso et al. 2019) agree that the DTP *"…has to contain all the informational sets necessary to the future actual physical twin (DTI).*.", the DTP structure and IRs related to the several performances to be evaluated is still undefined. (Jones D. et al., 2020) highlight that few researches investigated the DT across the entire lifecycle, pointing out several gaps especially concerning the early design and disposal phases. This suggests both that the actual benefit might have been missed and the DT requirements across the lifecycle should be investigated. This gap must be bridged in order to provide valuable DT application through a PLM perspective, in addition to useful information protocols and standards for DTP development. Thus, an IM approach is strongly recommended, as suggested by the IM Framework defined in the pioneering case of the National DT Britain (Hetherington and West, 2020).

Low digitalization and GPP adoption

Public procurement represents the 14% of the European Gross Domestic Product and is regulated by EU directives to maximise value in the public sector and ensure compliance with three key principles: equal treatment, non-discrimination and transparency (EU Commission, 2019). In 2017, EU promoted a common public procurement strategy defined in 6 measures (EU Commission, 2017) to improve procurement sector in a collaborative way between public authorities and stakeholders, among them the enhancing of digitalization to empower decision-making through data-driven processes. Despite this key role of digitalization within new EU directives (2014/24/EU Directive), public procurement processes are still highly fragmented and inefficient. One of the major issues concern the long "processing times", mainly due to the lack of a full digitalization as well as of automated procedures (EU Commission, 2017). Therefore, EU established some primary objectives including the integration of digital and data-based approaches throughout all the phases of public procurement. This could deliver full-digitalized processes and yield significant savings in terms of time and costs besides improving transparency and reducing disputes. In fact, improving efficiency in public procurement even of

1% could save 20 billion euros per year (EU Commission, 2017). The performance of single markets in EU state members was measured to understand their efficiency in public procurement (EU Commission, 2019). The findings pointed out that Italy performed poor with just two satisfactory indicators among the 12 selected, the "Decision Speed" was among the six not satisfied while other four were poorly satisfied. As (Agenzia per la coesione territoriale, 2018) highlights, the average starting time of a public procurement is of 4 years and 5 months and the tendering phase averagely lasts between 5 and 20 months. The aforementioned long "processing times" represent the time between the end of one phase and the start of the subsequent one, they are mainly due to bureaucratic delays (EU Commission 2017 & 2019). This issue is particularly severe in Italy, due both to the huge presence of Small and Medium Enterprises in the construction market and to the wide adoption of still document-based approaches. Concurrently, GPP, which integrates requirements and criteria in order to achieve value for money in the whole lifecycle of a project, is promoted both at international and European level to reach more sustainable practices. The 2014/24/EU Directive emphasizes the key role of public procurement in realizing a smart, sustainable, and inclusive growth. Italy was pioneering with the L.D. 50/2016 which represented an innovation in national procurement regulations, introducing GPP as mandatory in public tenders through the MEAT approach. The objective is to identify the most convenient bid by crossing quality and price, based on the lifecycle performance of a project. Nevertheless, GPP was poorly adopted, mostly due to the lack of staff training and GPP competences which generate issues in drafting sustainability criteria in tender documents. A worsen factor is the lack of digital and automated tools which prevent Public Clients to completely control project impacts in terms of both performance and sustainability. Furthermore, although L.D. 50/2016 currently requires use of BIM for all amounts starting from 2025, project deliveries are still document-based and checking the whole bids documentation is struggling. Thus, digital and automated methods would be indispensable to enable easily project performance control and visualization both at the level of single and global performance, promptly displaying the impact that some design choices might produce. Therefore, taking advantage of a system of DTPs which receives offers in real-time through a web-based platform and allows their timely evaluation and visualization at once is fundamental albeit very complex. Administrators, judging commission and all the involved parties could be aware of their choices and related sustainability impact.

Methodology

The research aims to leverage an open-source distributed digital framework to develop a useful DTPS for building performance evaluation in a PLM perspective, oriented to the future lifecycle management and GPP enhancement. Thus, an innovative approach, which integrates data and process models by means of BPMN and DTPs through a WoLD platform, is illustrated. An axiom of the present research is that the developed prototype must not be of the "disposable" type and intended just for the tender phase, rather it must be scalable and reusable in order to enable aware and optimized decisions concerning sustainability (e.g. costs, use of resources, compliance with environmental protocols, etc.) during the whole lifecycle. Therefore, it must be framed as Grieves did in PLM and as other studies affirmed (Alonso et al., 2019). The step forward that this research aims to provide is a DTP development methodology and detailed informative structure that could be exploitable both as a mean for tender evaluation and as the basis to develop future DTI. Thus, the DTP born in the tender phase as a tool exploitable in a MEAT procedure to automatically evaluate the bids uploaded through a web-based platform, enabling to identify the optimal solution in an objective way. In this phase, the DTPS takes the static project parameters as input, extrapolated by a tailored IFC bidding scheme exploitable to develop needed DTPs for the automated bids evaluation and scores assignment. After the tender awarding, the DTPS corresponding to the winning project, that is the bid with the best value for money, will form the basis for the DTIS useful in the O&M and disposal phases. It will be able to take as input both static and dynamic data from on field sensor networks (i.e. in the building or construction site) updating the database whenever there is a change and vice-versa. The DTIS should simultaneously receive instructions to adjust building behaviour when a deviation from expectations occurs, that is the actual DT which establishes a bidirectional communication with its virtual counterpart. The research aims to further promote the adoption of GPP in a MEAT approach and due to the current growing interest in sustainability criteria compliance and to the lack of automated, user-friendly tools to evaluate them (Grilo and Jardim-Goncalves, 2011) the developed methodology will be tested starting from such criteria evaluation. At first, it was not feasible to develop the whole DTPS enabling to simulate all the project performances, rather it will start from few evaluation criteria and then the method will be extended to cover the whole project evaluation. A bottom-up approach is adopted, starting from CAM as Public Clients are facing scarce skills and difficulties to define them in drafting for tenders besides difficulties in checking projects compliance (Lavagna et al., 2019). Once the methodology will be assessed on selected case studies, it could be repeated for other criteria involved in the evaluation of a building project (i.e fire safety, accessibility, structural behavior, etc.). In particular, the research aims to exploit a previous work which defined a replicable IM Modelling (IMM) approach to integrate and evaluate CAM criteria from the design to the call for tenders phase (Pellegrini et al. 2021). It dealt with Construction and Demolition Waste (CDW) minimization and selective demolition criteria and was tested on two DB Italian procurements, that is a brownfield renovation and a green field of a new school. The aim is to extend the previous work in a more holistic approach by adding

further CAM criteria evaluation such as building envelop performance in addition to lifecycle costs. Exploiting the previous case studies it intends to demonstrate how a tailormade DTPS could enable sustainability criteria automated evaluation through an holistic digitalized approach and provide both the increasing of GPP adoption and digitalization enhancement in tendering processes. Hence, the research deals with the definition of a replicable information methodology aimed at the vertical implementation of DTPs and their horizontal integration in a DTPS. For each criterion involved in the evaluation, a Vertical DTP (VDTP) will be developed, enabling the analysis of the single side performance (Figure 2). Then all the VDTPs related to an offer will be horizontally integrated in a DTPS (Figure 3) useful to evaluate the single bid global performance and also the impact on the overall. The focus is not just the development of the DTPs, nonetheless the attention is focused on the development of the set of processes and information concerning the creation and management of tailored DTPs, as it still lacks a defined information structure with related IRs. The defined approach could provide a change of paradigm, allowing conducting the tender procedure based on an IFC model defined by the Appointing Party to be filled by bidders. In particular, tender participants will be provided with an IFC scheme and related guidelines in order to formulate their offers (i.e. IRs needed for each VDTPs and corresponding IFC parameters or required formats). Once tender procedure will be open, bidders' IFC models will be uploaded on the web platform together with all needed documents and translated in graph format. All the parameters useful for the evaluation will be linked to them by means of rule-sets and tailored queries to extrapolate needed VDTPs. Outline information useful for simulations such as timetables, weather files, boundary conditions and so on, will be defined by the Appointing party and stored in the graph database, as well as be provided to the bidders. Contemporarily, the defined methodology enables to start the development of DTs and to manage information since the early design phase. Moreover, the use of resources, time and costs to produce the DT is optimized, this is valuable as the future is foreseen a high percentage of DTs adding value as enabling an optimal building management lifecycle up to its disposal (Dornier et al., 2021). This will result in improved collaboration among parties starting from the early phase and enhanced transparency. The objective and trustworthy evaluation of sustainability criteria compliance based on the actual use of the building rather than on rough saving assessments could be ensured through well-defined and machine-readable criteria. There could be other advantages but also some challenges discussed in the “Expected results” section. The main result will be a well-defined, structured and automated evaluation methodology for MEAT tender evaluation with digital bids evaluated as soon as submitted, assessed in comparison with traditional approaches.

Tender processes normalization

The first step will concern the formalization of all the processes and sub processes relating to the evaluation of the offers, namely: (i) global tender procedure, (ii) bid evaluation method and (iii) evaluation of single performances considered. As stated before, BPMN 2.0 notation will be exploited since it provides an intuitive graphical notation yet capable of representing complex semantics and providing machine-readable processes (i.e. xml format) that could call external interventions from both micro services and humans. The BPMN formalization enables to identify which tasks could be automated, which information is needed at a specific step of the process and by the related actor, facilitating automatable tasks identification per each process and the IRs for each VDTP needed. Consequently it is possible to

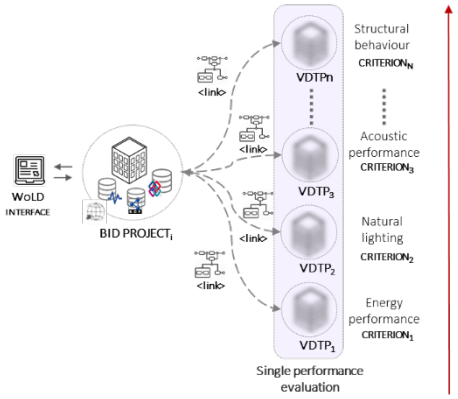

Figure 2: Vertical Digital Twins Prototypes development

check which of them could be directly filled in the IFC bidding schema and which one should be linked through existing or new tailored ontologies. In particular, VDTPs will be linked to procedural information ensuring consistency with respect to the IRs and providing the automation of some tasks for evaluating project performances. Finally, the BPMN formalization allows defining the needed outputs for single criteria and sub-criteria evaluation, along with the definition of queries and rules to extrapolate needed VDTP.

Vertical Digital Twins Prototypes development

In this second step, VDTPs (Figure 2) will be developed from the IFC models submitted by the participants and stored in graph format through the WoLD platform. Thanks to the BPMN formalization previously made, the IRs for each VDTP needed in the global evaluation could be defined and the graph models could be enriched accordingly. A key step is the definition of the queries to generate needed simulation models from the knowledge database. Ideally, for each bid it should be developed as many VDTPs as the number of tender evaluation criteria, starting from each bidding IFC model based on the given scheme and stored in graph format through the WoLD platform. The main outcome consists in a series of isolated VDTPs enabling single performance evaluation. At this step, it will be defined: (i) the queries to extrapolate each specific VDTPs from the platform and (ii) the KPIs (Key Performance Indicators) for each VDTP useful for evaluations and decision-making processes both during the tender phase and throughout the lifecycle (i.e. energy consumption, maintenance and replacement costs, EWC codes etc.). Monitoring these

KPIs, deviations from expected targets enables to promptly identify and correct them. It may seem an onerous step, but once the needed VDTPs are defined together with the related IRs and extrapolation query, it is sufficient to reiterate the process for each bid and it could be automated by integrating a machine learning system.

Digital Twin Prototypes System implementation

Once the VDTPs are defined, they will be horizontally integrated to set-up the holistic evaluation of each bid's project performances (Figure 3). This step will involve the formalization of the interconnection process which will set-up the DTPS, enabling the definition of the links between each VDTP and their semantic formalization through the sensitivity analysis conducted by an Artificial Intelligence (AI) system. A major outcome will be the simultaneous visualization of both global and single bids scores by means of tailored dashboards implemented through the WoLD platform. Thus the user can be aware of the impact that a change in input has on the project performances, both at global and local level, in addition to costs and sustainability. A major outcome at this step will be the definition of the queries which enables to implement the DTPS needed for the global bid evaluation (i.e. one DTPS for each bid or tender project), based on defined IRs.

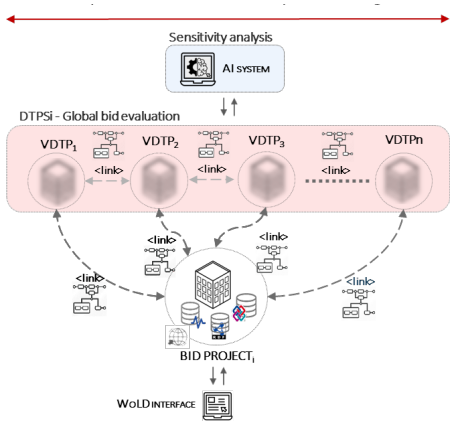

Figure 3: DTPS implementation and AI system integration

AI system integration and global tender evaluation

Another key step will concern the implementation of the most suitable AI system to provide the sensitivity analysis of the IRs both of the single VDTP and of the overall system (i.e. DTPS and tender evaluation). This in order to deep understand how a change in input impact on the single VDTP and on the overall, revealing hidden and direct links between various project's domains and enabling their formalization. As real cases are simulated, the AI system can be trained providing an ever greater knowledge of such links between the involved parameters in the tender evaluation. This enable to define and optimize a multicriteria scores aggregation system considering also the impact that a parameter change has both on the single performance and on the global one, in addition to that on sustainability and costs in a PLM perspective. In fact, it is not certain that significantly increasing a single parameter performance has positive repercussions also on costs or global performance. It could lead to greatly increased installation and maintenance costs compared to slight savings. Thus the proposed awarding system could enable a more objective, effective and aware bids evaluation. The Appointing Party can exploit the awarded DTPS to easily visualize the impact that some design choices have on defined KPIs and project performances, enabling more conscious and effective sustainable choices. In particular, it provides a holistic view for bids project evaluation, enabling to quickly and automatically check whether the tender IRs were actually met or not, avoiding to shift away from the original intent.

Methodology test and assessment

The final step will concern the DTPS implementation through the WoLD platform. Several tests will be conducted on the selected cases study to check whether it works or not, identifying critical issues to be overtaken and providing a first evaluation of the research project effectiveness. The main outcome will be an automated method for tender sustainability criteria evaluation, which will be assessed in comparison with a traditional approach based on defined KPIs. In particular, the bids received in the aforementioned real DB procedures for a new primary school and a brownfield renovation in northern Italy, based on a definitive project and evaluated through MEAT approach, will be taken as reference to compare the results. This will allow the optimization of tender IRs and projects performance, providing the final definition of data standards and protocols to support IRs definition and information exchanges between parties. In addition, standardized digital models to submit the biddings will be defined as well as the main features and IMM criteria to develop valuable DTPs from the early phase.

Expected results and outcomes

The presented methodology aims to enhance tender evaluation in a GPP perspective through its full digitalization and automation. Leveraging DTPs and BPMN notation, it aims to automatize bids compliance checking processes and project's performance evaluation, in addition to bids scores attribution.

The methodology is still at a theoretical level, so the results are discussed as expected outcomes to be confirmed during the test and validation phase on real cases study. The overall worth mainly lies in the full digitalization, transparency and shortening of the tendering phase. The disruptive aspect concerns the leveraging of an innovative approach which aims to set-up a DTPS through an open-source, distributed digital framework and to automatize sustainability criteria evaluation during tender procurement. This provides the formalization of the existent direct and hidden links between project performances and thus supports more aware and effective design choices starting from the early design phase. Accordingly, it will be possible to visualize and promptly understand how the modification of an input might affect both on the DTPs involved and on the global performance by means of a sensitive analysis conducted

through an AI system. As the DTPS is used it could be defined a hierarchy among the award criteria and the defined KPIs based on how much they impact on project performance, costs and sustainability, optimizing both the IRs and the MEAT evaluation method. This will lead to the definition of trustworthy standards, information and process management protocols for the tendering phase. Particularly concerning the definition of valuable building DTPs in a PLM perspective, suitable as the basis for actual DTIs useful to constantly monitor the identified KPIs throughout the building lifecycle. This could provide actual GPP by pursuing the highest possible degree of sustainability in terms of performance, use of resources and lifecycle costs. A twisting to the current evaluation system in public procurement could be provided given that currently it is not possible to dispose of simulation models to evaluate bids. Table 1 shows the differences between the main features of current evaluation approach and the proposed one.

Table 1 - Comparison between the main features of current tender evaluation approach and the proposed DTPS

	Current approach	DTPS perspective
Evaluator	Judging commission	WoLD platform with commission partial actions
Tools	Excel sheets Professional experience	Digital microservices (Software, digital tools..)
Formats	Paper and text documents	Open and machine-readable (IFC, json, xml..)
Awarding criteria weighting	Subjective, manually, based on commissioners experience	Objective, automated through an AI system, based on single and global impacts
Performance evaluation	Siloed set of performances	Systematic and simultaneous
Tender duration	5-20 months	Strongly reduced, few days

Until now the commissions of experts was central and judged bids on the basis of their own professional experiences, that is a subjective way. The proposed method foresees a marginal role of the commissioners with consequent objectiveness improvement and cost reduction. The bids evaluation will be entrusted to a powerful digital simulation tool (i.e. the DTPS). Based on the formalization and digitalization of the processes involved in the MEAT assessment, the DTPS will provide greater objectivity and transparency. In addition, the Appointing Party changes its role as becomes an active part of the evaluation process, receiving no more random documents from bidders and performances are no more evaluated with a not homogeneous, isolated and fragmented method. Rather, they will be evaluated as soon as the bidders upload their offers on the web-based platform. Consequently, offers can be simultaneously evaluated with respect to their uploading and tender assignment time can be drastically reduced, switching from average times ranging from 5 to 20 months (Table 1) to few days. Furthermore, the judging board will have just a notarial role, contrary to current approach strongly based on their personal experience and belief. Thus, by means of an automated digital method, based on the evidence provided by performance simulation through the DTPS holistic view, a more objective awarding could be provided and the most sustainable solution could be easier identified. Finally, the developed DTPS and the collaboration between parties can enable to exploit the awarded project to furtherly maximize the potential sustainability and minimize both maintenance and construction costs before developing the DTIS exploitable during the rest of lifecycle.

Conclusions and further development

The paper tackled the development of a replicable methodology to extend current BIM-based approaches in a PLM perspective and boost the on-going digital transition, overcoming existing limits. It aims to transpose Grieves DTP conception in the field of PLM to the AECO industry, with the main objectives to fully digitalize and shorten tender procedures in a GPP perspective. In this view, the development of DTs could start in the early-design phase, providing a building prototype which enables its performances optimization in a holistic rather than a discrete approach. The DTP can be used in tender evaluation to choose the optimal bids both with respect to the client's requests and regulations and to the overall sustainability of the project. An axiom is that it must not be a "disposable" prototype; rather, it must be structured to be enriched with dynamic data throughout the whole building lifecycle. Therefore, an IM approach is necessary to define the IRs for each VDTP related to the several project's domains, providing all the useful information to develop the actual DTIs for the O&M phase, up to decommissioning. These objectives could be achievable exploiting a WoLD platform based on a collaborative, distributed, open-source database suitable to develop effective DTs, as it contains all project data with their generating processes and change history. Such platform is based on the principles of SW and LD, providing highly scalable and enrichable VDTPs, starting from the bidding IFC models of tender participants. Moreover, it enables to extrapolate and link together several correlated VDTPs, resulting in a DTPS which enables the holistic evaluation of performances. Specific KPIs to evaluate biddings and building performances throughout the lifecycle, will be displayable. Along with the proposed advantages, there are many challenges. Among them the definition of IRs and new ontologies for each VDTP needed, due to the numerous and complex domains integrated in a construction project. Consequently, a scalable approach is adopted and the research will be tested on real DB Italian procurements previously exploited to integrate MEAT and IMM to promote sustainable strategies adoption focused on waste reduction and resource valorization. The aim is to extend previous work in a more holistic approach by adding further CAM criteria and automatizing their evaluation in the tendering phase. It will be demonstrated how a tailormade DTPS could enable sustainability criteria automated evaluation and provide both the

increasing of GPP adoption and digitalization enhancement in tendering processes. Then, through the definition and formalization of the links between other project's domains, a complete evaluation system for the whole project will be provided. Another challenge concerns the transition from the current project-based approach to the distributed process-based one with full transparency among stakeholders, due to the closeness of the sector. In addition, current Italian regulations prevent to dispose of a simulation models to evaluate bids. Nevertheless, the evaluation on real case studies is meant to demonstrate the system validity and enable to propose a revolution of the current evaluation method, providing a less subjective, more correct and sustainable one. Other issues will concern the integration of the best AI system to conduct sensitivity analysis and identify direct and hidden links between the inputs, so that they could be formalized. This allows to understand almost in real-time how a change in a VDTP input influence the overall and the single performance. It will be considered and explicated only the links identified as significant with respect to the award criteria and defined KPIs. Tolerance thresholds will be established depending on their impact heaviness on maintenance and construction costs or sustainability criteria.

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