Process modelling for managing digitalised information exchanges in construction inspections and quality checks

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Abstract. Processes of the Architecture, Engineering and Construction (AEC) industry are known to be characterised by a high level of complexity in terms of activities and involved actors, which requires a consistent exchange of information through each phase of a project life cycle. A digital transition applied to information modelling and management may support the optimisation of such processes. To overcome the traditional paper-based and document-centric approach, the so-called Common Data Environment (CDE) has been introduced and its adoption through the project life cycle is now regulated by ISO 19650. A CDE is a platform, whose purpose is to collect, manage and disseminate sets of information through a managed, interoperable and collaborative process. The fullest adoption of CDEs requires a methodological change towards data-based information exchanges. As a preliminary step to such a goal, the formalisation of procedures by process mapping and modelling can allow a more coherent management of use cases and related information exchanges. With a focus on the construction stage, the formalisation of inspection procedures is proposed through the Business Process Model and Notation (BPMN 2.0) format. Quality checks are taken into account in relation to the supply and installation of an External Thermal Insulation Composite System (ETICS). Quality control inspections and related activities are analysed and discussed within the framework of public works. An open source BPMN modeller and its workflow engine have been adopted. The result is a process model that (1) represents the complexity of managing information exchanges in such a scenario; (2) can be used as a basis for the development of a CDE where all the information is shared and accessible to the various actors of the construction process; (3) automatically feed, as a future work, an inspection management support system.

1. Introduction
In recent years, the construction industry, and in particular the public sector [1], has begun to investigate new innovative strategies based on digital approaches to improve information management during the entire project life cycle. Digital innovations like Building Information Modelling (BIM), in fact, could offer considerable advantages in the construction industry over the conventional methods, document-centric and paper-based ones, that still largely prevail in current practice [2][3]. The construction sector, being an industry which considers multiple players, requires a high degree of coordination to manage a complex construction process that involves a high exchange of information.
The information flows originated by the building process, are the result of the elaboration of multiple datasets. These data are generated in several phases and by different actors, which work to achieve a specific objective. The transition from different phases to another not only identifies a project
development but also identifies changes of actors, objectives, profit margins, information requirements, levels of detail, methods and tools for processing information. These changes introduce a high level of difficulty in the management of information flows and make the interoperability among different actors inefficient.

In order to better organise information flows, methodological standards have been introduced:

- ISO 19650-1 / 2 [4] [5] standard defines concepts regarding the organisation and digitisation of regulatory flows;
- UNI 11337-5 [6] defines information management in the adoption of BIM methods and tools.

Within such a context, process mapping and process modelling may support better understanding of complex systems. In fact, the adoption of these approaches in construction projects, especially if combined with BIM methodologies, is more and more discussed in the industry as a method to provide valuable insights to optimise data flows, to gather information and to share knowledge during construction processes through the life cycle management of a project. Gardini et al. (2020), for example, proposed the process modelling approach for the management of the inspection of execution processes in construction [7]. Moreover, a clear overview of construction processes and workflows is also needed as a preliminary step to guarantee the efficiency behind the implementation of so-called Common Data Environments (CDE). A CDE is a platform whose purpose is to collect, manage and disseminate sets of information through a managed, interoperable and collaborative process [4]; its adoption is now managed by the EN ISO 19650 series.

ISO 29481-1:2017 [8] recommends the Business Process Modelling Notation (BPMN) as an approach for representing process maps. The purpose of process maps is “to describe the flow of activities within the boundary of a particular business process, the roles played by the actors involved together with the information required, consumed and produced”. A process map includes the exchange requirements that are within the boundary of the process as well as an overview that provides a comprehensive description of the overall process. BPMN is an international standard [9] that is maintained by the Object Management Group. It “provides a means of graphically representing processes in a formal manner thanks to various standardised node and edge elements available” [2] and in the AEC context, BPMN is “often used to visualise the processes of model creation, collaboration and data exchange” [2].

With a focus on the construction stage, the paper evaluates the adoption of a process mapping and modelling approach as an adding value to the BIM-based management of a construction procedure. Moreover, the formalisation of inspection procedures is within the scope of this paper and it is proposed through the BPMN 2.0 format. In particular, quality checks are taken into account in relation to the supply and installation of an External Thermal Insulation Composite System (ETICS). Quality control inspections and related activities are analysed and discussed within the framework of public works. An open source BPMN modeller and its workflow engine have been adopted to execute the developed processes. Main findings and future works are finally discussed.

2. Proposed approach
The paper shows the preliminary results of an on-going research project on the adoption of a digital approach to the management of construction processes. In particular, with a focus on public works, the objective of the research is the development of an executable process to semi-automatically feed common data environments and manage information exchanges, providing support for the various stakeholders involved.

The proposed approach is based on four main steps: (1) analysis of normative texts, guidelines and other documentation materials useful to (2) map a construction process in terms of actors involved, activities to be carried out, data to be shared and documents to be produced. (3) Process modelling is then used to show the sequence of events, activities/tasks that occur in the process, as well as stakeholders involved and data to be exchanged. The modelling phase has been developed implementing
the BPMN 2.0 notation tools and adopting an open source process modeller and workflow engine (i.e., Camunda Modeller). Finally, (4) in the process execution phase a preliminary attempt to translate the representation of the process into an operational one has been developed.

3. Sample use case: the supply and installation of an External Thermal Insulation Composite System (ETICS)

The formalisation of procedures by process mapping and process modelling can allow a more coherent management of use cases and related information exchanges. With a focus on the construction stage, the formalisation of inspection procedures is proposed and quality checks are taken into account. EN ISO 9000:2015 defines ‘quality’ as the ‘degree to which a set of inherent characteristics of an object fulfils requirements’, which are defined as a ‘need or expectation that is stated, generally implied or obligatory’ while ‘a specified requirement is one that is stated, for example in documented information’ [6]. If the specified requirements are not met, EN ISO 9000:2015 speaks of non-compliance or errors [2].

Within the scope of this paper, digitalised information exchanges in construction inspections and quality checks are managed in relation to the supply and installation of an External Thermal Insulation Composite System (ETICS).

3.1. Analysis of normative texts and guidelines

Normative texts and guidelines for the installation of ETICS in a workmanlike manner have been analysed in order to identify process phases and activities [10] [11] [13]. The Cortexa manual [11] and notebooks [12] have been taken as main references. Cortexa is a founding member of the European Association ‘Manufacturers of Thermal Insulation Systems (EAE)’. The Cortexa manual is inspired by the best European practices, described in the EAE Manual, and has been adapted to Italian market needs by the Cortexa Technical Commission. The new 2020 edition of the Cortexa manual for the application of the External Thermal Insulation Systems (ETICS), specifying the design, the installation procedures and the certification needed by the installers. The goal of these documents is to describe the necessary conditions which have to be applied to carry out the activities in the best possible way. These considerations are even more important considering the fact that the benefits of this energy efficiency system are achieved only if the installation work is performed in a workmanlike manner.

Another standard that has been analysed is the UNI/TR 11715 ‘Thermal insulation products for buildings - Design and installation of thermal insulation systems for the exterior (ETICS)’ which describes in a precise and rigorous way how to proceed in the correct design and installation of state-of-the-art thermal insulation systems.

3.2. Process mapping

A process map is characterised by a set of interrelated activities that arise from an input and provide an output. Outputs and inputs can be represented by a product, documents or data. Along the execution of a process, many figures with different skills are required. Moreover, all these players are supposed to collaborate and interact in order to achieve the set goal. Thanks to the analysis of the specific texts indicated above, it has been possible to identify all the different actors involved in the executive process of installation of External Thermal Insulation Systems. Particularly, actors taken into consideration are three: the executor (the company or a subcontractor), the works management office (represents the client) and the supplier (manufacturer or distributor).

Subsequently, all the activities that each actor is supposed to carry out in order to lay a ETICS in a workmanlike manner were identified specifying, at the same time, all the checks points that must be accomplished along the process. Each check has been defined to have two different possible answers, a positive and a negative one. In case of a positive answer the transition to the next processing is allowed otherwise, a non-compliance has to be resolved before proceeding.

The activities that have been identified can be divided into activities that have to be carried out, communication activities, document creation activities and document/communication reception activities. Documents and data that are produced throughout the entire process are collected in the
Common Data Environment (CDE), which represents the central archive where information on the construction project are stored. The CDE is an environment constantly updated and its use improves collaboration, security and data verifiability.

3.3. Process modelling
The modelling of an ETICS supply and installation procedure has been developed using the BPMN 2.0 in order to represent the sequence of steps as a series of activities, events and sequence flows in a process model.

First, the entire process has been mapped at a high level (non-executable process), allowing the generation of a digital representation of the activities to be carried out chronologically. The map is made up of a macro and micro processes, such as the resolution of non-conformities.

The elements of BPMN used most frequently are sequence flow, pool, lane, task/activity, gateway, and message flow [14]. In this case, the notation tools that have been implemented are:

- pools: three pools have been created, one for each actor, and one for CDE;
- events: they represent the beginning and the end of each actor's process;
- activities: represents the activities in chronological order that must be carried out;
- gateway: was used to check the divergences and convergences of the sequence flow;
- data object: this tool has no effect on the sequence flow but represents data and documents produced by the activity.

![Figure 1. Part of the process map modelled in Camunda Modeler [15] with the BPMN 2.0 notation](image)

3.4. Process execution
A process can be modelled to be formalised and visualised. Moreover, it can be also executed automatically once generated using a workflow engine that performs the process step by step and in accordance with the modelled logic [2]. The workflow engine can also 'react to events during runtime as well as trigger events itself. Such an event might be a data input by the user, the calculation of
mathematical formulae, a decision resulting from an if-then condition, or the execution of text-based source code’ [2].

Once the modelling of the ETICS supply and installation process was obtained, it has been possible to verify the correctness of the modelling itself by implementing with some properties each notation tool used to make the process executable. Each notation tool can be customised using the properties panel; this panel can be used to assign the activities marked as ‘User Task’ to the various actors. Additionally, the properties panel allows the identification of the branches dictated by the gateway, and setting the sending and receiving of communications associated with the activities.

After completing the enrichment of the map, it has been possible to verify the correctness of the representation and automatically retrace the process from start to finish. The only tasks that required actors input to be complete were ‘User Task’.

![Figure 2. Customisation of “User task” activities by assigning the activity to the actor involved in the process](image)

### 4. Results and conclusions

The research project has investigated the applicability of the BPMN 2.0 notation in the construction sector as a way to model processes with the aim to develop a process-oriented digital quality assessment procedure. Based on the results obtained, the potential and functionality of the BPMN format in process modelling and automation for the construction industry are confirmed.

Mapping and modelling quality control inspections and related activities for the supply and installation of an external thermal insulation composite system has allowed the identification of all the different layers of complexity of the process, highlighting the critical steps with a high probability of a non-conformity generation. The content validation of the process map is currently under development based on semi-structured interviews with experts in order to evaluate its comprehensiveness and to identify possible missing factors.

Moreover, the execution of the process model in an open source workflow engine is a first step towards the goal to automatically feed an inspection management support system.

Finally, as a future work, the process model could be also used as a basis for the development of a CDE where all the information is shared and accessible to the various stakeholders. Furthermore, future activities will include the further specification of the level of information need for information exchanges in the analysed process and the direct link of the process model with the related building
information models and additional information containers within the framework of a common data environment.

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