



**CREATIVE CONSTRUCTION
e-CONFERENCE**

28 June - 1 July 2020

Proceedings

Creative Construction e-Conference 2020

ISBN 978-615-5270-62-8

Creative Construction e-Conference 2020

Proceedings

28 June – 1 July 2020,

ISBN 978-615-5270-62-8

Editors-in-chief: Miklós Hajdu and Mirosław Jan Skibniewski

Technical editors: Attila Varga, Róbert Hohol, Gergely Szakáts

All rights are reserved for Diamond Congress Ltd., Budapest, Hungary, except the right of the authors to (re)publish their materials wherever they decide. This book is a working material for the Creative Construction e-Conference 2020.

The professional and grammatical level of the materials is the authors' responsibility.



International Organizing Committee

(permanent)

- **Miklós Hajdu**
Chair of the International Organizing Committee, Budapest University of Technology and Economics, Budapest, Hungary
- **Orsolya Bokor**
Northumbria University, Newcastle upon Tyne, United Kingdom
- **Attila Varga**
Diamond Congress Ltd, Hungary
- **Róbert Hohol**
Diamond Congress Ltd, Hungary

Scientific committees

International Advisory Board

(permanent)

- **Mirosław Skibniewski, Chairman**
University of Maryland, USA
- **Miklós Hajdu, Co-chairman**
Budapest University of Technology and Economics, Hungary
- **Lieyun Ding**
Huazhong University of Science and Technology, China
- **Árpád Horváth**
University of California, Berkeley, USA
- **Mladen Radujkovic**
Alma Mater Europea ECM, Slovenia
- **Li-Yin Shen**
Chongqing University, China
- **Vivian Tam**
Western Sydney University School of Computing Engineering and Mathematics, Australia

International Scientific Committee

- **Mirosław Skibniewski**, Chairman
University of Maryland, USA
- **Clinton Aigbavboa**
University of Johannesburg, South Africa
- **Salman Azhar**
Auburn University, USA
- **Thomas Bock**
Technical University of Munich, Germany
- **Constanta Bodea**
Bucharest Academy of Economic Studies, Romania
- **Ioannis Brilakis**
Cambridge University, UK
- **Albert P.C. Chan**
The Hong Kong Polytechnic University, Hong Kong
- **László Dunai**
Budapest University of Technology and Economics, Hungary
- **Neil N. Eldin**
University of Houston, USA
- **Dongping Fang**
Tsinghua University, China
- **Laura Florez**
University College London, UK
- **Adel Francis**
Quebec University, Canada
- **Borja García de Soto**
New York University Abu Dhabi, UAE
- **Miklós Hajdu**
Budapest University of Technology and Economics, Hungary
- **István Hajnal**
Budapest University of Technology and Economics, Hungary
- **Tomáš Hanák**
Brno University of Technology, Czech Republic
- **Bożena Hola**
Wrocław University of Technology, Poland
- **Shabtai Isaac**
Ben-Gurion University of the Negev, Israel
- **H. David Jeong**
Texas A&M University, USA
- **Tamás Koltai**
Budapest University of Technology and Economics, Hungary
- **Sui-Pheng Low**
National University of Singapore, Singapore



- **Gunnar Lucko**
The Catholic University of America, USA
- **Hanbin Luo**
Huazhong University of Science and Technology, China
- **Zhiliang Ma**
Tsinghua University, China
- **Javad Majrouhi Sardroud**
Azad University, Iran
- **Ferenc Makovényi**
Szent Istvan University, Hungary
- **Levente Mályusz**
Budapest University of Technology and Economics, Hungary
- **Osama Moselhi**
Concordia University, Canada
- **S. Thomas Ng**
The University of Hong Kong, Hong Kong
- **John-Paris Pantouvakis**
National Technical University of Athens, Greece
- **Chansik Park**
Chung-Ang University, South Korea
- **Edyta Plebankiewicz**
Tadeusz Kosciuszko Krakow University of Technology, Poland
- **Augustin Purnus**
Technical University of Bucharest, Romania
- **Zoltán Sebestyén**
Budapest University of Technology and Economics, Hungary
- **Alfredo Serpell**
Pontificia Universidad Catolica de Chile, Chile
- **Geoffrey Shen**
The Hong Kong Polytechnic University, Hong Kong
- **Igal Shohet**
Ben-Gurion University of the Negev, Israel
- **Edgar Small**
University of Delaware, USA
- **John Smallwood**
Nelson Mandela Metropolitan University, South Africa
- **Ales Tomek**
Czech Technical University in Prague, Czech Republic
- **Ziga Turk**
University of Ljubljana, Slovenia
- **Zoltán András Vattai**
Budapest University of Technology and Economics, Hungary
- **Derek Walker**
RMIT University, Australia

- **Yiannis Xenidis**
Aristotle University of Thessaloniki, Greece
- **Wen-der Yu**
Chaoyang University of Technology, Taiwan

Conference Secretariat

Attila Varga
Diamond Congress Ltd.
H-1255 Budapest, P.O. Box 48, Hungary
Phone: +36 1 225 0210

<http://www.diamond-congress.h>



AUTOMATION AND ROBOTICS FOR CONSTRUCTION

Application of UAS and Revit for Pipeline Design

Hamlet Reynoso Vanderhorst, David Heesom, Subashini Suresh, Suresh Renukappa and Keith Burnham

Automated State-Survey System for Monitoring Salt Damages on Plastered Wall Surfaces

István Vidovszky and Farkas Pintér

Development of a Digital Twin Model for Real-Time Assessment of Collision Hazards

Leonardo Messi, Berardo Naticchia, Alessandro Carbonari, Luigi Ridolfi and Giuseppe Martino Di Giuda

Feasibility of Using Physiological Signals from a Wearable Biosensor to Monitor Dehydration of Construction Workers

Amit Ojha, Shahradd Shakerian, Mahmoud Habibnezhad, Houtan Jebelli, SangHyun Lee and Mohammad Sadra Fardhosseini

Investigating a 24 GHz CW-Radar for Non-Contact Vital Sign Sensing in Construction Machine Cockpits to Increase Safety on Building Sites

Stefan Pehr, Jörg Güttler, Tatsuo Arai, Thomas Bock and Mieko Ohsuga

Nested Network for Detecting PPE on Large Construction Sites Based on Frame Segmentation

Mohammad Akbarzadeh, Zhenhua Zhu and Amin Hammad

Providing Proximity Safety Alerts to Workers on Construction Sites Using Bluetooth Low Energy RTLS

Yusheng Huang, Amin Hammad and Zhenhua Zhu

Structure Equation Model for the Successful Implementation of ICT / Automation in Construction Project Management in India

Saurav Dixit, Priyanka Singh and Krystyna Araszkiewicz

Validation of a Formal Framework Model to Improve On-site Construction Productivity: Indian Scenario

Saurav Dixit, Dhurva Choudhary, Priyanka Singh and Krystyna Araszkiewicz

Will Artificial Intelligence (AI) Take over the Construction World? - A Multidisciplinary Exploration

Souhail Elhouar, Elodie Hochscheid, M. Ammar Alzarrad and Chance Emanuels

CREATIVE CONSTRUCTION TECHNOLOGY AND MATERIALS

An Investigation into the Integration of Building Information Modeling with Pre-Construction Industry in the Developed Countries and Iran

Javad Majrouhi Sardroud, Hamid Mehranpour and Abolfazl Arzanloo

Modular Construction vs. Traditional Construction: Advantages and Limitations: A Comparative Study

Karthik Subramanya, Sharareh Kermanshachi and Behzad Rouhanizadeh



Opportunities for Transportation Departments to Leverage Construction UAS Data

Bryan Hubbard and Sarah Hubbard

Reticulated Roof Structures Optimisation Based of Triangular and Quadrilateral Planar Panels

Anna Stefańska

CREATIVE MANAGEMENT IN CONSTRUCTION

A Broader View of Risk Management Process in Projects

Zoltán Sebestyén and Tamás Tóth

A Theoretical Assessment of the Impacts of Poor Risk Management in the Construction Industry - A Case of Ethiopia

Yisakor S. Ferede, Nokulunga X. Mashwama and Didibhuku W. Thwala

Attributes Indicating Communication Influence on Leadership Development: A Delphi Selection Process

Murendeni Liphadzi, Clinton Aigbavboa and Didibhuku Thwala

Barriers to ICT Adoption in Construction Revisited

Žiga Turk

Compatibility of Personality and Productivity: An Analysis of the Relationship with Construction Crews

Laura Florez, Phillip Armstrong and Jean C. Cortisoz

Construction Control Room for Project Monitoring and Control

Ali Ezzeddine, Lynn Shehab, Issam Srouf and William Power

Development of a Risk Management Process for the Construction Sector

Dina Alfreahat and Zoltán Sebestyén

Education's Impact on the Decline of Craft Workers in the United States Construction Industry

Scott W. Kramer, Carol Jayroe and April E. Simons

Effective Project Management Principles and Strategies in Transportation Infrastructure Projects

Elnaz Safapour, Sharareh Kermanshachi and Amirhosein Jafari

Effective Use of United States Foreign Aid to Fund Infrastructure Projects

Kevin McGuirk, Anoop Sattineni and Wesley Collins

Explicit Evaluation of Complexity in Construction and Real Estate Management

Wolfgang Eber

Formal Modeling of Smart Contracts for Quality Acceptance in Construction

Da Sheng, Hanbin Luo and Botao Zhong

**How Organization Will Enhance Benefits Realization by Using Innovation Project Management and AI (Artificial Intelligence)**

Tarek Tawfik, Jamila Al Maazmi and Omran Al Shamsi

Identifying Motivators and Challenges to BIM Implementation Among Facilities Managers in Johannesburg, South Africa

Chioma Okoro, Innocent Musonda and Andre Kruger

Identifying the Factors Affecting Sustainability Cost Toward Optimization of the Project Selection Process

Dina Alfrehat and Zoltán Sebestyén

Implementation of the Common Vulnerability Scoring System to Assess the Cyber Vulnerability in Construction Projects

Bharadwaj Mantha and Yeojin Jung and Borja Garcia de Soto

Improving But-For Delay Analysis and Concurrency Assessment

Moneer Bhih and Tarek Hegazy

Investigation of Possible Dominance of Factors Affecting Project Success

Zoltán Sebestyén, János Erdei and Dina Alfrehat

Knowledge Management and BIM Technology in Construction Project Management

Tomáš Mandičák and Peter Mésáros

Learning Curve for Improved Productivity in the South African Construction Industry

Somila Mhini, Nokulunga X. Mashwama, Didibhuku W. Thwala and Clinton O. Aigbavboa

Real Estate MSc Curriculum in the New Era of Artificial Intelligence

István Hajnal

The Integration of Newly Graduated Construction Managers into the South African Construction Industry

Thulani Khoza, Mark Abrey and John Smallwood

Women in U.S. Construction Management Positions: A Qualitative Look at Motivations, Challenges and Considerations

Scott W. Kramer, Stephanie Woods and April E. Simons

Women's Representation in Federal Transportation Agencies: A Descriptive Analysis

Behzad Rouhanizadeh, Amirhosein Jafari and Sharareh Kermanshachi

CREATIVE SCHEDULING IN CONSTRUCTION

A Deep Learning Algorithms to Generate Activity Sequences Using Historical As-built Schedule Data

Hamed Alikhani, Chau Le and H. David Jeong

A Project Crashing Strategy Considering Contract Clauses and Quality Considerations: An Illustrative Example

Gul Polat, Firat Dogu Akin, Harun Turkoglu and Atilla Damci

**Accelerating the Execution of Construction Projects by Relocating Resources**

Michał Tomczak and Piotr Jaśkowski

An Enhanced Resource-Constrained Critical Path Method (eRCPM)

Diana M. Franco Duran and Jesús M. de la Garza

Construction Industry Perspective on Planning and Scheduling Content

Saeed Rokooei, Neil Pickavance, Alireza Shojaei and Andrew Ross

Improving the Information Flow in the Construction Phase of a Construction Project

Matti Tauriainen and Antti Leväniemi

Predicting Time Contingency in Construction Schedules for USACE Projects

Anoop Sattineni, Anil Miglani and Lauren Redden

Project Crashing with Crash Duration Consumption Rate: An Illustrative Example

Harun Turkoglu, Gul Polat, Atilla Damci and Firat Dogu Akin

Project Planning by Modified Gauss S-Curve

Vladimir Križaić and Dražen Hranj

Workflow Optimization with Construction Scheduling under a Lean Perspective

Marco A. Bragadin and Kalle Kahkonen

SUSTAINABLE CONSTRUCTION, HEALTH AND SAFETY

A Damage-Based Analysis of Rework in Reconstruction of Infrastructure Projects Due to Natural Disasters

Elnaz Safapour, Sharareh Kermanshachi and Thahomina Jahan Nipa

A Methodology for Risk Assessment and Management for Nuclear Power Plant SMR Hit by High Explosive Warheads

Igal M. Shohet, Sima Michal Elkabets, David Ornai, Yosef Kivity, Erez Gilad, Robert Levy, Gal Shany, Matan Levi-Tzedek, Barak Tavron and Gabi Ben-Dor

A Socioeconomic-Based Analysis of Disaster Preparedness, Awareness and Education

Ronik Ketankumar Patel, Sharareh Kermanshachi and Mostafa Namian

An Analysis on Safety Risk Judgment Patterns Towards Computer Vision Based Construction Safety Management

Chansik Park, Doyeop Lee and Numan Khan

Analysis of Cost Performance Indicators in Reconstruction Projects:**A Comparative Study of Low vs High Level Damages**

Elnaz Safapour, Sharareh Kermanshachi and Thahomina Jahan Nipa

Challenges in Post-Disaster Housing Reconstruction: Analysis of Urban vs. Rural Communities

Apurva Pamidimukkala, Sharareh Kermanshachi and Elnaz Safapour

Critical Construction Work Items for Sustainable Hospitals

Claudia Valderrama-Ulloa, Pablo Canales and Ximena Ferrada

**Designing Sustainable Gabion Houses for Haiti Using Local Resources**

April E. Simons, Heath Barton and Ryan Logan

Digital Fabrication of Contemporary Structures in Architectural Design Optimization

Anna Stefańska and Saurav Dixit

**Establishment of a Framework to Measure Disaster Preparedness:
Development of Strategies to Enhance Disaster Preparedness Activities**

Ronik Ketankumar Patel, Sharareh Kermanshachi and Thahomina Jahan Nipa

Health and Safety Challenges on South African Regional Public Sector Projects

Nomakhwezi Mafuya and John Smallwood

Impact of Family Income on Public's Disaster Preparedness and Adoption of DRR Courses

Thahomina Jahan Nipa, Sharareh Kermanshachi and Ronik Ketankumar Patel

**Impact of Natural Disasters on Construction Projects: Strategies to Prevent Cost
and Schedule Overruns in Reconstruction Projects**

Apurva Pamidimukkala, Sharareh Kermanshachi and Sanjina Karthick

Is Virtual Reality Safety Training Making the Construction Industry Safer?

Jason B. Manning, Junshan Liu and Lauren Redden

Noise Reduction and Ventilation System: A Design of a New Intelligent Window

Keming Ye and Hanbin Luo

**Schedule Performance Analysis of Infrastructure Reconstruction Projects Due
to Extreme Events**

Elnaz Safapour, Sharareh Kermanshachi and Thahomina Jahan Nipa

**Sleep Duration and Results of the Psychomotor Vigilance Test in Construction Workers:
A Preliminary Study**

Ximena Ferrada, Silvia Barrios, Patricia Masalan, Solange Campos, Juan Carrillo and Yerko Molina

**The Contribution of BMS Application Towards the Sustainability and Life Cycle
Costs Optimization of Buildings: A Case of Public Utility Facilities in Poland**

Krystyna Araszkievicz, Patrycja Jakubowska and Saurav Dixit

**Towards Sustainability of Real Estate Development:
An Integrative Review of Smart City Planning Considerations**

Chioma Okoro, Andre Kruger and Marno Booyens

**VISUALIZATION, VIRTUAL REALITY BIM AND 3D PRINTING
FOR DESIGN AND CONSTRUCTION**

A BIM-Based Conceptual Model to Manage Knowledge in Construction Design

Ahmed Al Sehwawy and Omar Amoudi

A Comprehensive Map for Integrating Augmented Reality During the Construction Phase

Hala Nassereddine, Christian Schranz, Makram Bou Hatoum and Harald Urban



A Computer Vision-Based Approach to Classifying and Storing Image Data for Construction Safety Management

Zhitian Zhang and Hongling Guo

A Lightweight BIM-GIS Integration Method for Rural Building Design and Construction

Shuo Leng and Zhen-Zhong Hu

BIM-Based Cost Management Practices in the Quebec's Construction Industry

Ritha Oumbé and Conrad Boton

BPMN 2.0 Modelling for the Management of the Inspection of Execution Processes in Construction

Alice Gardini, Marco Alvisi Bragadin, Berardo Naticchia, Alessandro Carbonari and Alessandra Corneli

Evaluating the Effectiveness of Virtual Reality Construction Safety Training and Lessons Learned

Jeffrey Kim, Peesadech Zornnetr, Soundarya Korlapati, Nikolay Sargsyan, Satish Akula, Xin Wei and Cheryl D. Seals

Integrated Design Review Methodology for Critical Facilities Management and Maintenance

Igal M. Shohet, Kun-Chi Wang and Sheng-Han Tung

Transforming the AEC Industry: A Model-Centric Approach

Hala Nassereddine, Mahmoud El Jazzar and Melanie Piskernik



BPMN 2.0 Modelling for the Management of the Inspection of Execution Processes in Construction

Alice Gardini¹, Marco Alvisè Bragadin¹, Berardo Naticchia², Alessandro Carbonari² and Alessandra Corneli²

¹ *Università di Bologna, Bologna, Italy*

² *Università Politecnica delle Marche, Ancona, Italy*

Abstract

Nowadays digitalization is a growing challenge for the whole construction sector. Therefore, the need of supportive tools and procedures is becoming increasingly urgent in each construction project step and particularly for project supervision in the execution phase. This is a primary requirement especially for the public sector, since the legislative framework is becoming more and more focused on this aspect, in Italy as well as in the European and international context.

A formalization of the inspection procedures of project management in the construction phase is proposed through Business Process Modelling and Notation (BPMN) 2.0 language. The first key aspect of this proposal is to assume a model-based approach, which allows a more coherent information management, in contrast with the traditional document-based one. The second aspect concerns process modeling. In fact, the proposed method is based on processes, instead of BIM – based federated object-oriented models. Construction processes are modelled so that they can generate and feed the federated models themselves. In addition to this, Business Process Modelling and Notation can be used to create a collection of different procedures involved in the inspection management for construction projects. Also, BPMN model will allow an automatic feeding of an inspection management support system which will be developed in future studies, that will offer the full traceability of the procedures and the delivery of the quality certification of products. The case study of the inspection of ready-mix concrete cast-in-place process is analyzed and discussed.

© 2020 The Authors. Published by Budapest University of Technology and Economics & Diamond Congress Ltd
Peer-review under responsibility of the Scientific Committee of the Creative Construction Conference 2020.

Keywords: BIM, BPMN 2.0, digitalization, inspection of execution, process management

1. Introduction

The need of supportive procedures and tools for the digitalization of the construction field is increasing evident, especially concerning the public sector, since the legislative framework is becoming more and more focused on this aspect.

Building Information was traditionally gathered and communicated via documentation like construction drawings, construction specifications, bill-of-quantities and written reports. Building Information Modeling (BIM) approach has shifted construction information from a document-based to a model-based system, where the complete building information is stored in a system of federated models that allows for collaborative working, for on-demand retrieval of information and digital data storage. BIM, with its centralized modelling environment, tries to answer to the need of intercommunication between the different project stakeholders, in contrast with the traditional approach of independently - developed systems and stakeholder requirements [1]. Nevertheless, despite the integration of BIM at the geometrical

level has become widespread, it has not been the same regarding the development of transactional workflows to deal with interoperability issues. [2] [3]

The idea of adopting an approach based on System Engineering (SE) is the core concept of this paper. SE is an interdisciplinary sector that focuses on designing and managing complex systems during their whole lifecycle. In particular, SE provides languages and standards, which allow to represent the system and his operation, concentrating especially on the links between the processes and the products. [4]

Modelling of construction processes can be achieved through workflow charts. Flowcharts to represent process flows have been introduced by the Gilbreths in 1921 [5], and the current standard is ISO 5807:1985 [6], that has been widely used in the past especially in the ICT field. Flowcharting the process has different tasks, i.e. identifying inputs and outputs, identifying the value chain, providing a visual representation of event and operation sequences, identifying bottlenecks and controls. It is a graphical representation of a process or of a system, and many diagram techniques exist. [7]

In this contribution a formalization of the inspection procedures of project management in the construction phase is proposed using Business Process Modeling and Notation (BPMN) language. BPMN is a standard for business process modelling that is based on a flowcharting technique very similar to current flowcharts, that also provides an execution optimized business process language machine-readable [8]. Particularly, the inspection of ready-mix concrete cast-in-place process is analysed as sample case study.

2. State of the art

During the early 2000s, there has been a turning point for the evolution of SE field, consisted in the transition from a document-centric approach to a model-centric approach (Fig.1).

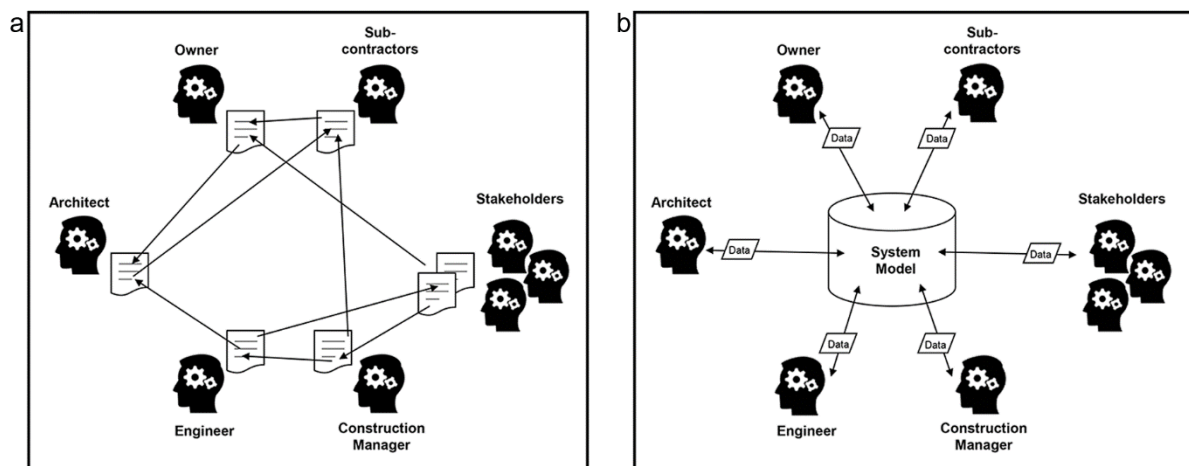


Fig. 1. (a) Document-Centric approach; (b) Model-Centric approach. [3]

However, despite the development of SE and BIM, the current practice of AEC sector is still grounded in the document-centric approach to exchange and develop building data [1]. This implicates the collection of information inside those documents, which, even if in the form of electronic files, restrict inevitably the interoperability of data exchanged between the different stakeholders. Moreover, the project data collected with this traditional method are often incomplete and inconsistent. The traditional document-centric approach describes a system literally, assuming the presence of a user between one phase and the other as a requirement, as an interpreter.

The model-centric approach responds efficiently to the lack of consistency mentioned above. In fact, many of the documents frequently required as intermediate deliverable can be generated automatically from the central model, which collects itself all the data. As Valdes et al. [8] states, "with the model-centric method, all objects depicted in different BIM or engineering tools are simply views of the underlying system model,

they are not the model itself. In a united Model Based System Engineering MBSE-BIM model, as all modelling elements are programmatically and systemically integrated, any change that is produced will be automatically propagated to the rest of the model.”.

This paper proposes to apply this Model-Based approach to the process digitalization. In this way, process models will not have documents as inputs or outputs, but they will directly condition the central model (or database). Processes are modelled in order to feed the model, in contrast with the common practice to create models first and then verify if processes are compliant with them.

3. Proposed method

Business Process Model and Notation (BPMN) is a modelling notation defined by Object Management Group (OMG) [9]. This notation bridges the gap between business process description flow charts and machine-readable business process descriptions [10]. Basically, this notation allows to map the visual description of a process into the appropriate execution language.

The advantages offered by BPMN are:

- An intuitive notation to represent business processes (flow charts);
- Standardization, which facilitates communication
- A comprehensible representation of constructs defined in software-execution language

Camunda Modeler [11] is the software utilized to realize the BPMN process diagrams for the research underlying this contribution. The structure of a Camunda BPMN is sketched in Fig. 2.

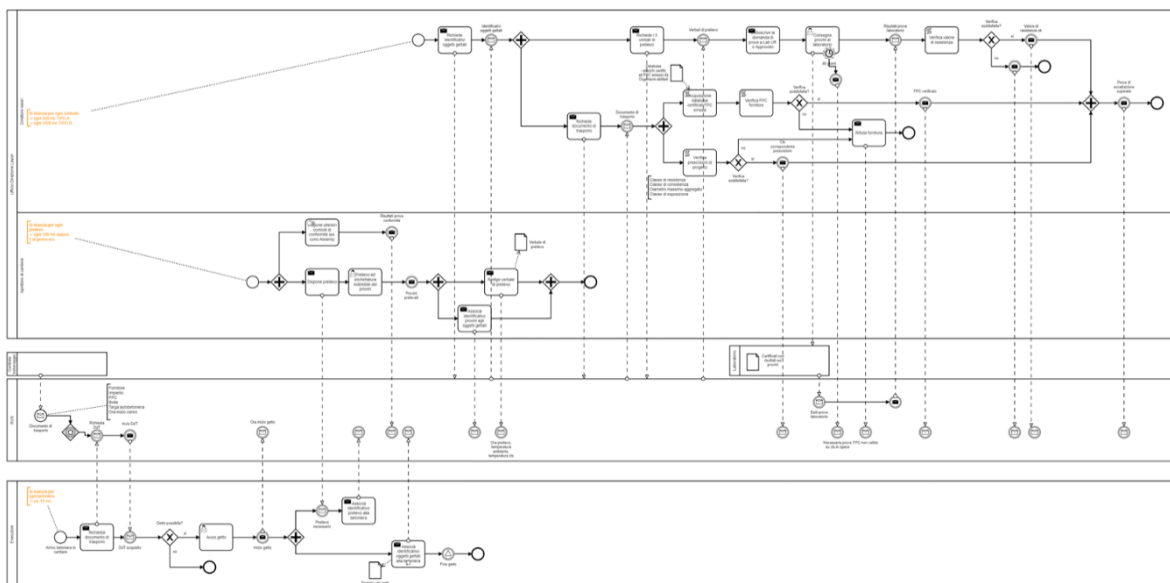


Fig. 2. Structure of a BPMN. The sample case study of inspection of ready-mix concrete cast-in-place process.

4. Sample case study

The inspection of ready-mix concrete cast-in-place process is analysed as sample case study. The cast-in-place of concrete in formworks is a very common construction sub-process, and the project supervisor must perform contract-based and regulation based quality tests. The inspection procedure is characterized by many correlated sub-processes, and implies a remarkable modelling complexity. Furthermore, the inspection of ready-mix concrete cast-in-place is a critical task for detecting a building structure quality and therefore needs to be assessed by several documents, following national standards, regulations and guidelines.

4.1. Stakeholders

BPMN diagrams describe and highlight the processes relations between the different stakeholders involved by organizing process operations and events by lanes of the chart. Each lane corresponds to one player of the process (fig. 2).

Besides the professionals designated for the inspection and the supervision processes, it was found that another lane needs to be designed to optimize the process flow. This additional lane, defined as System BUS, is intended to act as a communication channel, which will permit to the different stakeholders to interface and exchange coherent information.

This element can be conceived as a sort of database to collect data, which will inform the different parts during all the process phases.

4.2. Process instances

The inspection of ready-mix concrete cast-in-place process has been modelled as a series of nested-BPMs (Fig. 3). Indeed, basing on the Italian regulations, the procedure is characterized by instances of different levels:

- 1st level: instantiated by each inspection procedure (executed on 6 concrete sample collections)
- 2nd level: instantiated by each concrete sample collection (executed every 100 mc of concrete casting and at least one per day)
- 3rd level: instantiated by each concrete casting (executed from the moment in which the truck mixer leaves the concrete mixing plant)

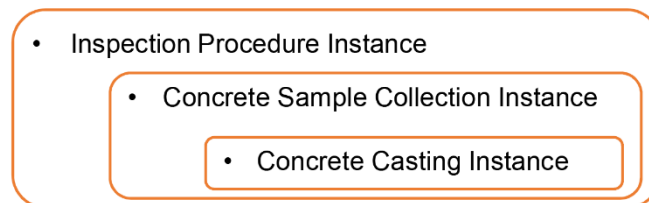


Fig. 3. Inspection of ready-mix concrete cast-in-place process: nested instances.

4.3. Model interaction

As mentioned above, the adoption of a model-centric approach is one of the key aspects of the modelling discussed in this paper. Particularly, the proposed BUS lane consists in a database aimed at collecting all the data directly from each stakeholder. In this way the information could be stored in a coherent, even automatic way. Consequently, the different stakeholders could just query the database to obtain the information.

Additionally, the proposed method does not ask the stakeholders to manipulate the federated model themselves. Otherwise, the instances are modelled in order to feed the database, which will inform the model itself.

Considering the sample case study, the following steps are fundamental for the interaction with the model:

- Concrete mixer ID – Concrete sample collection ID association
- Concrete mixer ID – Cast Object ID association
- Concrete sample collection ID – Cast Object ID association

Thanks to these bijective relations, once an inspection procedure is completed, it would be possible to automatically inform the model objects, for example by adding a Boolean field to the IFC object structure intended to record the result of the inspection (fig. 4).

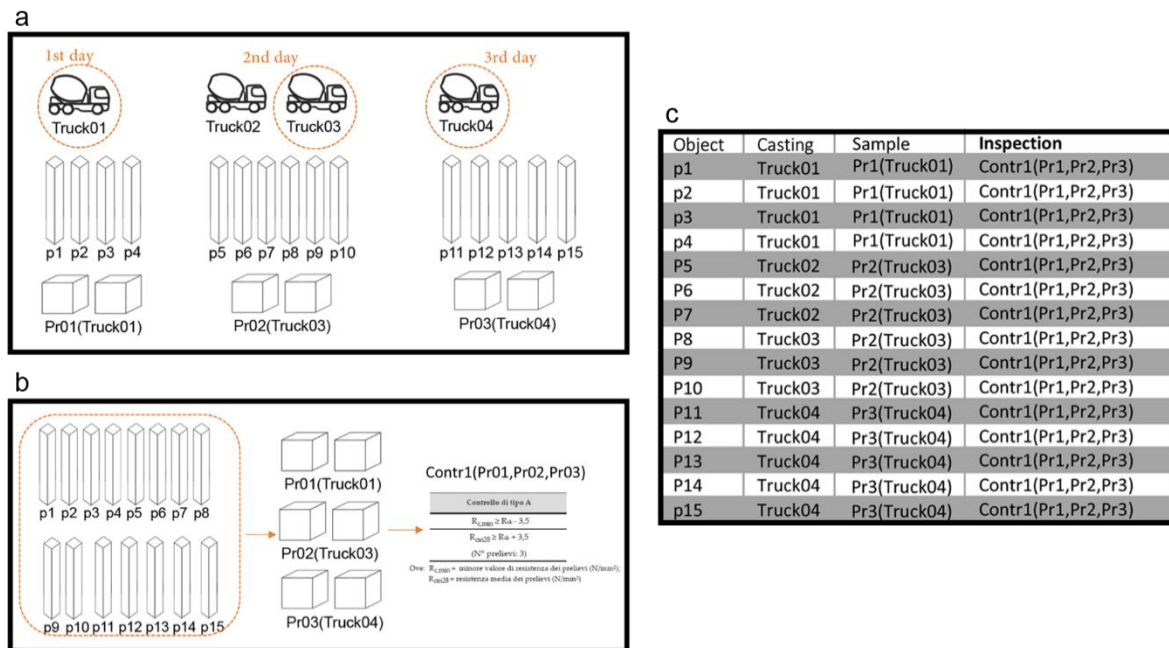


Fig. 4. Example of inspection of ready-mix concrete cast-in-place process: (a) sample collecting instance, (b) inspection procedure instance, and (c) database.

5. Results and conclusions

The research work has explored the potentiality of applying BPMN to the AEC sector with a positive output. In the same way, more BPMN based procedures concerning the management of the inspection of construction execution processes could be modelled in future studies, in order to create a collection of procedures ready to use by researchers and professionals.

The present contribution has permitted to outline the architecture of a product management system that could be the basis for the development of a tool to support the different stakeholders of building and construction projects, particularly in the execution phase. The use of BPMN – based support tools could guarantee a total traceability of the procedures, facilitating the supervision and preventing the risk of irregularities and quality non-conformities, often encountered in the concrete cast-in-place sub-processes. Also, future research work could be aimed at developing a process-oriented digital quality assessment procedure for construction products and deliverable built with BPMN.

6. Acknowledgements

Research grant PRIN 2017 “A distributed Digital collaboration framework for small and medium-sized engineering and construction enterprises”.

7. References

- [1] F. Opitz, R. Windisch, R.J. Scherer R.J. Integration of document – and model – based building information for project management support. Proceedings of the Creative Construction Conference 2014, CC2014. Procedia Engineering 85, pp. 403-411. <https://doi.org/10.1016/j.proeng.2014.10.566>
- [2] S. Azhar. Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. Leadership and management in engineering, Vol. 11, no. 3, 241-252, 2011. [https://doi.org/10.1061/\(asce\)lm.1943-5630.0000127](https://doi.org/10.1061/(asce)lm.1943-5630.0000127)
- [3] J. Laitinen. Model Based Construction Process Management. Durability of building materials and Components 8. National research council Canada, 1999.
- [4] L. Delligatti. SysML distilled: A brief guide to the systems modeling language. 2013, Addison-Wesley.
- [5] F.B. Gilbreth, L.M. Gilbreth. Process Charts. American Society of Mechanical Engineers (ASME) 1921 U.S.
- [6] International Standard Organization. ISO 5807:1985 Information Processing – Documentation symbols and conventions for data, program and system flowcharts, program network charts and system resources charts. 1985 ISO.
- [7] M.A. Fryman. Quality and process improvement. 2001, Delmar Pub. ISBN: 978-0766828728.
- [8] F. Valdes, R. Gentry, C. Eastman, S. Forrest. Applying systems modeling approaches to building construction. In ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction. Vol. 33, p. 1. 2016. IAARC Publications. <https://doi.org/10.22260/isarc2016/0102>
- [9] Object Management Group. Business Process Model and Notation (BPMN) version 2.0. 2011.
- [10] P. Y. H. Wong, J. Gibbons. A Process Semantics for BPMN. In: S. Liu, T. Maibaum, K. Araki (eds). Formal Methods and Software Engineering. ICFEM 2008. Lecture Notes in Computer Science, vol 5256. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-88194-0_22
- [11] Camunda. Camunda modeler. www.camunda.com (accessed december 2019).