Available online at www.sciencedirect.com

ScienceDirect

Procedia Economics and Finance 21 (2015) 32 – 39

Procedia Economics and Finance

www.elsevier.com/locate/procedia

8th Nordic Conference on Construction Economics and Organization

# An innovative approach to e-public tendering based on Model Checking

Angelo Luigi Camillo Ciribini[a]*, Marzia Bolpagni[b], Elisabetta Oliveri[b]

[a]*University of Brescia, Via Branze 43, 25123 Brescia, Italy*
[b]*Construction Technologies Institute-National Research Council, Via Lombardia 49, 20098 San Giuliano Milanese (MI), Italy*

**Abstract**

The public construction sector has recently started to put more effort into cost savings and improvement of efficiency. Therefore, public clients have started to promote new strategies, embracing innovative approaches such as Building Information Modelling (BIM) and e-Procurement. Tendering plays a key role for the success of the overall process; however, the selection of the best contractor is still a difficult task. The paper investigates how tendering can be integrated with Model Checking in order to control the compliance between the client's requirements and bidders' offers within a digital environment. The research shows that, although the BIM is still not widely adopted in tendering procedures, Model Checking tools are already available to support the jury, as well as bidders. Moreover, even though BIM can be implemented in several procurement procedures, it is more effective if a collaborative and integrated behaviour is promoted. Results can help increase public clients' awareness of the limits and potentials of an innovative approach and to set BIM requirements and guidelines.


Selection and/ peer-review under responsibility of Tampere University of Technology, Department of Civil Engineering

*Keywords:* Building Information Modelling (BIM); e-Procurement; Model Checking; Intelligent Information Management (IIM); public procurement; tendering.

## 1. Introduction

The public construction sector has recently started to put more effort into cost savings and improvement of efficiency. Every year, a significant part of the GDP of several European Countries is allocated to the construction industry, especially the public sector (European Parliament, 2012). Therefore, public clients have started to promote

*Angelo Luigi Camillo Ciribini
*E-mail address:* angelo.ciribini@unibs.it


Selection and/ peer-review under responsibility of Tampere University of Technology, Department of Civil Engineering
doi:10.1016/S2212-5671(15)00147-1

new strategies, embracing innovative approaches such as Building Information Modelling (BIM), which, for the first time, is included in the new European directive on public procurement (European Parliament, 2014). Indeed, the directive states that 'for public works contracts and design contests, Member States may require the use of specific electronic tools, such as of building information electronic modelling tools or similar' (European Parliament, 2014). This opportunity will hopefully be an incentive for an increasing number of EU Member States to integrate public procurement with BIM.

In Europe, the BIM implementation scenario in the public construction sector is still highly heterogeneous and only few Countries, such as UK, can rely on a well-defined government strategy. Indeed, the UK Government will mandate BIM for all centrally procured Government contracts by 2016 and it will require a smart construction industry 'that is efficient and technologically advanced' (HM Government, 2013). This means that the construction industry will increasingly compete on new bases, moving from an analog to a digital world.

The aim of this study is to investigate how a public client can improve the management of BIM-based Tendering and Awarding processes according to the EU directive on public procurement. Nowadays, the tender phase is still a crucial step for the success of a project and the selection of the most qualified bidder is a difficult task when information are unstructured and ill-defined (Mohemad et al., 2011). BIM is seldom requested and data are mostly paper-based, thus information is often inadequately transferred and misinterpreted (Eastman et al., 2011; Liu et al., 2011). For this reason, tendering usually faces design negligence, conflicts, omissions, miscalculations and inconsistencies in tender documentation such as drawings and specifications (Eastman et al., 2011). Moreover, public clients are not used to set clear requirements that can be easily checked against bidder's offer and this attitude is usually accountable for delays, claims and higher prices (Eastman et al., 2011; McAuley et al., 2012).

## 2. Methodology

First, in order to understand the current implementation of Model Checking within e-Public Tendering, a literature review was performed.

Secondly, a holistic single-case study method was adopted to evaluate challenges and possibilities in a real-world context (Yin, 2009). As the use of BIM is not widespread in public tendering, the research study was performed on a traditional project, which was translated into a BIM environment. The public tender case study was chosen based on the clarity and the good definition of the tender documentation structure.

Data were collected both from published tender documentation available to bidders and from documents used by the client to generate tender files. The published documentation was downloaded from the official website of the public tender. It contained both text files and 2D drawings in a non-editable format (.pdf). Moreover, the client provided editable files to facilitate data analysis, but the content was equivalent to already published material.

Data were analysed by translating traditional tender documentation into a BIM environment through commercial software. Indeed, a Building Information Model of the project was created based on 2D drawings and written specifications. Moreover, client's requirements were translated into machine-readable rule sets in order to control the Building Information Model.

## 3. Building Information Modelling and Model Checking

Nowadays, there is no official and univocal definition of Building Information Modelling (BIM); Eastman et al. (2011) define it as 'a verb or adjective phrase to describe tools, processes, and technologies that are facilitated by digital machine-readable documentation about a building, its performance, its planning, its construction, and later its operation'. Thus, BIM clearly deals with the entire life-cycle of a facility and it increases awareness during the decision-making process, reducing the risks historically associated with the construction sector. The result of Building Information Modelling is a Building Information Model, which is a virtual model of the project that provides not only geometrical information, but, above all, alphanumeric data. In order to effectively implement BIM, people involved in the process have to collaborate and share information through open standards, such us Industry Foundation Classes (IFC) and Construction Operations Building Information Exchange (COBie). Indeed, data must be univocal and referred to the same source, from which everybody can extract the latest version of information at any time. The BIM approach can be adopted also for the Infrastructure sector and, due to the relevance of information management, usually the acronym BIM stands for ‘Building Information Management’ and the term ‘Intelligent Information Management’ (IIM) is also used as a synonym. Therefore, the most valuable feature of BIM is ‘Information’, which can be shared and communicated to all parties involved, it is created once and may be reused many times throughout the life cycle of the facility (Furneaux et al., 2008).

Data must comply with several requirements, thus a quality assurance is essential to validate information during the process. Usually, the quality control is called ‘Model Checking’; also in this case there is no official definition, but it can be described as a process performed on a model, especially on its information (Hjelseth et al. 2010) where rules, constraints or conditions are applied with results such as ‘pass’, ‘fail’, ‘warning’ or ‘unknown’ when requested data is incomplete or missing (Eastman et al., 2009). The rigorous translation of traditional written regulation into machine-readable rules is an important step of Model Checking. An important study was conducted in 2011 by Hjelseth and Nisbet (2011), who developed the RASE methodology based on mark-up applied to the normative text. Model Checking can be performed through three consequential steps: BIM Validation, Clash Detection and Code Checking. The BIM Validation is conducted on each discipline of the project in order to control its congruence and accuracy based on geometry and alphanumeric values. Usually, during this phase there are errors due to wrong modelling (e.g. overlapping elements) or wrong design (e.g. improper position of elements). Later, Clash Detection is performed to detect possible interferences among merged models of different disciplines (e.g. Structural model vs MEP model). Thanks to Clash Detection, coordination problems can be solved in advance, out of the construction site. Finally, Code Checking allows to check the model against requirements (e.g. client’s requests, building regulations, fire safety rules). Code Checking is also called ‘Automatic Code Checking’, ‘Automated Compliance Checking’ or ‘Rule Checking’. Dimyadi and Amor (2013) have clearly reported the main initiatives for the development of Automatic Code Checking in the past years. Both government projects and strictly commercial ventures have taken place; the most significant are CORENET by the Building Construction Authority of Singapore, Solibri Model Checker (SMC) by the Finnish software house Solibri Inc., FORNAX by novaCITYNETS, EXPRESS Data Manager (EDM) by the Norwegian Jotne EDM Technology, AutoCodes by Fiatech, REScheck and COMcheck by the US Department of Energy, SMARTcodes by the US International Code Council, Bentley Design++ by Bentley Systems, Avolve ProjectDox by Avolve Software and AEC3 RASE tools by the consulting company AEC3 (Holte Consulting AS, 2014). Most of these initiatives deal with Automatic Code Checking of Information Models for releasing Building Permits, and the implementation of Model Checking in Tendering has not been further investigated. Indeed, there is little literature in this area. The most valuable case is the Norwegian architectural competition for the new National Museum in the old Oslo west railway station which took place in 2009. During the tendering, Statsbygg (2010) provided a digital platform to manage BIM-based files as well as BIM-based documentation and specifications. Moreover, Model Checking was implemented to control bids against client’s requirements (Statsbygg, 2010). However, only general checks were performed on account of the nature of the procurement process adopted. Indeed, an architectural competition does not usually contain detailed requirements (e.g. specific property values of objects).

## 4. Traditional and Innovative Procurement procedures

### *4.1. Procurement methods*

Beside traditional procurement methods, such as Design-Bid-Build (DBB), Design-Build (DB), Design-Build-Operate (DBO), Design-Build-Finance-Operate (DBFO) and Construction Management (CM) (Lahdenperä, 2008), new procurement procedures are spreading in the AEC industry in order to reduce risks and costs. Some of them are Cost Led Procurement (CLP), Integrated Project Insurance (IPI), Two Stage Open Book, Integrated Project Delivery (IPD) and Project Alliancing (PA).

CLP, IPI and Two Stage Open Book are procurement methods introduced by the UK Government in 2011 (Cabinet Office, 2012). Indeed, the UK Government states that the new procurement models ‘embrace early contractor involvement, higher levels of integration and transparency and the option of independent assurance. They also emphasise the requirement for improved client capability. The client must know what they want, what it should cost and how best to go to market to achieve their objective. These are critical factors that will drive innovation, identify waste, secure knowledge transfer and corresponding growth opportunities. When considered alongside other existing and emerging approaches to construction procurement, encompassing both buildings and economic infrastructure, the new models offer considerable potential to reduce the cost of construction to the public sector, and therefore taxpayer. Alongside reduced costs, it is likely that the models will contribute to improved programme certainty, reduced risk and greater innovation, as well as improved relationships throughout the supply chain' (Cabinet Office, 2012).

The aim of IPD is similar to previous procurement methods; indeed it 'integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimize efficiency through all phases of design, fabrication and construction' (AIA, 2007). Additionally, PA, also called 'Alliance Contracting', is a procurement process based on joint responsibility and 'no fault, no blame' culture, promoting principles of openness and trust (Petäjäniemi et al., 2012).

Despite significant differences on the management of these innovative procurement procedures, all of them encourage the early involvement of counterparties and a collaborative behaviour, trying to move from a 'everyone against everyone' approach to 'we are all in the same boat'. This is the reason why Building Information Modelling can be used to achieve these goals, as it allows for cooperation and transparency.

On the other hand, it is important to underline that Building Information Modelling can be implemented in several procurement methods, from traditional to innovative ones. For example, in Design-Bid-Build a client could include a Building Information Model in tender documentation to better understand the complexity of the project. However, in this case BIM cannot express its full potential (Salmon, 2012) because decisions were already taken without the participation of the contactor (Eastman et al., 2011).

### *4.2. Procurement platforms*

Among the numerous initiatives financed by the EU to improve the management of public works, there is the implementation of platforms for the electronic Procurement (e-Procurement) (European Commission, 2012). Nowadays, they are still not widely used, even if the EU recognises several benefits and promotes them (European Commission, 2012). Indeed, in 2010 the European Digital Agenda affirmed that social-economic advantages can be reached thanks to a digital single market based on fast and ultra-fast internet and interoperable applications (European Commission, 2010). However, there are some limitations due to lack of interoperability, of investments on networks and of digital literacy and skills (European Commission, 2010). Furthermore, fragmented digital markets, the rising cybercrime and risk of low trust in networks, insufficient research and innovation efforts and missed opportunities in addressing societal challenges, are all additional barriers (European Commission, 2010). In the light of events, the European Union has decided to promote several initiatives. One of these was the implementation of cross-border e-Procurement solutions through PEPPOL (Pan-European Public Procurement On-Line) pilot project. PEPPOL did not provide an e-Procurement platform, but rather the interoperability bridges needed to connect the already existing platforms for Member States (European Commission, 2012). At a later stage, Open e-PRIOR platform was created to allow cross-border e-Procurement through PEPPOL standards (European Commission, 2012). Moreover, the EU is working on e-Tendering and e-Prior projects to digitalized pre- and post-award phases (European Commission, 2012). The e-Procurement implementation scenario in Europe is deeply fragmented and several models of application can be detected (e.g. centralized national or regional platforms, mandatory or voluntary initiatives) (IDC, 2013).

The growing spread of BIM in public procurement will condition the traditional management of e-Procurement platforms. Advanced studies on the integration of BIM and e-Procurement are carried out in Portugal although a platform is not yet available (Grilo et al., 2011). UK, instead, is developing a digital tool, called 'Digital BIM toolkit', to collect, validate and store public data coming from Level 2 BIM standards (SBRI, 2014).

## 5. Case Study presentation and Results

An Italian case study was chosen to translate public client's tender requirements into machine-readable rule sets within the Italian research project INTEGRATE, a framework agreement between the National Research Council of Italy (CNR) and the Lombardy Region. In Italy, BIM is still not widely adopted in public tendering; thus, a trial was conducted on a traditional project. The case study could rely on a contract amount of more than 40 million euro and it followed a traditional procurement method (DB) with the lowest price selection criteria. Indeed, bidders were asked to provide shop drawings and construction works on the basis of detailed drawings. Only traditional 2D documentation (.pdf) was delivered and a Building Information Model was not required. The aim of the project was to reach the highest levels of sustainability on site as well as during the facility management, supporting a green economy. Detailed tender requirements were listed in a non-editable paper-based format and different scores were allocated to each requirement. When the study started, in June 2014, the tender phase was already closed and the jury was evaluating bids.

First, 2D drawings and written specifications were translated into a Building Information Model thanks to Autodesk Revit® 2015. Then, tender requirements were implemented into rule sets adopting Solibri Model Checker® following the RASE methodology (Hjelseth et al., 2011).

The majority of requirements were implemented in machine-readable rule sets. Indeed, it was possible to check geometrical properties of the elements (e.g. maximum/minimum thickness of layers, dimension of panels of the façade) as well as their properties (e.g. cold flexibility values of membranes, static air permeability, water tightness of curtain walls, thermal transmittance of doors, skylights, gates and curtain walls, thermal conductivity of insulation, thermal lag of wooden or concrete roofs, specific power of lightings, energy efficiency of extractors). Moreover, rule sets were developed to check the presence of objects (e.g. detectors in the garage).

The implementation of these rule sets was very effective because differences in requirements that were supposed to be identical were noticed in different tender documentations. Indeed, there were lexical conflicts (e.g. same object named and described differently) as well as numeric ones (e.g. different values ranges required for the same property). Thanks to Model Checking, instead, univocal specifications were set.

Finally, some trials were performed to simulate the jury's work. Wrong and possible values were added to the Building Information Model and, intentionally, some required fields were not filled. At a later stage, the Building Information Model was exported using an open standard (.ifc) and it was imported into Solibri Model Checker®. Model Checking enabled the automatic detection of non-compliant solutions as well as empty fields. Moreover, it was possible to export check results in an editable format (.xlsx) to compare different bids.

## 6. Discussion

As already mentioned, in the case study a Building Information Model was not required, so the client could not use rule sets to check and compare different offers. However, this approach could be implemented in future tenders and the client could include rule sets in tender documents. Thus, the jury will be able to more effectively evaluate the content of offers and bidders will have the possibility to carry out a self-evaluation before the final submission.

Thanks to this approach, the evaluation of offers is more objective because it is based on the same rules that control offers in a semi-automatic way. Thus, different bids can be compared through equal evaluation criteria. These possibilities are relevant for public procurement, that is based on values such as transparency and impartiality. Moreover, a traditional evaluation does not usually check all the elements but it follows a sampling-based approach. Model Checking, instead, allows to check the entire project and not only the types of plans or sections.

However, it is important to underline that at the moment Model Checking cannot totally replace the jury because not all the specifications can be translated into machine-readable rules (such us subjective requirements).

In addition, Model Specifications should be provided to tenders in order to correctly set the Building Information Model for Model Checking. Indeed, the same Building Information Model cannot always be used to achieve different goals and several steps are needed to prepare a 'good' Model suitable for this purpose. For example, the

Model Specification should include a list of required information for each object and modelling indication (e.g. creating separate layers of a wall or a single block).

Moreover, thanks to an e-Procurement platform information flows can be tracked and facilitated. Indeed, process is standardised and data can be inserted only once and reused many times. This approach reduces costs, time and risks; indeed, potential claims, disputes or conflicts also decrease because inconsistencies are more easily detected. Thus, honest bidding is effectively promoted and bidders are compelled to present higher quality offers, competing on their ability to carry out design and construction work. Efficient companies will be rewarded and no longer excluded. This behavior promotes a positive attitude and bidders will invest less in lawyers and more in training staff and developing methods that are more competitive. Therefore, bidders are less encouraged to present underpriced bids to win, hoping to recover their profits from later claims based on incomplete or wrong client's information. Thus, thanks to this innovative approach, the tender price will be closer to the final cost.

In closing, new procurement methods are becoming more widespread where cooperation among several parties is being promoted. However, it is not simple to create open and trustful relationships with parties having a traditional background where one party wins to the detriment of the others. In addition, laws should be updated to allow a cooperative behavior, while, actually, some new procurement methods are not in compliance with national regulations. It is not always possible to perform foreign approaches, for example, in Italy the Project Alliance cannot be implemented because the public administration must be protected from any risks that might come from design and construction works and contractors have a separate insurance policy.

## 7. Conclusions

The research shows that even though BIM can be implemented in several procurement procedures, it is more effective if a collaborative and integrated behaviour is promoted.

Moreover, although the Model Checking adoption in e-Public Tendering is still not widespread, Model Checking tools are already available to support the jury, as well as bidders.

In order to move from an analog to a digital approach and effectively monitor bids, clients should transpose contents of the briefing process into tender computable documents as machine-readable requirements. However, it is important to remark that current Model Checking cannot totally replace the jury because some specifications cannot be implemented into rule sets. Finally, new tender specifications are needed to use Model Checking.

## 8. Future work

There is little literature in this area, thus, further research studies are needed to investigate limits and possibilities of Model Checking applied to e-Procurement tendering.

Moreover, future work should investigate innovative approaches to monitor not only the content of bids, but also the information flows concerning bid submissions. In other words, the Digitalised Tendering and Awarding Process need to be focused upon the (Business) Intelligence of the Processes rather than merely upon offers.

The client should be given the possibility to distinguish between potential promises and real capabilities of the preferred bidder over the contractual time in order to reduce the risks. Indeed, the credit worthiness and the investor confidence are hugely affected by the ability of the awarding body and client organization to mitigate risks. Starting from the tender phase, clients should be able to evaluate not only the main contractor but the entire supply chain. Consequently, a common and shared platform could allow the client to be acquainted with performance and behaviour indicators of all the players involved in the process and to compare them against the requirements.

## References


AIA, 2007. Integrated Project Delivery. A Working Definition, Version 2 Updated 06.13.2007. Available at <http://aiacc.org/wp-content/uploads/2010/07/A-Working-Definition-V2-final.pdf> (last visit 26 October 2012).

Cabinet Office, 2012. Government Construction, Construction Trial projects. Available at <http://www.cabinetoffice.gov.uk/sites/default/files/resources/Trial-Projects-July-2012.pdf> (last visit 29 October 2014).

Dimyadi, J., Amor, R., 2013. Automated Building Code Compliance Checking - Where is it at? Proceedings of the 19th International CIB World Building Congress. Brisbane, Australia. Available at <http://www.academia.edu/4094621/Automated_Building_Code_Compliance_Checking_-_Where_is_it_at> (last visit 3 November 2014).

Eastman, C., Lee, J., Jeong, Y., Lee, J., 2009. Automatic rule-based checking of building designs. In: "*Automation in Construction*", 18(8), pp. 1011-1033. Available at <http://www.sciencedirect.com/science/article/pii/S0926580509001198> (last visit 3 November 2014).

Eastman, C., Teicholz, P., Sacks, R., Liston K., 2011. BIM Handbook: A guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors. 2nd ed. USA: John Wiley & Sons, Inc..

European Commission, 2010. COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS. A Digital Agenda for Europe. Brussels, 19.5.2010. COM(2010)245 final. Available at <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52010DC0245&from=IT> (last visit 26 November 2014).

European Commission, 2012. COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS. A strategy for e-procurement. Brussels, 20.4.2012. COM(2012) 179 final. Available at <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52012DC0179&from=IT> (last visit 26 November 2014).

European Parliament, 2012. Public Procurement Indicators 2011. Brussels, 5 December 2012. Available at <http://ec.europa.eu/internal_market/publicprocurement/docs/modernising_rules/public-procurement-indicators-2011_en.pdf> (last visit 13 November 2014).

European Parliament, 2014. Directive 2014/24/EU of the European Parliament and of the Council of 26 February 2014 on public procurement and repealing Directive 2004/18/EC. Available at <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L:2014:094:FULL&from=RO> (last visit 20 November 2014).

Furneaux, C., Kivvits, R., 2008. BIM – Implications for Government. CRC for Construction Innovation, Brisbane. Available at <http://eprints.qut.edu.au/26997/1/26997.pdf> (last visit 12 November 2014).

Grilo, A., Jardim-Goncalves, R., 2011. Challenging electronic procurement in AEC sector: A BIM-based integrated perspective. In: "*Automation in Construction*", 20(2), pp. 107-114. Available at <http://www.sciencedirect.com/science/article/pii/S0926580510001378> (last visit 8 November 2014).

Hjelseth, E., Nisbet, N., 2010. Overview of concepts for model checking, CIB W78 2010, 27th International Conference – Applications of IT in the AEC Industry. Cairo, 16-18 November 2010. Available at <http://www.academia.edu/873824/Overview_of_concepts_for_model_checking> (last visit 8 November 2014).

Hjelseth, E., Nisbet, N., 2011. Capturing normative constraints by use of the semantic mark-up rase methodology, CIB W78-W102 2011 International Conference – Applications of IT in the AEC Industry, Sophia Antipolis, 26-28 October 2011. Available at <http://2011-cibw078-w102.cstb.fr/papers/Paper-45.pdf> (last visit 5 November 2014).

HM Government, 2013. Construction 2015. Industrial Strategy: government and industry in partnership. Available at <https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/210099/bis-13-955-construction-2025-industrial-strategy.pdf> (last visit 15 November 2014).

Holte Consulting AS, 2014. Status survey of solutions and issues relevant to the development of ByggNett. Oslo. Online. Available at <http://www.dibk.no/globalassets/byggnett/byggnett_rapporter/byggnett-status-survey.pdf> (last visit 3 November 2014).

IDC, 2013. Study on e-Procurement Measurement and Benchmarking MARKT 2011/097/C. Lot 1 – Public Procurement Performance Indicators. D2 e-Procurement State of Play Report. Available at <http://ec.europa.eu/internal_market/publicprocurement/docs/eprocurement/studies/130601_e-procurement-state-of-play_en.pdf> (last visit 15 November 2014).

Lahdenperä, P., 2008. Financial analysis of project delivery systems. Road projects' operational performance data revisited. Helsinki: VTT Research Notes 2445. VTT. Available at <http://www.vtt.fi/inf/pdf/tiedotteet/2008/T2445.pdf> (last visit 26 October 2014).

Liu, T. and Hsieh, T., 2011. BIM-based Government Procurement System- The Likely Development in Taiwan, IAARC Publications, Proceedings of the 28th ISARC. Seoul, Korea 29 June - 2 July 2011. pp. 758-763. Available at <http://www.iaarc.org/publications/fulltext/S22-6.pdf> (last visit 12 November 2014).

McAuley, B., Hore, A., West, R., Kehily, D., 2012. Addressing the Need to Reform Construction Public Procurement in Ireland through the Implementation of Building Information Modelling, Proceedings of the 1st ASEA-SEC International Conference on Research, Development and Practice in Structural Engineering and Construction. Perth Western Australia, 28 November - 2 December 2012. Available at <http://arrow.dit.ie/cgi/viewcontent.cgi?article=1035&context=beschreccon> (last visit 17 November 2014).

Mohemad, R., Hamdan, A. R., Othman, Z. A., Noor, N. M. M., 2011. Modelling Ontology for Supporting Construction Tender Evaluation Process, 2011 International Conference on Semantic Technology and Information Retrieval, Putrajaya, Malaysia, 28-29 June 2011, pp. 285-288. Available at <http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5995803> (last visit 2 November 2014).

Petäjäniemi, P., Lahdenperä, P., 2012. Alliance contracting – one for all and all for one (Finland), European Infrastructure Procurement Symposium, Conflict between Institutional Frameworks and Managerial Project Practice. Copenhagen, Denmark, 8 May 2012, pp. 12-15. Available at <http://www.netlipse.eu/media/53848/EIPS.pdf> (last visit 26 November 2014).

Salmon, J. L., 2012. Wicked IPD Procurement Programs: IPD & BIM Solutions Unleashed. Autodesk User Group International (AUGI). 5 June 2012. Available at <http://www.augi.com/library/wicked-ipd-procurement-programs-ipd-bim-solutions-unleashed> (last visit 25 November 2014).

SBRI, 2014. A digital tool for building information modelling. Website <https://sbri.innovateuk.org/competition-display-page/-/asset_publisher/E809e7RZ5ZTz/content/a-digital-tool-for-building-information-modelling/1524978?p_p_auth=3KwdjD0Z> (last visit 10 November 2014).

Statsbygg, 2010. National Museum at Vestbanen - Competition programme.

Yin, R., 2009. Case Study Research: Design and Methods. 4th Ed Thousand Oaks: SAGE.