Stakeholder competency in evaluating the environmental impacts of infrastructure projects using BIM

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Stakeholder competency in evaluating the environmental impacts of infrastructure projects using BIM

Abstract

Purpose: BIM literature reveals a growing interest in the development of a competency-based approach to manage the long-term goals of BIM implementation in infrastructure projects. One long-term goal is mitigation of environmental impacts. It is proposed that by integrating environmental systems within the BIM model the technology can act as an early warning indicator to assist stakeholders identify and evaluate environmental impacts before they become critical to delivery. The purpose of this paper is to (1) assess the effectiveness of BIM in identifying environmental impacts (EI’s) on infrastructure projects and (2) investigate the correlation between stakeholder competency and evaluation of EI’s.

Design/Methodology: 71 informants that have relevant experience in infrastructure projects were investigated using a 2-stage methodology comprising (a) a questionnaire to determine the BIM indicators used to identify EI’s and the stakeholder competencies required to assess and evaluate EI’s and (b) Behavioral Event Interviews (BEI) to validate the competencies identified.

Findings: The findings showed that risk assessments are the most critical early warning indicator in identifying EI’s specifically when implemented within the cost management process. The key stakeholder competencies required to successfully evaluate EI’s were identified as Project Organisation and Building Equitable Relationships. BEI’s showed these stakeholders to also have high levels of behavioural and contextual awareness. This suggests that, contrary to perceived perception, successful management of EI’s is more dependent on collaborative working than the acquisition of technical skills. Findings also indicated that Croatian BIM stakeholders are less experienced than UK BIM stakeholders in project implementation and delivery and that less experienced BIM stakeholders require more emphasis on technical knowledge whilst the importance of ‘soft skills’ is more apparent in experienced stakeholders, notably amongst the UK participants.

Orginality/Value: The implications for infrastructure projects show that effective management of EI’s can be achieved through alignment of the BIM model with the cost management plan implemented by stakeholders working collaboratively. Hence
the strategic focus for AEC companies working on infrastructure projects should be the development of staff interpersonal competencies rather than solely on project goals and/or an over-emphasis on technical skills.

Keywords: BIM, Infrastructure projects, Environmental impact, Competency, Risk assessment, PMBoK

Introduction

Building Information Modelling (BIM) is a digital representation of a project's physical and functional characteristics. At its simplest level, BIM provides a common environment for all information defining a building, facility or asset together with its common part activities (NBS, 2015). A key benefit of BIM is therefore the accurate representation of the parts of a building in an integrated data environment (CRC Construction Innovation, 2007). The potential capability of BIM in information delivery has been embraced by the construction industry at many levels including design analysis, estimating and cost planning, acoustic and thermal performance assessment, scheduling and simulation, checking designs against codes and regulations and facilities maintenance (Steel et al., 2012). However, there remains an area which has received scant investigation notably the capacity of BIM for delivering information on environmental impacts.

Watson (2010) proposed that as a disruptive technology BIM presents opportunities for addressing the emerging challenges of sustainability, low carbon and more resilient infrastructure. Furthermore, government reports indicate that industry expectation for Green BIM practice is increasing (McGraw Hill, 2010). More recently Bryde et al., (2013) argued that the next logical step in researching BIM would be to extend its criteria to include environmental management namely the practices to ensure that projects adhere to environmental laws and regulations. However, the robustness and usefulness of automated information is entirely dependent upon the quality and accuracy of information at the point of upload as well as the originators understanding of what the information will be used for. This is one of the reasons why it is proposed that BIM's success in manipulating information needs to be closely aligned with the competences of the stakeholders who operate the BIM
model. This paper seeks to investigate to what extent BIM is effective in identifying environmental impacts on infrastructure projects and how this aligns with the competence of the project stakeholders to evaluate those impacts.

**Context**

In this study, infrastructure projects refers to both economic projects (toll-roads, airport, bridges, tunnels, rail networks, seaports, gas distribution networks utilities, electricity and renewable energy production and distribution, water treatment and distribution facilities) as well as social infrastructure projects (schools, health care facilities, prisons and intra-city railroads). A report on the Croatian construction industry published in July 2015 provided detailed market analysis, information and insights into the industry post-recession. The report identified that the industry has remained weak following the global and European financial crises. In real gross value-added terms, the industry in 2013 was 57.0% its size in 2008. Despite this, it is considered that the rate of decline has slowed and the industry is set for a period of recovery (DZS, 2016). Similarly the UK construction industry’s output rose in 2014 by 9.5% in real terms, the biggest increase since 1990 (Timetric, 2014). Additionally output from the construction sector in the UK is at around the 2005 level, in real terms, below output in the 2006 to 2008 period.

In the UK, infrastructure orders rose in 2009 and 2010 and have since remained at roughly the same level generating much of the stability being evidenced currently in the UK construction sector (BIS, 2015). In Croatia a series of infrastructure projects have recently been launched such as the investment of HRK2.5 billion (US$436.5 million) in the construction and refurbishment of the roads network and HRK127.0 million (US$22.2 million) for the combined heat and power (CHP) plant Sisak - Block C project (Timetric, 2014). Similarly to the UK, the Croatia government has recognized the importance of investment in infrastructure to support economic development following global recession. Subsequently there has been a significant investment in both countries in infrastructure projects and this drive may also trigger an increase in environmental impacts occurring in infrastructure projects in both countries. However, in conjunction, both countries have recently established deadlines by which large construction projects are to be fully BIM compliant. By January 2016, 28 European Union member states are required to specify, promote,
or mandate the use of BIM in infrastructure projects financed by EU public funds. Whilst the United Kingdom already requires BIM for public works, Croatia is in the phase of intensive preparation prior to implementation. This study was prompted as a comparative analysis of the alignment of capabilities of both jurisdictions by 2016.

Literature review

It is evidenced that the sustained use of natural resources in the construction industry has adverse impacts on the environment; depleting natural resources, polluting the environment and endangering biodiversity. This is more acutely evidenced in the infrastructure sector which has associated impacts for societal development and culture (Couto and Mendonça, 2011).

Environmental impacts

Environmental impacts of infrastructure projects have consequences for land, water, vegetation, air, noise and vibration. Whilst many impacts are a natural consequence of the decision to construct, some impacts have adverse implications for both the environment and the ongoing project. Impacts are mostly recognised as technical issues that have inputs; energy, soil movement, recycling, and outputs; emissions including CO₂, dusts, noise, ecosystem damage (Couto and Mendonça, 2011). Adverse impacts may have consequences for many years in some projects, and permanently for others (Hayes, 2014). The environmental impacts of an infrastructure project during its useful life can be represented through ‘inputs’ and ‘outputs’. The ‘inputs’ include energy and materials whereas the ‘outputs’ include pollution and waste (Figure 1).

This paper is concerned with the outputs implicit at the ‘Site Preparation’ and ‘Construction’ stage as identified in Figure 1. Using this model the key outputs marked in bold are those corresponding to the phases’ under investigation namely air pollution, groundwater issues, waste issues, land mass issues, chemical issues, biological issues and energy issues. Non-conformances relate to situations where
these outputs exceed regulatory benchmarks and become critical in terms of environmental management and project delivery. Environmental impacts (EI) are defined as a change to the environment that is caused either partly or entirely by one or more of the given environmental issues exceeding regulatory benchmarks, as established in the Environmental Management Systems (EMS), and which may have a potentially adverse effect on the delivery of the ongoing project.

Environmental Management Systems

The environmental management of infrastructure projects is focused around the international standard namely ISO14001. This standard is applied on site through the Environmental Management Plan (EMP); a site-specific document developed to ensure that all necessary measures are identified and implemented in order to protect the environment and comply with environmental legislation. A site-specific EMP must be prepared for all infrastructure projects in the UK and Croatia. As well as the EMP there are also a plethora of project-specific environmental management tools that support the EMP and govern work on site. See Table 1.

Table 1 Commonly used site-based environmental management tools

These are often flexible documents that are frequently revised in accordance with international regulatory changes and bespoke site conditions. This flexibility means that stakeholders have to continuously re-interpret the text which gives these tools a symbolic role in projects. The tools are largely administrated by specifically appointed stakeholders such as the SHEQ Manager (Safety, Health, Environment, Quality). By concentrating environmental expertise in a few appointed stakeholders much reliance is placed on the internal distribution of EMS requirements to guide project stakeholders to act pro-environmentally. This discourse is governed by a compliance-driven push communication process whilst the daily acts of implementing environmental directives in the project are rife with uncertainty requiring rapid adhoc decisions that often rely on pervious knowledge, experience and affect (Gluch and Raisanen, 2012). Subsequently, apart from this engrained approach there are limited vehicles for communicating quickly across the project team.
It is proposed that BIM is a possible enabler of transformation in breaking this ‘isolation’ between existing project practice and emerging best practice in environmental management. By integrating environmental tools within the BIM model, the technology can act as an early warning indicator to assist project stakeholders to identify and evaluate environmental impacts early in the project process before they become critical to delivery. This approach is not novel and has been previously addressed in part by Alwan et al., (2015) in their alignment of 3D simulation transfer processes to streamline the environmental assessment of buildings that have been designed digitally using BIM. Their investigation indicated that environmental assessment, namely LEED evaluation, was feasible within the BIM process and highlighted the benefits of streamlined data software exchange through applying data interoperability of a building design, thereby negating the requirement to rely solely on 2-D conventional documentation for environmental assessments.

Aligning Environmental Management with BIM

In this study the Environmental Management Plan (EMP) and the BIM model is aligned through the five phases of the PMBoK process to provide a framework by which to track the identification and evaluation of environmental impacts during a project. The Project Management Body of Knowledge (PMBoK, 2013) is an established framework for project management and is based around 8 core processes of project management namely:

1. Scope Management
2. Cost Management
3. Time Management
4. Quality Management
5. Communication Management
6. Personnel Management
7. Procurement Management
8. Risk Management

In this study environmental Impacts (EI) will be identified and managed through one or more of these core processes at different stages in the project lifecycle. It is therefore important to determine in which process/es EI’s are identified and
evaluated, as this will determine which core project management processes are most critical in the management of EI's during delivery of an infrastructure project.

Environmental Management and Stakeholders

Scant articles address environmental management issues in projects (Kwak and Anbari, 2009; Crawford et al., 2006; Themistocleous and Waerne, 2000). Those which do, fail to address social and stakeholder aspects, instead advocating traditional project monitoring or controlling tools as solutions to manage environmental issues. Gluch and Raisanen (2012) propose that new and emergent environmental management practices and routines are inherently contradictory to established culture within projects. Furthermore, project practices appear to amplify the contradictions between environmental management and project management rather than mitigate them. As a result team members strive toward different goals. For this reason, environmental management requires a degree of flexibility to allow reiterations in the project process to facilitate unexpected changes and variations in context. Lampel (2001) argues that flexibility in projects depends on the acquisition and development of specific competencies amongst the stakeholders to support the process (Dainty et al., 2005; Edum-Fotwe and McCaffer, 2000). A competency-based approach is one in which successful evaluation of the environmental impact is incumbent on the right individual competencies being in place at the appropriate stage of the project process (Murphy et al., 2015). Therefore, it is imperative that a study investigating successful environmental management is aligned with the competencies of stakeholders.

Evaluating Environmental Impacts

A primary objective in environmental management is to avoid or reduce potential adverse impacts. For those impacts that cannot be avoided or reduced it is necessary to find measures that optimize the realization of the infrastructure project. Such measures are largely identified using risk analysis techniques. Hayes (2014) proposed that there are three risk management stages for addressing environmental impacts in infrastructure projects namely; (1) determining critical environmental impacts (cEI), (2) analyzing cEI options and (3) decision making including avoidance and mitigation (see Fig. 2).
Hayes (2014) suggested that whilst avoidance and mitigation are important, impacts (or ‘critical’ impacts) will continue to be the primary concern for developers who may not be able to avoid adverse consequences such as filling wetlands, disrupting wildlife corridors or other sensitive habitat, or negatively affecting areas in and around parks, wildlife refuges, recreation areas, and other specialist areas thus avoidance may be the only realistic option.

Fig. 2  Risk mitigation of critical environmental impacts (after; Hayes, 2014)

Section 1508.20 in the Council on Environmental Quality’s NEPA regulations outlines the mitigation measures that infrastructure projects should be applying when evaluating environmental impacts (NEPA, 2015) namely;
(a) Avoiding the impact by not taking a certain action or parts of an action
(b) Minimizing impacts by limiting the degree or magnitude of the action and its implementation
(c) Rectifying the impact by repairing, rehabilitating, or restoring the affected environment
(d) Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action
(e) Compensating for the impact by replacing or providing substitute resources or environments.

To adequately integrate such risk mitigation measures into the BIM model it is necessary to identify the indicators which the BIM model employs to flag up potential EI’s, at which stage in the project process these are activated and who evaluates the outputs.

Project Stakeholders

Project stakeholders are the principal players in the implementation of a collaborative technology such as BIM (Manseau and Shields, 2005). They are also the participants whose competency can adversely impact the BIM implementation process (Anderson and Manseau, 1999; Moore and Dainty, 2001; Blayse and Manley, 2004; Dubois and Gadde, 2002; Miozzo and Dewick, 2002). Poor decision-making by stakeholders is usually largely non-intentional. In many cases the role of
the stakeholder may form part of a series of passive events but their activity is often
the key trigger that can cause an impact to occur (Miozzo and Dewick, 2002). The
project stakeholders implicit in this study are those participants who have direct
involvement in the inputs, operation and manipulation of the BIM model from
inception through to delivery of the project and span across consultants, contractors
and client bodies.

The current body of BIM literature reveals scant investigation into the competency of
project stakeholders to evaluate the risk of environmental impacts. Using an Activity
Theory approach Gluch and Raisanen (2012) identified that environmental
boundaries in projects are mentally restricted in a stakeholder’s perception to the
finite time span of the project rather than the possible implications beyond project
closure. In effect they identified that environmental issues in projects are regarded by
stakeholders as ‘momentary’ in that they occur during the project lifespan and,
consequently, when the project is completed it is perceived so too are the problems. Succar
(2013) proposed that to enable project stakeholders to effectively implement BIM, it
is important to identify the BIM competencies and use this to generate process
workflows such as environmental management. Murphy et al., (2015) developed a
risk assessment methodology for mapping stakeholder competency with the BIM
implementation process. Ding determined that significant factors for BIM adoption
are architects’ motivation, technical defects, while management support and
knowledge structure appear to be less important (Ding et al., 2015). However, more
recently it was also identified that construction companies’ decisions for adopting
and implementing a construction technology, such as BIM, usually takes place at the
organisational level. Thus, maximizing the understanding of this decision-making
process requires a transition from an individual level perspective to an organisational
level (Sepasgozar et al, 2016).

Competency in Construction

Construction projects are ostensibly about people and the influence they bring to
bear on the construction process (Seymour et al., 1997). There is a growing
awareness that the technical management of project processes alone is not enough
to generate successful project outcomes, rather the competences of those leading
and implementing the processes are also important (Nahod, 2013). Construction
management research has established linkages between the skills and competency of the project manager and project success (Edum-Fotwe and McCaffer, 2000; Dainty et al., 2005, Nahod, 2013). In collaboration with the project manager, large, infrastructure projects operate using teams working collaboratively towards a successful project outcome. The right competency exhibited by individual team members will support the core processes within the project whilst establishing more effective competencies within the firms from which the team members operate (Egub, 1997; Moore et al., 2002; Succar, 2013; Murphy, 2014). Competency provides a “starting point to bridge individual and organisational levels of analysis” (Salvato and Rerup, 2011-pp 474). To establish a project's performance, it is therefore important to establish the competency of the individuals who form teams.

A number of competency frameworks for project management have been established by professional or trade organisations to provide a basis of reference for members. The International Project Management Association (IPMA) published the first standard for project management competence in 1997, the International Competence Baseline (ICB), after which an improved version was issued in 2006, with increased emphasis on contextual and behavioural competences (IPMA, 2006). Similarly the Project Management Institute’s (PMI) definition of personal competency, adopted from Crawford (1997), is 'the behaviours, motives, traits, attitudes, and self-concepts that enable a person to successfully manage a project' (PMBOK, 2013). Recent studies have sought to explore the relationship between stakeholder competence and BIM implementation. A study by Brewer and Gajendran revealed links between the attitude formation of team members and their subsequent ICT decision-making behaviour (Brewer and Gajendran, 2011). It found that specific behaviours collectively resulted in the (1) formation of a differentiated project team culture, (2) sub-optimal ICT usage, and (3) minimal utilisation of BIM capabilities. Succar (2013) sought to classify individual BIM competencies to generate process workflows to facilitate BIM improvements. A later study by Murphy (2014) classified BIM competencies into 'Operational' and 'Organizational' competency. Existing literature is aligned to produce a set of BIM-related competencies which are investigated in this study (Table 2).

Table 2  BIM-related Competency
In summarizing the literature there are two key strands of investigation and interrelationships:

- The potential to align existing environmental assessment tools and systems (Environmental Management Plan) within the BIM model to generate early warnings (indicators) of potential environmental impacts on project delivery.
- The competency of project stakeholders, directly involved in the input, implementation and manipulation of the BIM model to intercept and mitigate EI’s.

**Methodology**

The methodology was designed in two stages. The first stage was to determine the indicators used by BIM to identify EI’s and was carried out using a questionnaire survey to participants in UK and Croatia. The second stage was designed to evaluate EI’s and validate the competencies of project stakeholders, identified in Stage 1, using Behavioral Event Interviews (BEI).

**STAGE 1: IDENTIFYING ENVIRONMENTAL IMPACTS USING BIM**

In the study self-administered questionnaires were employed as the primary data collection mode. This method provided the geographical flexibly required across the two key population groups i.e.: UK and Croatia. The survey was developed to extract the following:

a) Determine through which indicator/s an EI is identified through a BIM model.

b) Determine through which indicator/s an appropriate mitigation response is enabled by the project stakeholder and adjust the BIM model accordingly.

c) Determine through which indicator/s the above response is monitored and controlled by the project stakeholder.

d) Determine the personal competencies employed by project stakeholders in evaluating EI’s.

A pilot study was carried out to ensure clarity and relevance of the questionnaire. This was conducted with the feedback of a consultant and contractor BIM Manager.
Based on the feedback received, minor adjustments were made to the questionnaire to remove any ambiguities. A total of 300 questionnaires were issued electronically to participants 50% to Croatia and 50% to UK participants.

The target group consisted of: Contractors, Consultants, Clients and specialist suppliers/subcontractors all of whom have had direct involvement in the input, implementation and manipulation of the BIM model in an infrastructure project. Initial survey questions classified respondents, namely: employment type (public, private, own business or other): role (see Table 3): experience (0-1, 1-5, 5-10 years respectively): value of involved infrastructure project.

Of the 300 questionnaires issued a total of 71 forms were returned and considered usable. Due to the relatively recent growth of BIM in projects participants experience of participants were categorized as having; less than 1 years’ experience (24%), less than five years’ experience (32%) or between 5 and 10 years’ experience (44%). There was almost double a response rate for those respondents who had 5 to 10 years’ experience, in comparison to those less than 1 year experienced informants. This may indicate the increasing prevalence of BIM in infrastructure projects across both countries.

Nearly a quarter of the respondents were project managers working for a contracting organization (see Table 3).

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The average value of infrastructure projects which participants were involved was approximately 11 billion €. In terms of current employment:

- 24% of respondents were sole business owners
- 30% were Public sector employees
- 42% were Private sector employees

In terms of responses received from both countries, 45% of respondents were from Croatia and 55% from the UK.
RESULTS: Analysis of the responses

Data was collected from the questionnaires and a Pareto analysis was undertaken to identify the BIM indicator/s which predominately identify environmental impacts on projects. Pareto Analysis is a statistical technique used in identification of those few factors that produce significant overall effect against those numerous factors which may have proportionately minimal significant effect. Also known as the 80/20 rule, the principle is that by identifying the critical 20% of implicit factors in a problem one can identify 80% of the impact on the problem. See Table 4.

Table 4 Pareto Analysis data

A Pareto chart was developed from the resultant data (See Figure 3). Risk Assessments were evidenced as the primary BIM indicator used in identifying EI’s. Risk assessments accounted for 20% of the critical factors implicit in the identification of EI’s whilst the culmination of the remaining factors accounted for the remaining 80%. The least significant indicator was carbon emissions monitoring. This may indicate relatively low usage of BIM later in infrastructure projects namely for maintenance of projects and is worthy of further research.

Fig.3 Pareto Chart of BIM indicators

The findings also identified that the cost management process is the most significant PMBoK process that facilitates the assessment and analysis of EI’s in projects (see Figure 4). The relationship between cost management and risk assessments are well established in literature (Akintoye and MacLeod, 1997; Baloi and Price, 2003; Haimes, 2015). Significantly the application of the BIM model as an enabling tool does not alter this relationship. However, research has evidenced that, as project complexity increases, risk assessment tools have more limited use and the project is increasingly dependent on the competency of stakeholders to evaluate the reality of the risk (Williams et al., 2012).

Fig.4 PMBoK processes used to manage EI risk
A Chi-square test was carried out to evaluate the types of EI’s which were identified in the study. The test did not evidence any statistical significance between the range of EI’s investigated (means are 2.06 - 2.65; min:0, max:10) nor highlight any one specific EI which was identified as having a greater potential for being observed using BIM indicators (See Table 5). Energy issues were identified as the most difficult to analyse using BIM. This may be a reflection of the primacy of energy issues post-construction. It may also be a reflection of deficiencies in stakeholder competency.

Table 5 Potential for BIM in identifying EI’s on infrastructure projects

Participants were required to rank the importance of personal competencies for evaluating EI’s. There was minimal statistical significance evidenced across the resultant data set albeit Project Organisation and Building Equitable Relationships were identified as having a marginally increased impact on successful evaluation of EI’s. It was therefore proposed to undertake a second stage of investigation namely Behavioural Event Interviews (BEI) to further analyse Stage 1 results.

Stage 2: EVALUATION COMPETENCY using Behavioural Event Interviews

McClelland’s (1973) McBer method to coding competencies from Behavioral Event Interviews has been previously applied to identify competency within construction projects (Dainty et al., 2005; Murphy et al., 2015). Behavioural Event Interviews (BEI) is a structured interview format used to collect information about an individual’s past behaviour. BEI is based on the premise that past behaviour is the best predictor for future behaviour. BEI uses open ended questions to uncover and analyse a candidate’s behaviour to specific scenarios and is conducted face-to-face. The resultant data helps identify competencies that predict superior or effective performance. The BEI’s were structured under 3 key sections namely; (1) Technical competency, (2) Contextual competency and (3) Behavioural competency, which were derived from the IPMA Competence Baseline Version 3 (IPMA, 2006) and applied as follows:
Section 1. Technical competency was investigated using Self Rating tool of knowledge and experience (scores 1-10 for each)

Section 2. Contextual competency was investigated using critical event scenarios in which participants were required to consider the most appropriate decision they took in a given context.

Section 3. Behavioural competency was investigated based on their responses to a series of questions on ethics, value appreciation and reliability.

Interviews were carried out using the STAR Technique (Situation-Task-Action-Result) which provides a basic framework for understanding behaviour in past situations (Spencer and Spencer, 1993). See Figure 5.

Fig 5: (Situation-Task-Action-Result) The STAR Technique after; Spencer and Spencer, 1993

The STAR technique was employed in a 5 stage process namely:

Step 1. A brief explanation of the process is given and formal permission is requested to tape the interview.

Step 2. The participant is asked to describe their role, using key tasks, responsibilities and outputs in his/her current role so as to identify possible critical incidents.

Step 3. Participants are asked to describe these critical incidents employing the STAR technique.

Step 4. Participants are asked to describe the characteristics, knowledge, skills or abilities they consider were required to address those critical incidents.

Step 5. The final transcript of the interview is provided to the participant to verify it is an accurate record of the interview.

Self-rating Index

Amongst the interview participants it was recognised that the degree of expertise of the participants could affect the reliability of the results. A means to addressing the impact of variations in expert opinion was through the use of a self-rating mechanism (Dalkey et al., 1970). Self-rating is a means of inviting participants to rate their own
expertise, or competence, in an area under discussion. Self-rating usually takes the form of a Likert-style index where expertise is scaled from 1-5 indicating scope of expertise as determined by core criteria from the literature (Dalkey et al., 1970). The use of the 5-point Likert scale for self-rating in this study is consistent with work by Shields (1987). It was considered important that the self-rating score was taken after the participant’s response to the question to ensure focus on the questions rather than the participant’s competency. Additionally, a Pilot survey was carried out with an independent panel of 3 experts (1 academic and 2 practitioners) to capture their feedback to the protocol being employed. On the basis of the Pilot survey outcomes a number of refinements were made to the procedures to inform the ongoing investigation.

The Behavioral Event Interviews (BEI) were undertaken with 10 participants from the previous Stage 1 questionnaire and 6 experts in the field. There were 9 BEI participants from the UK and 7 from Croatia. The interviews lasted between one to two hours and were recorded and transcribed in full. Interviewees were confronted with preliminary results from the questionnaire and were given the opportunity to react and provide feedback. The transcribed material was coded using procedures recommended by Strass and Corbin (1998) and Miles and Hubermann (1984). The interview excerpts were employed by structuring them into categories. Key words, phrases and concepts were extracted, compared and contrasted and then triangulated with the findings from cross analysis of other BEI’s.

Analysis of the responses and discussion
In assessing the Behavioural Event Interviews contextual and behavioural competencies showed an increased impact on decision making. It was apparent that there was only less pronounced impact of behavioural competencies (statistic mean: 0,66) over knowledge competency (statistic mean: 0,62) (See Table 6).

Table 6  Comparison of stakeholder competency in evaluating EI’s using BIM
In correlating the BEI data with Stage 2 data it was increasing clear that it was the ‘softer’, people-focused competencies that had a significantly increased impact in evaluating EI’s over technical or knowledge-based competencies. A Matrix of Interdependence was formulated, subject to factor analysis, to obtain groupings of data arrays (See Table 7). It was evidenced that behavioural and experience-based competencies preceded knowledge and contextual competencies for managing the EI’s in infrastructure projects using BIM.

Table 7  Factor analysis of competency for managing EI’s in infrastructure projects

Regarding the participating countries, there was no significant difference between Croatian and UK respondents; dispersion of results was slightly higher in Croatian respondents (about 15% in total), but relatively small number of respondents doesn’t facilitate further conclusions.

Understanding the differences between environmental issues on BIM and non-BIM projects is still a challenge in Croatia. There was concern in selecting Croatian experts for this study as Croatian BIM stakeholders are less experienced than UK BIM stakeholders in project implementation and delivery. Less experienced BIM stakeholders require more emphasis on technical knowledge whilst the importance of ‘soft skills’ is more apparent in experienced stakeholders, notably amongst the UK respondents. In general the study sample was too small to prove a direct correlation between BIM experience and environmental impact evaluation however it is determined that the general assumption is that BIM experience has a positive impact on environmental impact evaluation. It was also determined that less experienced respondents don’t perceive as broad a perspective of BIM as more experienced respondents. The subtext would still indicate that understanding the differences between environmental issues on BIM and non-BIM projects is still a challenge in Croatia. It is proposed that this could be the objective of further research.

Conclusions
Findings showed that risk assessments were the most critical indicator through which BIM identifies EI’s in infrastructure projects in both sample countries. More specifically, risk assessments within the Cost Management process of the PMBoK framework. Specifically the implementation of the Cost Management Plan facilitates the assessment of risk in infrastructure projects and risk and cost management are the core facilitators of effective detection of EI’s. The use of BIM as an enabling tool in this study does not alter this relationship.

BIM presents greater potential for facilitating the analysis of chemical and biological issues due to the complex nature of the calculations implicit in these issues. However energy issues were identified as potentially the most difficult EI for BIM to analyse which may be a reflection of the primacy of energy issues in the operational phase as opposed to during construction. This also supports earlier results by Motawa and Carter (Motawa and Carter, 2013).

The key competencies required to evaluate the information received from the BIM model were identified as Project Organisation (Values the diversity of the members of the project team and their cultures and demonstrates an understanding of the Project vision) and Building Equitable Relationships (Builds and maintains equitable relationships amongst team members). The subsequent Behavioural Event Interviews (BEI) identified that there was significantly increased evidence of behavioural and contextual competencies applied by stakeholders evaluating EI’s as opposed to technical competency. Specifically the extent of contextual competencies used increased proportionately to the level of impact of the EI in the external environmental of the project which stimulated the conditions on decision making by stakeholders. These results confirmed stage 1 results that Project Organisation (Contextual competency) and Building Equitable Relationships (Behavioural competency) are the primary competencies required in evaluating EI’s in infrastructure projects. Additionally they support a growing body of evidence that there is a strong correlation between empathy and project performance (Zhang, Fan, 2013); that construction companies’ decisions in implementing BIM usually takes place at the collaborative, organisational level as opposed to the individual technical level (Sepasgozar et al, 2016) and that competency bridges the individual and organisational levels of BIM analysis (Salvato and Rerup, 2011).
Findings suggested a significant degree of correlation between BIM experience and environmental impact evaluation bearing in mind the sample size as discussed earlier. It was clear that BIM experience heightens the importance and awareness of ‘softer’ competencies which have a positive impact on environmental evaluation compared to technical knowledge which is more widely considered essential to the adoption of BIM as a technology. Roles in BIM projects may also have some impact on environmental evaluation but this requires long-term and wider research to fully determine.

The overall findings are significant for a number of reasons. Currently in the construction sector extensive resources are being applied by AEC companies to address the BIM-related technical skills of staff (Ding et al., 2015). However BIM is, in essence, a tool to facilitate visualisation for the team and successful delivery is more dependent on collaborative working rather than the acquisition of software skills (Rizal, 2011). Although software is developing rapidly this study suggests that the focus for AEC companies should be more aligned to the development of relevant people competencies and interpersonal attributes rather than the emphasis on technical skills. This is borne out in a growing awareness that the technical management of project processes alone is not enough to generate successful project outcomes (Nahod, 2013) and supports previous work on BIM implementation which recognises the importance of companies adopting a people-focused approach at both strategic and operational levels (Khosrowshahi and Arayici, 2012; Murphy, 2014; Singh and Holmstrom, 2015).

References


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Fig. 1  Environmental Impact of buildings in its Life Cycle; after Couto and Mendonca, 2011
<table>
<thead>
<tr>
<th>Environmental Management Tool</th>
<th>Primary Output focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMS (ISO 14001)</td>
<td>All issues</td>
</tr>
<tr>
<td>Site Waste Management Plan (SWMP)</td>
<td>Waste issues</td>
</tr>
<tr>
<td>Key Performance Indicators (KPI's)</td>
<td>Agreed issues</td>
</tr>
<tr>
<td>Risk Assessments</td>
<td>All issues</td>
</tr>
<tr>
<td>Incident Management Tracking</td>
<td>All issues</td>
</tr>
<tr>
<td>Carbon Emissions Monitoring</td>
<td>Air pollution</td>
</tr>
<tr>
<td></td>
<td>Energy issues</td>
</tr>
<tr>
<td>Non-compliance Reporting</td>
<td>All issues</td>
</tr>
<tr>
<td>Considerate Constructers Scheme (CCS)</td>
<td>All issues</td>
</tr>
<tr>
<td>RIDDOR (Reporting of Injuries, Diseases and Dangerous Occurrences Regulations)</td>
<td>Chemical issues</td>
</tr>
<tr>
<td></td>
<td>Biological issues</td>
</tr>
<tr>
<td>Air Monitoring</td>
<td>Air pollution</td>
</tr>
<tr>
<td>Noise monitoring</td>
<td>Air pollution</td>
</tr>
<tr>
<td>Hazardous Waste Register</td>
<td>Waste issues</td>
</tr>
<tr>
<td></td>
<td>Chemical issues</td>
</tr>
<tr>
<td></td>
<td>Biological issues</td>
</tr>
</tbody>
</table>

*Table 1* Commonly used site-based environmental management tools
Fig. 2  Risk mitigation of critical environmental impacts (after; Hayes, 2014)
<table>
<thead>
<tr>
<th>BIM-related Competency</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal Effectiveness</td>
<td>Demonstrates self-awareness and personal capability.</td>
</tr>
<tr>
<td>Commitment to Quality</td>
<td>Improves work practices to desired results and support productivity.</td>
</tr>
<tr>
<td>Navigating Change</td>
<td>Demonstrates adaptability and resilience in response to changing work environment and demands.</td>
</tr>
<tr>
<td>Communication</td>
<td>Communicates effectively in conversation and writing with a broad range of people.</td>
</tr>
<tr>
<td>Building Equitable Relationships</td>
<td>Builds and maintains equitable relationships.</td>
</tr>
<tr>
<td>Teamwork</td>
<td>Actively collaborates with others to produce desired results in a supportive environment.</td>
</tr>
<tr>
<td>Service Focus</td>
<td>Effectively assists and serves the Project community to meet required needs and goals.</td>
</tr>
<tr>
<td>Project Organization</td>
<td>Values the diversity of the members of PM team and their cultures. Demonstrates an understanding of the Project vision, mission and goals.</td>
</tr>
</tbody>
</table>

*Table 2  BIM-related Competencies*
<table>
<thead>
<tr>
<th>Project Stakeholder roles</th>
<th>Response %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Manager (Contractor)</td>
<td>20.30%</td>
</tr>
<tr>
<td>BIM Coordinator/BIM Lead</td>
<td>15.60%</td>
</tr>
<tr>
<td>Academic</td>
<td>14.10%</td>
</tr>
<tr>
<td>Design Manager (Contractor)</td>
<td>12.50%</td>
</tr>
<tr>
<td>Other (please specify)</td>
<td>10.90%</td>
</tr>
<tr>
<td>Design Consultant (Architect)</td>
<td>9.40%</td>
</tr>
<tr>
<td>Project Manager (Client)</td>
<td>7.80%</td>
</tr>
<tr>
<td>Specialist Consultant</td>
<td>3.10%</td>
</tr>
<tr>
<td>Supplier</td>
<td>3.10%</td>
</tr>
<tr>
<td>Subcontractor</td>
<td>3.10%</td>
</tr>
<tr>
<td>Others</td>
<td>9.9%</td>
</tr>
</tbody>
</table>

Table 3  Participating respondent roles at Stage 1
<table>
<thead>
<tr>
<th>Indicator</th>
<th>Ranked 1st</th>
<th>Cumulative total</th>
<th>% Cumulative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Assessments</td>
<td>54</td>
<td>54</td>
<td>20</td>
</tr>
<tr>
<td>Noise monitoring</td>
<td>33</td>
<td>87</td>
<td>32</td>
</tr>
<tr>
<td>ISO14001</td>
<td>29</td>
<td>116</td>
<td>43</td>
</tr>
<tr>
<td>Site Waste Management Plan (SWMP)</td>
<td>25</td>
<td>141</td>
<td>53</td>
</tr>
<tr>
<td>Considerate Constructors Scheme</td>
<td>21</td>
<td>162</td>
<td>60</td>
</tr>
<tr>
<td>Environmental Performance Indicators (EPI's)</td>
<td>21</td>
<td>183</td>
<td>68</td>
</tr>
<tr>
<td>RIDDOR (Reporting of Injuries, Diseases and Dangerous Occurrences Regulations)</td>
<td>17</td>
<td>200</td>
<td>75</td>
</tr>
<tr>
<td>Air Monitoring</td>
<td>17</td>
<td>217</td>
<td>81</td>
</tr>
<tr>
<td>ISO18001</td>
<td>17</td>
<td>234</td>
<td>87</td>
</tr>
<tr>
<td>Hazardous Waste Register</td>
<td>13</td>
<td>247</td>
<td>92</td>
</tr>
<tr>
<td>Incident Management Tracking</td>
<td>13</td>
<td>260</td>
<td>97</td>
</tr>
<tr>
<td>Other</td>
<td>8</td>
<td>268</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 4 Pareto Analysis data
Fig. 3 Pareto Chart of BIM indicators
Fig. 4  PMBoK processes used to manage E1 risk
<table>
<thead>
<tr>
<th>Issue</th>
<th>No</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air pollution issues</td>
<td>15</td>
<td>0</td>
<td>2</td>
<td>.87</td>
<td>.640</td>
</tr>
<tr>
<td>Groundwater issues</td>
<td>16</td>
<td>-1</td>
<td>2</td>
<td>.94</td>
<td>.998</td>
</tr>
<tr>
<td>Waste issues</td>
<td>15</td>
<td>0</td>
<td>2</td>
<td>1.13</td>
<td>.743</td>
</tr>
<tr>
<td>Land masses issues</td>
<td>15</td>
<td>-1</td>
<td>2</td>
<td>1.13</td>
<td>.915</td>
</tr>
<tr>
<td>Chemical issues</td>
<td>15</td>
<td>-1</td>
<td>2</td>
<td>.73</td>
<td>.884</td>
</tr>
<tr>
<td>Biological issues</td>
<td>15</td>
<td>0</td>
<td>2</td>
<td>.53</td>
<td>.640</td>
</tr>
<tr>
<td>Energy issues</td>
<td>15</td>
<td>0</td>
<td>2</td>
<td>.93</td>
<td>.799</td>
</tr>
</tbody>
</table>

*Table 5*  
Potential for BIM in identifying EI's on infrastructure projects
Fig 5: (Situation-Task-Action-Result) The STAR Technique after; Spencer and Spencer, 1993

**Situation**
What was the Situation in which the candidate was involved?

**Task**
What was the task that needed to be accomplished?

**Action**
What actions did the participant take?

**Results**
What results were achieved?
<table>
<thead>
<tr>
<th>Statistic</th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Error</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qtech_know</td>
<td>16</td>
<td>30</td>
<td>48</td>
<td>37,19</td>
<td>1,787</td>
<td>7,148</td>
</tr>
<tr>
<td>Qtech_exp</td>
<td>16</td>
<td>13</td>
<td>48</td>
<td>31,50</td>
<td>3,059</td>
<td>12,237</td>
</tr>
<tr>
<td>Qcontext_scen</td>
<td>16</td>
<td>7</td>
<td>15</td>
<td>11,06</td>
<td>,559</td>
<td>2,235</td>
</tr>
<tr>
<td>Qbehav_comp</td>
<td>16</td>
<td>44</td>
<td>60</td>
<td>49,81</td>
<td>1,266</td>
<td>5,063</td>
</tr>
<tr>
<td>Qtech_know_rel</td>
<td>16</td>
<td>,50</td>
<td>,80</td>
<td>,6206</td>
<td>,02959</td>
<td>,11835</td>
</tr>
<tr>
<td>Qtech_exp_rel</td>
<td>16</td>
<td>,22</td>
<td>,80</td>
<td>,5263</td>
<td>,05071</td>
<td>,20284</td>
</tr>
<tr>
<td>Qcontext_scen_rel</td>
<td>16</td>
<td>,35</td>
<td>,75</td>
<td>,5531</td>
<td>,02794</td>
<td>,11176</td>
</tr>
<tr>
<td>Qbehav_comp_rel</td>
<td>16</td>
<td>,59</td>
<td>,80</td>
<td>,6644</td>
<td>,01688</td>
<td>,06752</td>
</tr>
</tbody>
</table>

Legend:
Qtech_know – knowledge: for technical competency: self-assessment
Qtech_exp – experience: for technical competency: self-assessment
Qcontext_scen – scenarios: for contextual competency: event interview
Qbehav_comp – event interview: for behavioural competency: self-assessment:

Table 6  Comparison of stakeholder competency in evaluating EI’s using BIM
<table>
<thead>
<tr>
<th>Component Matrix ( ^a )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component</td>
</tr>
<tr>
<td>Technical competency - knowledge</td>
</tr>
<tr>
<td>Technical competency - experience</td>
</tr>
<tr>
<td>Contextual competency</td>
</tr>
<tr>
<td>Behavioral competency</td>
</tr>
</tbody>
</table>

Extraction Method: Principal Component Analysis.

a. 1 components extracted.

Table 7  Factor analysis of competency for managing EI’s in infrastructure projects