Attaining Performance with Building Information Modelling

A systematic literature review of product and process modelling in AEC

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Abstract. *The paper presents the findings of a systematic literature review of approximately 200 scientific sources. It is designed with the aim to identify the current benefits and factors of high performance in Architecture, Engineering, Construction (AEC) since the introduction of Building Information Modelling (BIM). We formed and confirmed two main propositions associating the performance of the AEC to the use of BIM. The mapping of the current impact and benefits of BIM showed that the role of the managers, suppliers, owners and authorities is underestimated, as well as the initiation and use stage of project development. At the same time, the performance in the AEC industry can be improved by an array of possibilities where IT research and policy-making authorities contribute – from establishing new collaboration protocols until improving existing or creating new BIM tools.*
Keywords. *Building Information Modelling (BIM); Architecture, Engineering and Construction (AEC); supply chain management; life-cycle phases; stakeholders.*

INTRODUCTION

Performance in architecture

The idea of performance in architecture has been extensively debated during the last years, in example in the "Performative Architecture" symposium organized in 2003 by Kolarevic and Malkawi (2005). Discussion has focused on the "apparent disconnect between geometry and analysis" despite the variety of the available digital tools (Kolarevic and Malkawi, 2005) and on performance perceived as a qualitative criterion in architecture. For the recipient of the built environment and the critical thinker, performance is an objective quality measure, which offers rationale and clarifies the multiplicity of current approaches and phenomena in architectural artefacts.

Performance is an important consideration in many other industries, ranging from education to commerce. For example, terms such as Performance Indicators or Key Performance Indicators – although still a jargon from industry that lacks clear definition – are "items of information collected at regular intervals to track the performance of a system" (Fitz-Gibbon and Tymms, 2002). From this perspective, performance is also the success factor in design. The design process and the design object are the two sides of the same coin. Yet, in architecture, arguably due to the subjective input of the designer, performance is neglected and the emphasis is on the aesthetic qualities of the architectural object. But yet again, when performance becomes a serious consideration in architecture, it is generally restricted to the performance of the design product, the artefact, the building. Little is being researched over the performance of the design process and its significance for the quality of the product.

Until recently Computer Aided Design (CAD) software was the basis of computerization in architectural practice and its use portrayed the contemporary architectural process (Aouad, 2012). The introduction of Building Information Modelling (BIM), approximately ten years ago (Eastman et al, 2008) and its broad settlement as an integrated interdisciplinary design environment (Deutsch, 2011); suggests significant changes in not only the representation of the design product but also in the structure of the design and construction processes.

Authors' approach

The advancements in technology, in both software and hardware engineering (programming, computing and networks) have resulted in a variety of solutions that gradually ameliorate the status of the field. BIM technology – approach or process – is an object-oriented modelling tool that contains 3D data with "parametric intelligence" (Eastman et al, 2008). In design theory, BIM is seen as an evolution of pre-existing technologies and approaches including CAD and product modelling. This attribute adequately covers the product aspect of architecture. On the other hand, BIM is a recent arrival in construction and design management, i.e. the process side of AEC. In addition to being a design tool, BIM is also a powerful management tool (Hardin, 2009).

Currently, there is still a lot of room for theory building on how exactly BIM and management can collaborate towards the achievement of an integrated approach in architecture. This statement coincides with the position of the authors. Thus, the approach of BIM from our part is nor technical, nor in terms of design, but from a design-and-construction management point of view and particularly from a supply chain (SC) perspective. AEC has a "highly fragmented" structure (O' Brien et al, 2009). Due to the lack of collaboration and coordination between the different organizations that participate in the industry, its contemporary image is of low performance. We define performance as the maximum proportion of output to input. The four theoretical perspectives of approaching the building SC are economy, organisation, social and production perspectives (Vrijhoef, 2011). Originating from these four SC perspectives, we categorised ten focal points – interrelated but loosely clustered – from which to research BIM (Figure 1) through a "construction SC management" conceptual lens.

Research question

The main inquiry of the paper is the impact of BIM in the performance of AEC industry from a supply chain perspective. First (Q1), which exact phases and actors of the AEC currently receive more benefits from the application of BIM? This investigation will identify the positive performance of BIM in certain phases and stakeholders. The reverse argument identifies

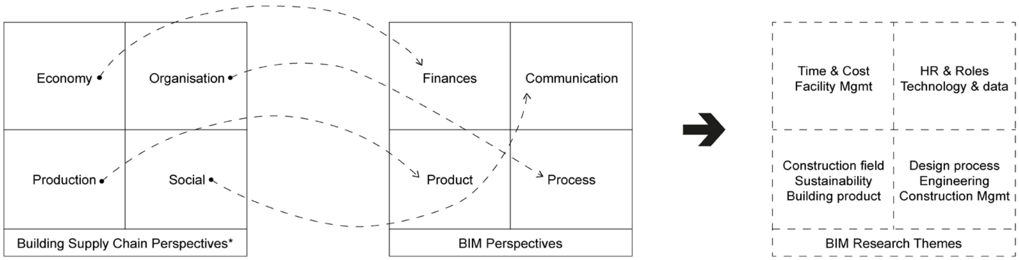

Figure 1
Foci for researching BIM (adapted from Vrijhoef, 2003).

the neglected – or less researched – phases and actors during the development and employment of BIM applications. Second (Q2), which specific features of BIM improve the performance of AEC industry throughout the whole supply chain and how?

The study addresses both the professional and academic side of the field, given that knowledge form practice and theory is interchangeable in the engineering domain. Our goal is to reconsider the ways we can achieve the performance required by contemporary architecture and the built environment by illuminating the benefits of applying BIM in architectural projects and identifying gaps in literature and theory. At the same time, the authors consider performance in suggesting a system of actions for the management of architectural projects.

METHODOLOGY

This paper uses a qualitative approach and performs a quantitative or quantifiable analysis on a merely qualitative material, in this respect the bibliographic material. Traditionally case studies are the norm in conducting research into the performance of a process. Indeed, case studies offer a variety of qualitative results with inductive character and deep understanding of the research problem. Unfortunately, a case study produces a local, specific and project-driven knowledge output that is difficult to be generalised into the performance of other systems. The output is often limited to the interviewees' or the researchers' point of view. On the other hand, a wide bibliographic research offers a spherical coverage in actors, phases and processes, which is after all the focus of the managerial perspective. These two methods (case study and literature research) are better to be considered as complementary rather than rivals in designing a research.

At this point, it is important to clearly position this paper in its scientific context. As mentioned before, it follows a managerial perspective concerning the impact of BIM in the performance of AEC. Since the managerial perspective in this case is focused on SC management, it is crucial to categorise it according to this research approach. There are five types of research design for a supply chain study: substantive justification for theory building, surveys in SC management, case study research in SCs, action research in SCs and modelling SCs (Seuring et al, 2005). However, there is no right or wrong as to which method to choose – descriptive or empirical – as long as the scope is clear and its application adequately employed.

Literature review has proven to be a very useful tool for both qualitative and quantitative studies. Among others, a literature review provides a framework for establishing the importance of the study and relates it to the larger on-going discussion. In this case, the proposed methodological tool is a "*systematic quantitative literature review",* a tool originating from ecology and environment sciences. It offers an overview of existing approaches and "by mapping the literature it is possible to highlight the boundaries around generalisations derived from the literature" (Pickering and Byrne, (In Press)). The literature review described here acts as a big variance data entry method. This paper is the report of only one component – due to paper length limitations – of the larger systematic literature review that was conducted between February and June 2013. The findings that are presented here are content-related preliminary findings of the whole study.

DATA COLLECTION AND DISPLAY

Collection of the material

The primary material comes from scientific sources and has no commercial origin. Periodical scientific texts or other sources that require a short time interval between the development and the publication of the research are the main material of this study. Comparing such material to books, they capture a more genuine and dynamic – although sometimes raw or incomplete – state of the research in time. Consequently the selection of the material is limited to peer reviewed material such as journal articles and conference papers.

Throughout the literature, the term *Building Information Modelling* or *BIM* appears from 2002 onwards mostly in commercial publications but it is only around 2006 that the subject starts to become a research object in scientific publications too. The total number of scientific source on *Building Information Modelling* or *BIM* during 2006-2013 according to Google Scholar (assessed on May 6, 2013) is 5010, where the key terms appear in the body of the text, and 344, where the key terms appear only in the title. In order to emphasise on the material that is indeed relevant to BIM, the appearances throughout the body of the text are considered of minor importance, since the term BIM may be only mentioned in the "discussion" or the "reference" sections of the source. At the same time in Scopus database (assessed on May 6, 2013), which does not hold a global coverage in journals and conference proceedings, there are 272 sources and our topic appears on the title, the abstract or the keywords. All the afore-described steps are quantifiable and repeatable.

Display of data

The collected material complies with the main research context, which is BIM in the AEC industry from an academic and an industrial point of view. Of course a sort of bias may be applied in the selection of the material, since selecting a sample of 272 or 344 sources allows the subjective character of the research designer to interfere. The inability to include material for reasons such as copyright and accessibility was the only limitation in this process. Since the resulted collected sample of 198 sources was not too large, no special sampling strategy was used. The failure to include the rest of the material was considered random. Aiming to explore the potential of BIM (as a process or a tool) from a managerial perspective, the research focuses on ten sub-themes: time & cost, facility management, design process, engineering & consultancy, construction management, construction field, sustainability, building product, human resources & roles and technology & data.

The selected material is analysed and categorised in order to answer the questions posed in the introduction. After the analysis, each scientific source provides a data set with information. The data collection method uses computer-assisted survey information collection software, i.e. an online survey tool. An evaluation form designed as a questionnaire collects and displays the data. The questionnaire has a three-part skeleton composed of a descriptive part (basic information), an analytic part (focus on the content and the quality) and a conclusive part (epilogue and recap). The first two parts of the evaluation form are designed in a quantitative manner with closed questions in order to categorise the sources and communicate the findings as much objectively as possible. The third part contains open questions and accumulates qualitative data. From these two types of data only the quantitative – first two parts – are presented and discussed in this paper.

DATA ANALYSIS AND RESULTS

Analysis of data

The data collected from the evaluation forms of the selected material underwent a two-level analysis. The first level involved the semantics of the scientific texts. It included data in relation to the characteristics of the publication and the categorisation of the primary author (Table 1). The second level concerns the pragmatic content of the sources focusing on the overview level as well as quality assessment of the sources. The main findings are presented in the second and third table (Tables 2 and 3). Descriptive statistics have been used to summarise the data in a shorter form. Since most of the variables are qualitative or categorical, the mode – or else the frequency measure – of the sample is the most important and usable measure that can be applied to all variables regardless their type.

Findings

The raw findings are presented in the three tables. Table 1 presents certain attributes of the scientific sources in a condensed form. Both the number of publications and percentages are stated here in order to present an overview of the origins of the existing research material on BIM. Table 2 gathers the mentions of BIM benefits. We categorise and corre-

Table 1
Condensed results from first level of analysing the scientific sources on BIM in absolute and relative units.

Characteristics of scientific sources on BIM	Sources	Frequency (%)
Primary author with background from academic research	161	81.31
Primary author with background on Construction Management	60	30.30
Primary author with senior expertise in industry or academia	136	68.69
Research based on case studies	126	63.64
Global applicability of the research	159	80.30
Research published in scientific journals	105	53.03

late these benefits according to the project phases of AEC and the actors participating to it. Table 3 collects the benefits from using certain BIM features categorised under the relevant SC research perspectives.

Results

Most of the publications on BIM (81.30%) have been authored by researchers originating from the academia (Table 1). A number of these researchers is also active in industrial organisations. Construction

Table 2
Benefits from using BIM per actor of the AEC industry and project phase in absolute numbers of the sources.

BIM benefits (Number of references in the sources)	Architects	Managers	Engineers	Consultants	Contractors	Suppliers	Owners & FM	Regulatory Authorities
Initiative	53	43	35	22	29	12	26	21
Design	124	78	107	52	64	20	42	30
Construction	54	57	74	29	65	27	27	20
Use	16	27	23	17	15	13	48	16

Table 3
BIM features and SC research perspectives correlation derived from the literature in absolute numbers.

BIM features (Number of references in the sources)	Feasibility tools	Contracting tools	Specification tools	Preliminary massing	Visualisation	Collaboration tools	Clash detection	Mechanical tools	Environmental analysis	Cost estimation	Direct fabrication control	Construction scheduling	Quantity take-off	Facilities management
Time & cost	32	14	22	5	16	22	28	12	8	33	10	35	11	6
Facility mgmt	6	2	16	5	11	15	12	10	13	5	5	5	0	18
Design process	31	24	46	27	87	58	44	18	28	24	16	18	11	15
Engineering	22	18	31	12	38	37	34	23	15	16	14	23	10	6
Constr. mgmt	20	24	27	7	23	43	23	8	4	21	14	44	11	5
Constr. field/site	11	17	23	7	20	20	19	13	3	15	12	30	10	5
Sustainability	13	0	5	1	9	9	9	1	20	6	2	2	0	5
Bldg product	13	6	17	3	18	22	9	7	18	8	3	6	2	13
HR & roles	8	9	7	4	12	31	12	0	3	4	3	6	1	7
Technology & data	13	12	49	8	40	40	30	20	18	15	14	24	8	14

BIM benefits (%)	**Architects**	**Managers**	**Engineers**	**Consultants**	**Contractors**	**Suppliers**	**Owners & FM**	**Regulatory Authorities**
Initiative	**26.77**	21.72	17.68	11.11	14.65	*6.06*	*13.13*	10.61
Design	**62.63**	**39.39**	**54.04**	**26.26**	32.32	*10.10*	21.21	**15.15**
Construction	27.27	28.79	**37.37**	14.65	**32.83**	**13.64**	13.64	*10.10*
Use	*8.08*	*13.64*	*11.62*	*8.59*	*7.58*	6.57	**24.24**	*8.08*

Table 4
Summary of references on the actors and phases of the AEC industry benefited from BIM.

managers have authored 30.30% of the research on BIM. This element strengthens our initial proposition that BIM is considered more as a tool to achieve an occasional high performance, rather than as a permanent project management tool or a process to be used towards the integration of the construction supply chain. At the same time, the fact that not only junior but also a lot of senior researchers are keeping busy with BIM reveals that they are already convinced about its potential and the impact and are committed to put their expertise in action. The majority of the publications (63.64%) use case studies and experiments to validate their hypotheses.

Table 4 contains the data of Table 2 in percentages and indicates with **bold** the number of sources where the actors and the phases experience more benefits from the employment of BIM and with *italics* where the actors and the phases profit less. Apparently (A1) the architects and the engineers are the actors who are either the participants more involved in the research and adoption of BIM – or are simply considered the primary actors – in BIM literature (Table 4). Surprisingly, construction managers are not equally prominent to these primary actors, as one might have expected but they are more involved in all phases of a project, while contractors are referred to mostly in the construction phase. Suppliers are also referred in the construction phase but are limited to peripheral roles in the rest of the building life-cycle. On the other hand, owners and regulatory agencies seek immediate involvement but achieve only fragments of presence mostly during the initiative and use stages.

Table 5 emphasises with **bold** the mentions of the most prominent BIM features and with *italics* of the most underused. The aim here is to indicate the features of BIM that improve the performance of AEC industry throughout the whole supply chain (A2). According to the literature review, BIM features such as visualisation, clash detection and collaboration tools are the most researched by far, which on the one hand increases the performance of the building product but on the other hand contributes to the performance of AEC only incidentally. For instance, quantity take-off and facility management tools – employed mostly for facilitating the suppliers and the owners respectively – are either neglected for certain research perspectives or only appear in the 6 to 9% of research into BIM. Likewise, while there are tools for the construction field, such as direct fabrication tools (Table 5), they are seemingly not widely applied or reported. Other BIM features mentioned but not included here are laser scanning and tools for safety on the building site.

DISCUSSION AND CONCLUSION

Discussion

The research design answered sufficiently the research questions. Comparing this research to other studies, the most apparent difference is to be found in the methodology. Identifying benefits and quantizing performance via literature review is not the norm in this domain. The present research shares common concerns and limitations as publications based on case study research. Comparing it with

Table 5
Summary of correlations between BIM features and SC research perspectives.

BIM features (%)	**Feasibility tools**	**Contracting tools**	**Specification tools**	**Preliminary massing**	**Visualisation**	**Collaboration tools**	**Clash detection**	**Mechanical tools**	**Environmental analysis**	**Cost estimation**	**Direct fabrication control**	**Construction scheduling**	**Quantity take-off**	**Facilities management**
Time & cost	**16**	7	11	*3*	8	11	14	6	4	**17**	5	**18**	**6**	*3*
Facility mgmt	*3*	1	8	3	6	8	6	5	7	3	3	3	*0*	**9**
Design process	**16**	**12**	23	**14**	**44**	**29**	**22**	9	**14**	12	**8**	9	**6**	8
Engineering	11	9	16	6	19	**19**	17	**12**	8	8	7	12	5	*3*
Constr. mgmt	10	**12**	14	4	12	22	12	4	*2*	11	7	**22**	**6**	*3*
Constr. field/site	6	9	12	4	10	10	10	7	*2*	8	6	**15**	5	*3*
Sustainability	7	*0*	*3*	*1*	*5*	*5*	*5*	1	**10**	3	*1*	*1*	*0*	*3*
Bldg product	7	3	9	2	9	**11**	5	4	9	4	2	3	*1*	7
HR & roles	4	5	4	2	6	16	6	0	2	2	2	3	1	4
Technology & data	7	6	25	4	20	20	15	10	9	8	7	12	4	7

previous studies, it focused on the performance of the AEC process via the use of BIM rather than "discussing how information systems can further contribute to this research domain" (Merschbrock and Munkvold, 2012). There are again limitations over how exactly to measure performance, a problem already mentioned in other studies (Barlish and Sullivan, 2012). A solution to this problem is be the classification of benefits as having a positive or a negative impact, as suggested in research on case studies (Bryde et al, (In Press)). Apart from sharing common concerns and limitations with existing researches, the present study has the dual advantage of including all the involved participants in the AEC industry and referring to all the stages of the AEC.

Although the findings presented here do not cover the full extent of the research conducted – due to paper length limitations – the main results already suggest concrete directions for further use. From the summarising tables in the results section (Tables 4 and 5) we indicate certain directions that require further attention and investigation (Figure 2). Undoubtedly, with the still rapidly evolving state of the information age, research directions in the field may change day by day. However, this study has showed that there are certain neglected research areas and correlations that arguably explain the low performance of the AEC industry. The content of this paper offers a guide to improving the behaviour of the neglected project phases and actors by integrating the construction supply chain. Concerning the methodology, the research adds on how to conduct literature research with an eye not only in the semantics and external characteristics of the scientific material but also in the overview level of the scientific material. The present method could also be employed in the future by either focusing on a narrower research field or including certain types of publications. Lastly, anticipating the criticism over the credibility of a literature review, we defend the selection of this research design by restating the quality assessment that was incorporated during the employment of the experiment.

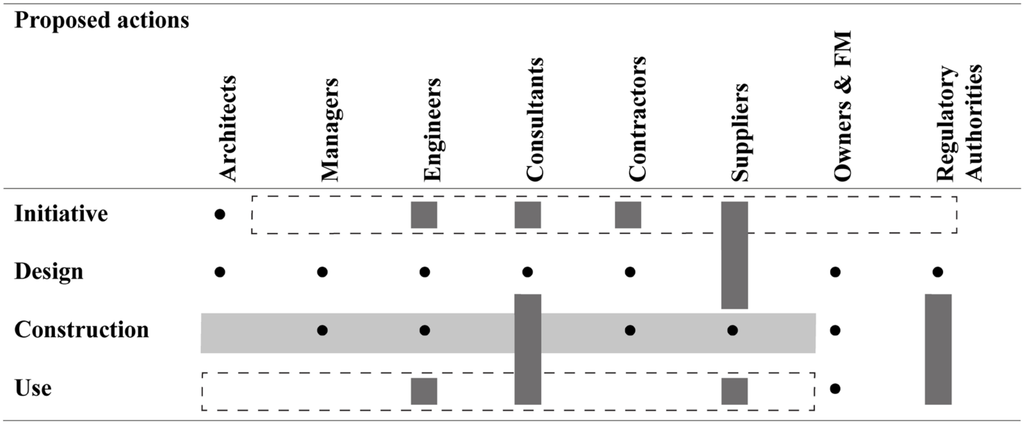

Figure 2
Proposed action framework for BIM research (Horizontal stripes: Collaboration protocols, dark grey: IT tools).

Conclusion

The study described in this paper identified the life-cycle phases and stakeholders who experience more benefits from the current application of BIM and thus are considered high performance parameters for the industry. On the other hand, the phases and stakeholders who are either neglected or simply left behind in the adoption of BIM are of low performance and may be subjected to future research. The research also revealed the BIM features that are currently used more extensively and the BIM features with low applicability of popularity in a sense.

Using the most and the least benefited from BIM actors and AEC phases (as indicated in Table 4), we identify gaps not only in the performance of the participants, but also in the performance of the various processes that take place during a project. For example, in the initiative phase, only the architects are adequately involved, while they are less involved – along with all other actors apart from the owners – in the stage of end-use. On the other hand, in the design phase almost all the participants – with the exception of the suppliers – are equally benefited from the implementation of BIM, whereas in the construction phase there is a continuous fluctuation in regard to the involvement of the actors (Table 4). At the same time, Table 5 reveals that preliminary massing, direct fabrication control and quantity take-off are the most underused tools.

Combining the research results from Tables 4 and 5, we propose a framework towards a highly performative AEC industry (Figure 2). New and stronger collaboration protocols between the managers and the owners should be implemented in the initiative phase, and likewise appropriate collaboration protocols should be applied in the use stage of AEC (dashed horizontal stripes). The employment of supply chain integration in construction aims to regularise and enhance the involvement of all actors in this stage and at the same time improve the performance of the AEC (light grey horizontal stripe). We also argue that the underused BIM features should be extended or improved in order to serve the involvement of all the stakeholders in the AEC process (dark grey stripes).

Finally, we observe that while the role of the architect is being given adequate attention in BIM research and adoption, the role of the manager is not equally emphasised. The existence of many and various BIM features arguably makes as the manager an integrator of the whole process rather than merely another BIM-user. To conclude, apart from reaching our own research objectives, the present study forms a roadmap for fellow researchers interested in the domain of BIM by revealing subjects for further exploration.

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