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Tool for Benchmarking BIM Performance of Design, Engineering and Construction Firms in The Netherlands

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Abstract

Building information modelling (BIM) is becoming more and more important to manage complex communication and information sharing processes in collaborative building projects. A growing number of design, engineering and construction firms have made attempts to adopt BIM to enhance their services and products. However, there remain many uncertainties in the implementation strategies and actual performance. Neither the success nor the bottleneck can be justified objectively since there is no common benchmarking for firms that are applying BIM. This article describes applied research to generate an instrument for benchmarking BIM performance. The instrument aims to provide insight into the current BIM performance level of design, engineering and construction firms. The purpose is to justify the qualification of the parties to be commissioned for projects, as well as to raise awareness and establish a common strategy for innovation through BIM. The benchmarking instrument is based on a quick scan method. It combines quantitative and qualitative assessments of the 'hard' and 'soft' aspects of BIM. The use of this instrument by BIM consultants in the Netherlands has taken place since early 2010.

Keywords – Benchmarking; BIM; maturity; performance; tool development

INTRODUCTION

Complex communication processes between numerous project participants involving large amounts of information often cause errors and omissions during design and construction (Eastman *et al*., 2008). Building information modelling (BIM) has, therefore, become more and more important for collaborative building projects. BIM comprises collaboration frameworks and technologies for integrating process- and object-oriented information throughout the life cycle of the building in a multi-dimensional model. BIM information sharing among project participants from different disciplines can be centralized and coordinated effectively (Sebastian, 2010). Both in theory and in practice, the added value of BIM for collaborative processes has been acknowledged, including more effectiveness, higher efficiency, reduced time and errors, and improved quality.

A growing number of design, engineering and construction firms have made attempts to adopt BIM to enhance their services and products. However, there remain many uncertainties in the implementation strategies and actual performance. In several countries, such as in the Netherlands, the USA, Finland and Australia, there have been attempts to provide an overview of all relevant definitions and initiatives related to BIM, as well as national standards or guidelines for BIM implementation (NIBS, 2007; Senate Properties, 2007; CRC Construction Innovation, 2009; Team BouwICT, 2010). Despite these attempts, there

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remain various techniques to use BIM and heterogeneous definitions of BIM performance. Many firms have made quick claims on their BIM qualification. On the other hand, others show reluctance to use BIM due to the difficulties in deciding the most appropriate organizational and technical approaches. Also, firms attempting to generate new or to enhance existing BIM deliverables can find little guidance towards identifying and prioritizing their respective requirements. This mismatch between expected BIM deliverables and unforeseen BIM requirements increases the risks, costs and difficulties associated with BIM implementation, allows the proliferation of 'BIM wash' – falsely professing the ability to deliver BIM services or products – and prevents industry players from achieving their full BIM potential (Succar, 2010).

Until now, neither success claims nor adoption reluctance can be justified objectively since there is no common benchmarking system for firms that use BIM in their processes and projects. The abundance of industry discussions and academic literature professing the ability of BIM methodologies to increase productivity has not yet been coupled with the availability of a widely acknowledged tool to reliably measure this productivity.

In response to the needs of clients, designers, engineers and contractors in the Netherlands, an assessment tool has recently been jointly developed by a research institute and a number of BIM consulting firms. The tool aims to serve as a standard benchmarking instrument. For clients, such a benchmarking tool is needed to select firms with adequate BIM knowhow to carry out projects with a certain level of complexity, and to organize the most effective knowledge-based collaboration. For designers, engineers and contractors, the tool is needed to reflect on their current capabilities, to plan further improvements and to obtain strategic positions in the competitive building sector, based on state-of-the-art knowhow.

This article describes to applied research develop a BIM benchmarking tool in the Netherlands based on a quick-scan method (TNO, 2009). In the next section, the literature survey and critical reviews of the existing assessment tools are discussed. The tool development process and tentative results are then presented. Subsequently, verification and validation are explained, based on expert opinions and pilot cases. Finally, recommendations are given on future scientific research and the plan to apply the tool in practice.

CRITICAL REVIEW OF EXISTING ASSESSMENT TOOLS

Recently, various working concepts and technologies for BIM have been developed worldwide. A number of BIM capability and maturity evaluation tools have been introduced in order to get a clearer insight into the performance of the fast growing and large diversity of BIM developments and applications. The development of BIM performance metrics is a pre-requisite for BIM performance improvement. Succar (2009) distinguishes BIM capability from BIM maturity. BIM capability is the ability to generate BIM deliverables and services. BIM maturity addresses the extent, depth, quality, predictability and repeatability of these BIM deliverables and services.

During the literature survey, three well-known assessment tools developed in the USA were found, namely the BIM capability stages, the BIM maturity index (BIMMI), the national BIM standard (NBIMS) which contains the Capability Maturity Model (CMM). In the Netherlands, several BIM consulting firms have independently developed assessment tools, such as BIM Meetlat (BIM measure indicator) by BouwnD, BIM Succespredictor (BIM success predictor) by DeBIMspecialist, and BIM Succesvoorspellers (BIM success forecasters) by Gobar. Below, these tools are described and critically reviewed based on their practical effectiveness to evaluate the most important BIM uses by designers, engineers and contractors, as envisaged by Eastman *et al*. (2008).

The BIM capability stages define the minimum BIM requirements that need to be reached by a team or an organization as it implements BIM concepts and technologies (Succar, 2009). It is a quick yet accurate way to assess an organization's ability to deliver BIM services. It includes three capability stages, with stage 3 being the most advanced. Along with these stages, there are five major milestones, namely pre-BIM as the fixed

starting point, object-based modelling, model-based collaboration, network-based integration and integrated project delivery or IPD (AIA CC, 2007) as the evolving target. However, since BIM capability stages are established when the minimum requirements are met, they cannot assess the abilities (or the lack of them) beyond these minimum requirements. BIM capability stages cannot detect variations in level of experience and modelling quality between two organizations that are both at the same BIM stage.

BIMMI was developed to address the shortcomings of the BIM capability stages (Succar, 2009). BIMMI refers to the quality, repeatability and degrees of excellence of BIM services; in other words, the more advanced ability to excel in performing tasks or delivering BIM services. BIMMI has five distinct maturity levels, namely initial/ad hoc, defined, managed, integrated and optimized. In general, the progression from the lower to the higher levels of BIM maturity indicates better control through minimizing variations between targets and actual results, better predictability and forecasting by lowering variability in competency, performance and costs, and greater effectiveness in reaching defined goals and setting new more ambitious ones. Compared with the BIM capability stages, the BIMMI provides both a clear overview and more detailed assessment. Nevertheless, its focus remains on the ability of the organizations and project stakeholders to deliver BIM products and services without assessing the maturity of the models and modelling processes of the delivered BIM products and services.

NBIMS CMM was developed to assess building information models. NBIMS CMM is the most commonly used assessment tool in the USA (McCuen and Suermann, 2007). It is a matrix with 11 areas of interest on the *x*-axis and 10 levels of maturity on the *y*-axis. The areas of interest include data richness, life-cycle views, change management, roles of disciplines, business processes, timeliness/response, delivery method, graphical information, spatial capability, information accuracy and interoperability/Industry Foundation Classes support. The ratings for maturity levels are on a scale of 1–10, with 10 being the most mature. Two versions of NBIMS CMM exist. The first version is the tabular CMM, which is based on a static Microsoft Excel workbook consisting of three worksheets. The second version is interactive CMM (I-CMM), which is based on a multi-tab Microsoft Excel workbook that includes several interdependent worksheets of functionality. The worksheets are interactive and actively update the BIM's maturity level as the user enters information.

NBIMS CMM is a tool for BIM users to evaluate their practices and processes. It can also be used for portfolio-wide analysis to establish an organization's current strategic or operational BIM implementation. In addition, it can be used to set goals to achieve greater information maturity for future BIM projects. However, there are also several limitations for the use of NBIMS CMM. It is an internal tool to determine the level of maturity of an individual BIM as measured against a set of pre-defined weighted criteria. CMM is not intended to be used to compare different models or BIM implementations. It is designed to measure the maturity of the model (including the modelling process), but not to measure the BIM maturity of the organization.

NBIMS CMM has been adapted for use in the Netherlands and presented as BIM Meetlat by a consulting firm BouwnD (Pikkaart, 2008). The 11 areas of interest on the *x*-axis and the 10 levels of maturity are translated from English into Dutch. The scoring system is maintained, that is, based on the results of the assessment, the BIM maturity can be recognized as bronze, silver, gold or platinum. From the scientific point of view, there is a lack of validation on how the original tool, developed within the American context, was adjusted to the Dutch context. Although it is usually assumed that BIM technologies are generic, the business processes and distribution of roles in different countries may vary. Such differences become crucial, since the BouwnD consultant uses BIM Meetlat to evaluate the maturity of the organization. This is beyond the focus and main objective of NBIMS CMM on which BIM Meetlat is originally based.

DeBIMspecialist has introduced an assessment tool called 'BIM Succespredictor', which comprises nine aspects: strategy, organizational structure, commitment, people, resources, engineering method, collaboration, BIM scope and results

(Hendriks, 2010). These aspects are categorized into corporate aspects and project aspects. Based on an interview, the DeBIMspecialist consultant highlights the particular shortcomings that limit the BIM success of an organization. Each shortcoming is then put into a direct relation with a specific corporate or project aspect. Subsequently, the possible consequences of these shortcomings are explained; for instance, insufficient corporate strategy on BIM would lead to ad hoc and inconsistent implementations; lack of quality of BIM products would render the results useless/with no clear added value. Compared with the other tools, this one is quite unique in the sense that it intends to warn an organization of possible negative implications if BIM capability is not adequate. Regrettably, the analysis is totally based on the expert opinion of a single BIM consultant who takes the interview; and, consequently, the validation is difficult. Moreover, the analysis is not quantifiable, which means that an objective overall comparison or benchmarking between different organizations cannot be made. Since the depth of the analysis is also very limited, this tool is only suitable to raise the BIM awareness of an organization, which hopefully leads to a follow-up discussion on the necessary improvements.

Another attempt to develop a BIM assessment tool has been made by Gobar with the 'BIM Succesvoorspellers' (Bergs, 2009). Similar to the BIM Succespredictor by DeBIMspecialist, this tool aims to comprehensively assess both the hard aspects (e.g. technologies and protocols) and soft aspects (e.g. organizational culture and motivation) of BIM. BIM Succesvoorspeller presents a clear overview of five main aspects of BIM and their inter-relationships. This can be considered as an improvement over other tools, which show a list of many various aspects that are seemingly unconnected. The tool puts 'human' as the central aspect that connects the other four aspects, namely strategy, business process, information and technology. It then links key performance indicators (KPIs) to the five main aspects. Although the tool is still in the development stage, a major scientific weakness has already been discovered in the analytical method, which is solely based on the qualitative judgement of the BIM consultant.

Based on the literature survey, the following conclusions can be drawn. A number of tools have been developed and used recently to measure the capacity and maturity of BIM. Unfortunately, the existing tools still have significant weaknesses. No current tool can measure the BIM maturity of both the model and the organization. NBIMS CMM focuses only on the model and the other tools focus only on the organization. BIM areas of interest addressed by different tools vary greatly. Different tools cannot be applied complementarily, since their criteria and weighing factors are not compatible. All tools aim at becoming an objective measure instrument, but the achievement of this aim is hampered by the lack of scientific underpinning for performing the analysis and validating the results. Furthermore, no tool has been commonly acknowledged and used in the construction industry. In the USA, a broader acceptance may be expected for the CMM since the tool is endorsed by NBIMS. In the Netherlands, independent BIM consultants that have developed the existing tools are small enterprises with limited market shares. Hence, no existing tool is able to serve as a national or an international standard benchmarking instrument.

DEVELOPMENT OF TNO BIM QUICK SCAN TOOL

The development of a BIM benchmarking tool aims to resolve the shortcomings of the existing assessment tools by introducing a new tool that can serve as a standard BIM benchmarking instrument in the Netherlands. Three main steps during the development of the tool can be distinguished, namely step 1 – exploratory field and desk research; step 2 – developing analytical method and setting-up assessment criteria; step 3 – development, practical verification and validation of the prototype tool.

The first step included exploratory field research, through interviews among construction clients and their consultants, to determine the most important aspects to be objectively assessed at tender and during selection of designers, engineers and contractors for a BIM-based building project. Additionally, exploratory field research through

interviews was carried out among designers, engineers and contractors to gain an insight into the existing ways used by these actors to present their BIM competencies to the client. Simultaneously, desk research was performed on the existing BIM guidelines, handbooks, measurement criteria and assessment tools. The critical review, as presented in the previous section, also resulted in lessons learned from the development and use of the existing assessment tools.

The second step comprised deciding on the underpinning method used for the new assessment tool to meet the needs of the clients and tool users as well as to create the highest practical impact. The new assessment tool is called the 'BIM Quick Scan'. Although the scan should be performed quickly, that is, in a limited time of maximum one day, the assessment is quite comprehensive. The analytical method (i.e. formulas for weighted calculation and cross-check analysis) was established accordingly. Next, a list with all relevant aspects for assessment was set up. These aspects were then categorized into 'hard' and 'soft' aspects for quantitative and qualitative evaluations. Much time and effort was spent on restructuring, detailing and refining the aspects and KPIs. This process was executed in five rounds by three experts from an independent research institute. The tentative results of each round were reviewed with a peer group consisting of BIM consultants, clients, designers, engineers and contractors who had participated in the exploratory field research.

In the third step, the prototype tool was developed after the final KPIs and assessment aspects were integrated with the analytical method. Practical verification and validation of the prototype tool were then carried out. This process is described more extensively in the next section of this article. In order to measure the performance, certain key KPIs were used. These KPIs allow the BIM Quick Scan tool to report past outcomes, both good and bad; to determine the quality and robustness of BIM services and products; to identify where improvements should be made and to allow BIM experts to independently judge an organization's performance. While it is important to develop metrics and benchmarks for BIM performance assessment, it is equally important for those metrics to be consistently accurate and adaptable to different industry sectors and organization sizes. The tool and its KPIs are, therefore, designed to conform to a set of guiding principles purposely developed to measure the specifics of BIM performance as follows (Succar, 2010):

- Accurate: clear, non-falsifiable and allow accurate, repeatable assessment.
- Applicable: can be utilized by all stakeholders across project life-cycle phases.
- Attainable: benchmarks can be achieved through progressive accumulation of defined actions.
- Consistent: when conducted by different assessors, measurements yield the same results.
- Cumulative: benchmarks are set as logical progressions; deliverables from one benchmark act as pre-requisites for another.
- Flexible: assessments can be performed across markets, organization scales and their subdivisions.
- Informative: measurements provide 'feedback for improvement' and 'guidance for next steps'.
- Neutral: measurements do not prejudice proprietary, non-proprietary, closed, open, free or commercial solutions or schemata.
- Specific: metrics are well defined and serve industry-specific assessment purposes.
- Usable: metrics are intuitive and can be easily employed to assess BIM performance.

The new BIM Quick Scan tool is intended to be used to scan an organization over four main chapters (Figure 1) that represent both 'hard' and 'soft' aspects of BIM, namely:

- chapter 1: organization and management;
- chapter 2: mentality and culture;
- chapter 3: information structure and information flow; and
- chapter 4: tools and applications.

Each chapter contains a number of KPIs in the form of a multiple-choice questionnaire. The total number of criteria is limited to 50 in order to keep an in-depth scan that can be performed with reasonable speed.

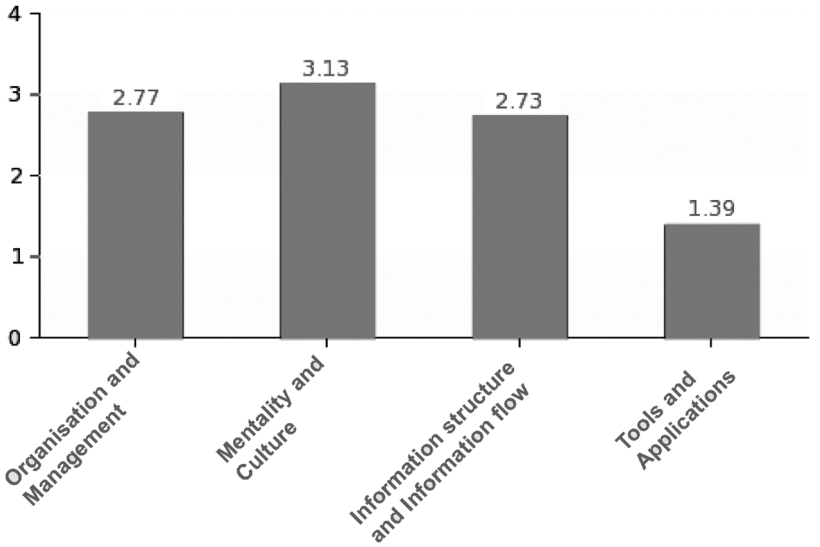

FIGURE 1 The main chapters of the Quick Scan tool
Source: TNO http://www.BIMQuickScan.nl (2010)

Within the first chapter (corporate management), the following KPIs are addressed: vision and strategy, distribution of roles and tasks, organization structure, quality assurance, financial resources and partnership on corporate and project level. The second chapter (organizational culture) focuses on BIM acceptance among the staff and workers, group and individual motivation, presence and influence of the BIM coordinator, knowledge and skills, knowledge management and training. The following KPIs are composed in the third chapter (data structure and information flow): use of modelling, open ICT standards, object libraries, internal and external information flow, type of data exchange and type of data in each project phase. The hardware- and software-related KPIs are pulled together in the last chapter (technology platforms and tools): use of model server, type and capacity of model server, type of software package, advanced BIM tools, model view definitions and supporting rules.

The analytical method is a unique combination between quantitative measure and expert opinion. The quantitative measure works as follows. With each KPI, there are a number of possible answers. For each answer, a score is assigned. Each KPI also carries a certain weighting factor. The sum of all the partial scores after considering the weighting factors represents the total score of BIM performance of an organization. The questionnaire is meant to be filled in by a BIM consultant based on an observation of the organization and an in-depth interview with the person in charge of BIM. This means that the expert opinions of the BIM consultant contribute to the justification of the answers. This also means that misinterpretation of the KPIs or the questions by non-experts can be avoided since all BIM consultants carrying out the BIM Quick Scan are certified by TNO, an independent research institute, after being trained and after receiving clear guidelines about the content and methodology of the assessment tool. The expert opinions become even more valuable for the analysis when the BIM consultant is experienced with the business operation of the assessed organization.

After analysing the results of the scan, an organization will receive a total score. A certain score always represents a certain level of performance. For benchmarking purposes, the scores are always consistent, that is, two organizations with the same score are directly comparable in terms of BIM performance. The upper limit of the score is open, which means that the

maximum score can be higher as the standard levels of performance increase along with the improvement of knowledge and technologies. A simple example can be given as follows. After a scan in 2010, Company A gets a score of '8' while the maximum score in that year is 10. Based on the latest BIM development in the following year, the maximum score is determined at 12. The score of Company A (an 8) will still be valid, but it means that the performance gap with the state of the art grows larger.

The scores for each chapter and the total score are mapped in a radar diagram (Figure 2). This diagram visualizes the level of performance related to different BIM aspects. Underperformance of particular aspects can, therefore, be easily pointed out and put into perspective in comprehensive relation with the other aspects.

During the development of the BIM Quick Scan tool, the process for applying and disseminating the tool in practice was taken into account. The assessments are performed by a certified BIM consultant upon a formal request from an organization. After analysing the results, the BIM consultant generates a report using a standard TNO template. The report contains the score, explanation of the BIM performance according to the score, and recommendations for improvement. All the results will be stored in the centralized online database for anonymous benchmarking purposes. An organization can repeat the assessment over time in order to monitor its own progress of BIM performance. Based on the assumption of the average time required for the adoption of new technology and working methods, the minimum interval period between two assessments in the same organization is six months.

Next to achieving the objective of being a standard benchmarking instrument, the BIM Quick Scan tool is also expected to help stimulate BIM innovation in the Netherlands. In order to accelerate this process, the BIM Quick Scan should be accepted by as many organizations as possible in the Dutch construction industry. Therefore, major clients and leading BIM consultants should endorse this tool. Major clients, both public and private, are expected to use this tool to determine the BIM qualification of the candidate partners during the selection or the tender process of a project. Leading BIM consultants are expected to commit to use BIM Quick Scan as the standard assessment tool to define the most appropriate advice or assistance based on their clients' current BIM performance level. The tool will also be promoted through various collaboration platforms and communities of practice.

As a way to disseminate and continually improve the tool with active participation of the users, an annual BIM Quick Scan congress will be organised. The congress has three main purposes: first, to update the construction industry on the current BIM level in the Netherlands; second, to upgrade the assessment criteria and maximum score based on

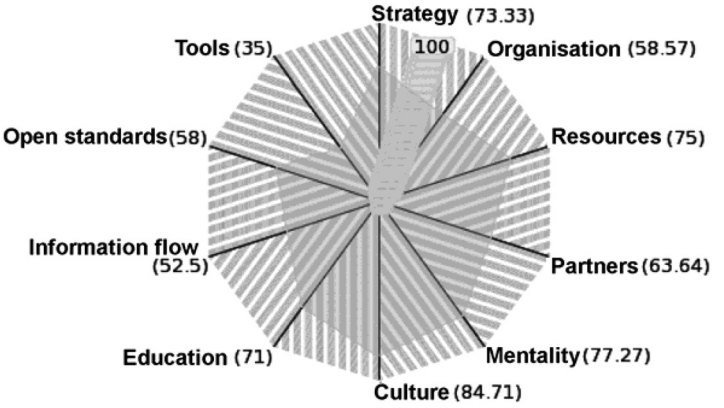

FIGURE 2 Mapping of the Quick Scan results in radar diagram
Source: TNO http://www.BIMQuickScan.nl (2010)

the feedback from performed assessments over the preceding years and the state-of-the-art BIM development; and third, to monitor the qualifications of the certified BIM consultants and to equip them with the latest guidelines about BIM Quick Scan. The guidelines are restricted for use by the certified BIM consultants. The guidelines are meant to clarify the rationale and purpose of the assessment criteria and the justification of possible answers; to clarify the weighting factors related to the different criteria in case one BIM aspect is given a higher priority compared with another; and to present supporting examples or cases.

For raising BIM awareness among the broad range of organisations in the construction industry, a simplified version of the BIM Quick Scan tool will be made available free of charge on the Internet. An organization can perform a self-scan and get an indicative score without further analysis. It is expected that the indicative result will trigger the organization to learn more about BIM performance levels, and to pursue more detailed assessment and advice from a certified BIM consultant listed on the website. In order to guarantee the accessibility and affordability of the BIM Quick Scan, especially for smaller enterprises, TNO will set a maximum price for having the scan performed by a certified BIM consultant.

VERIFICATION AND PRACTICAL VALIDATION OF THE NEW TOOL

The prototype BIM Quick Scan tool was put into verification and validation processes. The verification was done by an expert panel. The panel consisted of 15 experts, as follows: three researchers representing the knowledge areas of BIM technology, BIM implementation process, benchmarking and tool development; one university professor on architectural design systems; one business consultant; and 10 experienced BIM consultants. All the experts involved possessed practical and theoretical knowledge of the development and application of instruments to measure BIM performance. The verification process comprised reviews and expert meetings. The approach, structure, analytical method and KPIs of the BIM Quick Scan tool were subjected to scrutinized reviews by the experts. Each expert delivered his critical comments and, during the expert meetings, these comments and proposals for improvement were then discussed and decided upon. This process was repeated in two rounds.

The validation was carried out through two pilot cases. The first case represented a fictional firm; its profile and performance was created to reflect the whole spectrum of BIM aspects and practices to be evaluated. The second case focused on a real firm; it was a medium-sized design and consulting firm that had recently adopted BIM. Ten BIM consultants were independently sent to both firms to execute the BIM Quick Scan. All findings were presented and analysed in the subsequent expert meeting.

The pilot cases showed that, after independent assessments by the 10 BIM consultants, 80% of the total of 50 assessment criteria delivered equal results. This confirmed that the BIM Quick Scan tool was coherent and reliable. Variations in the results of the other 20% of the assessment criteria were studied in detail. Most variations were caused by ambiguous interpretations. Two solutions were taken to tackle this problem: (a) providing clearer definitions and more extensive explanations with examples in the standard guidelines to the consultants and (b) adjusting the weighting factors based on the reconsiderations of the level of importance and the degree of accuracy of the KPIs. A lower weighting factor was assigned to certain KPIs that were necessary for clarification, yet may lead to wider variations in score. By doing this, subjectivity in expert opinions was allowed only to a limited extent, without a major influence on the objectivity of the analysis. Several other variations were caused by lack of relevance of the assessment criteria, for example, with regard to novel concepts that were not yet commonly accepted. These criteria were then removed and stored in the 'ideas box' for possible inclusion in the future updates of the tool.

The impact of the BIM performance assessment to the particular company was also investigated based on feedback from the representatives of the real company that was used as a pilot case. The impact turned out to be positive, both at the management level, as well as at the expert staff level of the company. The prototype tool was thus

proven to achieve an adequate readiness level in terms of technical content, analytical method, user-friendliness and practical impact. A remark should be made, though, that neither the verification nor the validation process was designed to meet a full scientific standard.

CONCLUDING REMARKS

This article describes the applied research to generate an instrument for benchmarking BIM performance. The instrument aims to provide insight into the current BIM performance level of organizations in the Dutch construction industry. The purpose is very practical; that is, to justify the qualification of the parties to be commissioned for projects, as well as to raise the awareness and establish a common strategy for innovation through BIM.

Literature review shows that various existing BIM maturity assessment tools are not yet sufficiently 'mature' to serve as a standard benchmarking tool that is objective (i.e. perform qualitative and quantitative analyses), comprehensive (i.e. evaluates the model, modelling process and organization) and collective (i.e. commonly accepted in the construction industry). In order to overcome the existing shortcomings, the BIM Quick Scan tool has been developed. This new tool has unique characteristics that are as follows:

- BIM Quick Scan combines quantitative and qualitative assessments and accommodates valuable expert judgement in such a coherent way that the objectivity of the analysis is assured.
- It possesses a sufficient degree of consistency so that it can be used for a direct comparison between two organizations, as well as for benchmarking the performance of numerous organizations over time.
- It covers the 'hard' and 'soft' aspects of BIM at corporate level, ICT infrastructure level and model/modelling level.

The prototype of the BIM Quick Scan tool has been achieved through research and development from 2009 to 2010. This prototype tool has successfully passed the practical verification and validation processes. The implementation plan – which includes training and certification of BIM consultants, development and update of the guidelines and dissemination strategies – has been established. At present, 10 certified consultants have been performing the Quick Scan with various firms in the construction industry. As the number of certified consultants is growing, a broader practical impact of the Quick Scan will be gained.

The tool is expected to be used to assess individual firms, as well as firms involved in project organizations. Over the years, as the number of assessed firms grows, valuable information for national benchmarking can be collected. Future research is strongly recommended to validate the benchmarking results and to develop the most effective BIM take-up strategy based on the current performance level. Scientific validation of the KPIs and analytical methods is recommended to improve the quality, consistency and reliability of the tool. Graduate or doctoral research on this subject will be relevant to strengthen the scientific validation of the tool and to bridge academic and professional initiatives on sustainable BIM implementation and performance measurement.

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REFERENCES

AIA CC, 2007, 'Integrated project delivery: A guide', report by AIA California Council.

Bergs, R., 2009, 'BIM success forecasters by Gobar', Paper presentation at Kick-off Meeting TNO BIM Quickscan, Utrecht, 23 September 2009 [in Dutch].

CRC Construction Innovation, 2009, *National Guidelines for Digital Modelling*, Brisbane, Icon.Net Pty Ltd.

Eastman, C., Teicholz, P., Sacks, R. and Liston, K., 2008, *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors*, New Jersey, John Wiley & Sons.

Hendriks, H., 2010, *BIM Success Predictor by DeBIMspecialist*. Available at: www.debimspecialist.nl/diensten_debimspecialist/product/ [accessed 8 March 2010] [in Dutch].

McCuen, T. and Suermann, P., 2007, 'The interactive capability maturity model and 2007 AIA TAP BIM award winners', *AECbytes Viewpoint* **33** (6 December 2007). Available at: http://www.aecbytes.com/viewpoint/2007/issue_33.html [accessed 8 March 2010].

NIBS, 2007, *National Building Information Modelling Standard*, Washington DC, National Institute of Building Sciences.

Pikkaart, J.K., 2008, 'BIM measure tool by BouwnD', Paper presentation at BIM Caseweek, Utrecht, 17 November 2008 [in Dutch].

Sebastian, R., 2010, 'Integrated design and engineering using BIM: a pilot project of small-scale housing development in the Netherlands', *Architectural Engineering and Design Management* **6**, 103–110.

Senate Properties, 2007, BIM Requirements, Senattii.

Succar, B., 2009, 'Building information modelling maturity matrix', in J. Underwood and E. Isikdag (eds), *Handbook of Research on Building Information Modelling and Construction Informatics: Concepts and Technologies*, Hershey PA, IGI Publishing.

Succar, B., 2010, 'The five components of BIM performance measurement', in *Proceedings of CIB World Congress, Salford*.

Team BouwICT, 2010, *BIM Dictionary.* TNO [in Dutch].

TNO, 2009, 'Research project proposal TNO-MKB Technologiecluster BIM Quickscan', internal report (2009) [in Dutch].

TNO, 2010, *BIM Quickscan*. Available at: www.BIMQuickScan.nl [accessed 20 July 2010].