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ORIGINAL ARTICLE

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A visual information tool for user participation during the lifecycle of school building design: BIM

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Abstract

User participation is a key element in decision processes concerning the accommodation of dynamic organisations such as schools. This article addresses the discrepancy between the perspectives of the architects and engineers, as the makers of school buildings, and school management, teachers and students, as the users of the buildings, and proposes that productive and efficient participatory design of school buildings requires appropriate information tools. Visual information technology tools, such as Building Information Modelling (BIM), already used in interaction between architects, engineers, consultants, etc., are proposed to support school managers, teachers and students in participating in all stages of the life cycle of their school building. The proposed use of BIM is compared to a retrospective analysis of a Dutch school which realised a completely new secondary education building. The article concludes with recommendations to increase the impact of visual information technology tools such as BIM in the design of school buildings in Europe and beyond.

1 | INTRODUCTION

The influence of the built environment on the learning experience is a recurring subject in both educational and architectural studies. The physical learning environments impact quality of learning (Choi, Van Merriënboer, & Paas, 2014; Ellis & Goodyear, 2016) and many studies illustrate the value of user participation in school design (Hofmann, Hondl, & Templeton, 2014; Woolner, 2010, 2015). A continuing challenge, however, is the discrepancy between two views on school buildings (Woolner, Hall, Wall, & Dennison, 2007): on the one hand, the makers of the built environment - architects, engineers and other professionals in AECO (Architecture, Engineering, Construction, Operation) who tend to focus on technical matters, and on the other, teachers and students who may treat buildings as a fixed, indifferent or even unresponsive background of their teaching and learning. A telling example of the differences in perspective is that architectural publications routinely include school photographs without teachers and students, as if the activities for which the buildings were designed would detract from the appreciation of the built form. Conversely, teachers and students tend to take buildings for granted and try to teach and learn within their limitations – something humans manage with remarkable adaptability, even in rather unsupportive environments (Braster, Grosvenor, & del Mar del Pozo Andrés, 2011). This article elaborates on the use of visual information technology tools to create and use opportunities for collaborative, inclusive life cycle processes for better interaction between a school building and teachers and pupils or students as its users.

Accommodating teaching and learning activities in school spaces is often limited to re-arranging furniture rather than realising or improving its potential for specific educational conditions (Koutamanis, 2006; Maier, 2011; Tweed, 2001). Adaptability and misguided tolerance of the users account for much of the dissatisfaction with the built learning environment. The accumulation of even minor unsatisfactory features in a school building severely limits its potential for both teachers and students (Braster et al., 2011). It is therefore important that the communication between teachers, students and AECO professionals helps to make explicit and resolve problems as early and as transparently as possible. Getting things right from the beginning is critical, not only because problems may unjustly affect a number of pupil generations, but also for economic reasons. In the Dutch educational policy system, for instance, a secondary school receives a one-off investment budget for its building that covers a period of (at least) 40 years within which no additional budgets are made available for modifications and improvements. This discontinuity in investment in the optimisation of school buildings can also be observed in other countries like the UK (Mahony, 2011; Mahony & Hextall, 2013).

Using visual tools in the participatory building design process is beneficial as a way of bringing together different stakeholders with various importance and influence to discuss building design. Visual tools lend themselves well to participatory projects with students in schools and universities (Clark, Laing, & Woolner, 2013). They can help stakeholders who have a limited understanding of each other's roles and concerns to gain a basic understanding of and empathy with the views of others (Clark, 2010; Woolner, 2010), as well as those who struggle with reading huge amounts of official documentation, or may lack confidence to express their views in front of others with different perspectives (Woolner & Clark, 2015).

In the interaction between designers, architects, engineers, and consultants, the use of visual approaches and information technology is common practice. These tools could also support managers, teachers and students in participating in the design process of their school building, enabling them to improve the alignment between educational goals and policy and the built learning environment. In this article, we will elaborate on an example of a visual information technology tool - Building Information Modelling (BIM) – in the new context of participatory design of the built learning environment.

The proposed use of BIM is compared to a retrospective analysis of the design process at an innovative Dutch school, the Werkplaats Kindergemeenschap (henceforth WP) in Bilthoven, The Netherlands, which realised a new secondary education building in 2006 without the structural use of a visual information tool like BIM. The reflection on this particular design process is fed by the experiences of the business director of the school, who is a co-author of this article, and the data of a recent publication on this topic (Burke & Könings, 2016). The WP was established in 1926 by Kees Boeke on the basis of Christian-pacifist principles that prepared children to contribute to a peaceful world. As a result, the school has offered education that deviates from the norm, putting emphasis on communal activities, self-direction and social responsibility. Hence, it has rather specific accommodation requirements. Participation in the design, construction and use of the school building is a key issue in the WP and this makes it an interesting case to analyse. From this case, the article derives recommendations to increase the impact of these technologies for the inclusive, participatory design of school buildings.

2 | A BUILDING'S LIFE CYCLE

The discrepancy between the perspectives of different stakeholders partly derives from what happens at various stages of the life cycle of a school building and the transitions between stages. A building's life cycle comprises four major stages (Franzen, Hobma, De Jonge, & Wigmans, 2011; Koutamanis, 2014). Applied to the school context, these are:

1. *Initiative*: Before starting to design, school management, teachers, students and related stakeholders, such as educational policy makers, specify what is needed: the feasibility of the school, its location, budget, brief, etc.

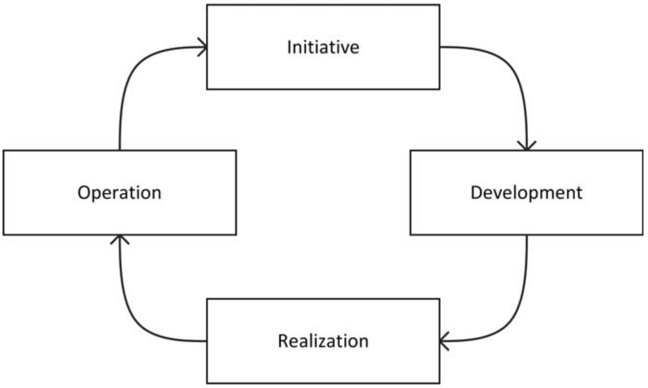

FIGURE 1 Stages in a building's lifecycle

2. *Development*: Designers, engineers and consultants develop designs of the school building that satisfy the needs specified in the initiative stage (Simon, 1996).
3. *Realisation*: The school building is constructed as specified in the development stage.
4. *Operation*: The finished school building is occupied by teachers and students who deploy their teaching and learning in it, and is maintained by AECO professionals.

What makes these stages a cycle (Figure 1) is that a school building in operation triggers new initiatives: as soon as teachers and students enter a school, problems and opportunities are identified. The problems may be due to its design or construction (including deviations from the brief), changes in ways of teaching and learning (differences with the original brief are inevitable over time) due to innovations in educational approaches or wider social conditions (as with the recent need to equip existing buildings with computer networks or improve their energy performance). A new initiative often leads to new development and realisation stages (refurbishment or extension, but possibly abandonment of the building).

The challenge with user participation in school design is that its intensity and content varies with each stage. Whilst AECO professionals are continuously present and have consistent areas of interest (e.g., structural engineers are responsible for the structure of the school building at all stages), school management, teachers and students may be valuable informants for the initiative and insightful evaluators during development, but largely absent in the realisation and often passive recipients of what AECO professionals have made in the operation stage (Könings, Bovill, & Woolner, 2017, pp. 306–317; Van Merriënboer, McKenney, Cullinan, & Heuer, 2017, pp. 253-267). Establishing continuous presence of management, teachers and students is key to increasing the effectiveness and reliability of user participation in the design process.

In all stages of the life cycle, there are four interconnected aspects (Koutamanis, 2014). The *form* refers to the geometry of the school building and its construction, the classrooms or other spaces it comprises and the building elements (walls, doors, floors, etc.). *Activities* describe all teaching and learning activities that take place in the school building, e.g., group work or plenary instruction. *Behaviour* refers to the interaction between the shape of the school building and the educational activities that take place in it. Finally, *performance* becomes apparent in the evaluation of behaviour, based on either general educational and AECO criteria, such as building regulations, or specific ones, such as the demands of the school, as defined in the initiative stage.

These aspects have varying relevance for different stakeholders during the design process. Teachers and students are a primary source of information on school activities, especially those that are not common knowledge among AECO professionals, such as the particular needs of a pedagogical approach. This information is critical for the specification of activities and requirements in the initiative stage and to understand behaviour. Understanding how educational activities interact with a school building is useful in the initiative and development stages, but even more critical as a trigger for new initiatives or conscious adaptations of activity patterns.

The long and chequered history of user participation in architecture demonstrates awareness of its utility in Initiative and Development (De Graaf, 2016; Jenkins & Forsyth, 2010; Luck, 2007; Toker, 2007), although there may be better tools to bring together stakeholders' perspectives and decision making. The problem with user participation is that it often remains confined to the abstract levels of intentions and impressions. Its products generally require an interpretation by AECO professionals (Hofmann et al., 2014). To have a real impact, participatory design needs to enter the core processes of AECO in a transparent and constructive manner that allows school directors, policy makers, teachers and students to fully understand how their input is processed and the consequences of their choices. Anecdotal evidence for this problem abounds. In the WP case, the school stipulated floor edgings in corridors and stairs that would simplify cleaning, but in the stairs the opposite happened, as the balusters were attached to the treads.

3 | IMPROVING PARTICIPATION IN DESIGN: INFORMATION TECHNOLOGY TOOLS

All stakeholders should have the opportunity and means to contribute to the design of a school building, although their level of influence should depend on their role in the daily use of the building (Könings et al., 2017, pp. 306–317) and its main educational purpose. In this article, user participation refers to teachers and students. However, parents, janitors and other, often invisible support staff can also be involved, and even neighbours, other members of the local community with a particular stake, and guest users of the school facilities (e.g. clubs that use the school after school hours).

One challenge is how one could create and employ opportunities for collaborative, inclusive life cycle processes for better interaction between a school building and teachers and students as its users. We propose that *information* and adequate sharing of information form the basis for the structural improvement of user participation. In AECO, new information technologies are available which can help stakeholders to become full participants throughout the whole life cycle of the school building.

4 | BUILDING INFORMATION MODELING (BIM)

BIM is a computer technology for the comprehensive, consistent and coherent representation of buildings (Eastman, 1999; Eastman, Teicholz, Sacks, & Liston, 2011). Regarding collaboration between AECO professionals, rather than letting each one make their own drawings, BIM has shared 3D models that integrate all the information (geometric and alphanumerical) from all the parties involved. To describe a building, it uses predefined symbols for elements such as walls, doors, windows and roofs, complete with all relevant properties. The symbolic representation of BIM establishes a common information basis for all AECO professionals (Singh, Gu, & Wang, 2011). For example, the shape of a classroom wall may come from an architect, its construction from a structural engineer, and additional properties from a fire engineer (see Figure 2 for an example of a BIM screen dump). Hence, BIM contains a full, up-to-date representation of the school building, including communication between stakeholders and decision making. A shared model forms a stable basis that makes evident conflicts and lacunae, facilitates process management and interaction, and prevents design failures that may become apparent too late. A relevant example from the WP case concerns the positioning of photocopying machines in the corridors of the building. The Fire Department objected to that when the building was completed. The machines had to be repositioned in the *domains* (open spaces that combine activities traditionally taking place in classrooms), a move that necessitated spatial and infrastructural adjustments.

BIM facilitates continuity in information sharing throughout the life cycle (Bryde, Broquetas, & Volm, 2013). BIM deployment in AECO is currently directed primarily towards the development and realisation stage. This is when most AECO professionals must produce and communicate large amounts of information and separately or jointly take rapid decisions. Nevertheless, BIM could also become the hub of information exchange in the whole life cycle of a school building and support continuity by recording its history, including how it is used by teachers and students, changes in the physical spaces, and the educational activities through time.

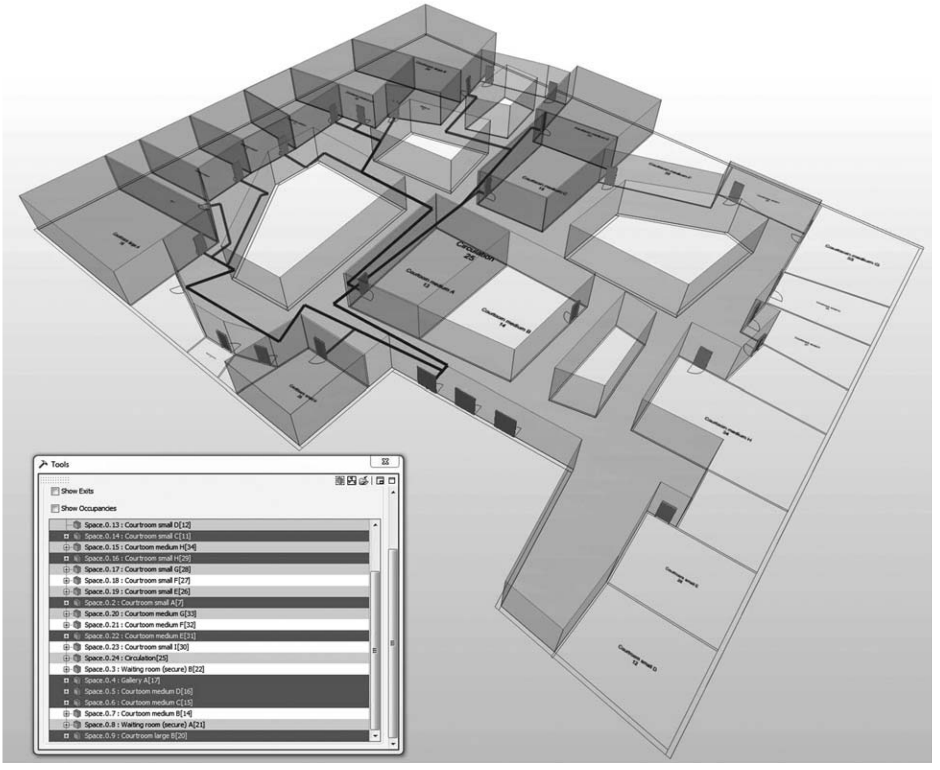

FIGURE 2 3D model of a floor in BIM, including analysis of fire egress routes

Recently, there has been growing interest in extending the use of BIM to the operation stage, usually for the benefit of institutional clients who remain involved in the use of their buildings in a technical or financial sense (Bosch, Volker, & Koutamanis, 2015; Love, Matthews, Simpson, Hill, & Olatunji, 2014). BIM helps to perform additional tasks of registering. In schools, this could extend to registering timetables and their effects on the occupation and use of classrooms and other spaces.

The participation of users through BIM has yet to attract sufficient attention (Kerosuo, 2015). This is not in line with its holistic ambitions and potential. The following section suggests how BIM could be employed in each life cycle stage with respect to user participation. In the absence of fully comparable cases, the potential of BIM is drawn from general studies, e.g., on conflict resolution through BIM (Sampaio & Berdeja, 2015) and partially matching cases, such as analyses of thermal comfort and energy retrofitting of schools using BIM (Giuda, Villa, & Piantanida, 2015; Volkov, Sedov, Chelyshkov, & Kulikova, 2014). The resulting cumulative characteristics are compared with the WP case, which followed the same stages and returned results that could be considered characteristic of good participatory design along conventional lines, i.e., without BIM.

5 | BIM AND USER PARTICIPATION IN THE LIFE CYCLE

5.1 | Initiative

The initiative stage deals with preparations for designing and constructing a school building, such as deciding on its location and budget. A key product of this stage is the brief: the specification of what users need in their school in terms of goals, constraints and requirements (Blyth & Worthington, 2010; Peña & Parshall, 2012; Salisbury, 1998). Goals call for an energy-efficient building, fire safety, easy orientation or open and transparent classrooms. They are analysed through advanced techniques such as simulations (e.g., for energy consumption or fire egress), but may also involve judgement by experts, clients and users (e.g., evaluation of openness). Constraints form guidelines on various aspects of the design of the school, from the positioning of learning and teaching activities within the available space and the number of storeys, to the type of materials or colours allowed and building costs. Requirements describe what is needed for each educational activity: floor area, space height, light level, facilities, relations to other activities, etc.

Integrating educational activities in a model in BIM would involve predefining each activity specified in the brief as a type of space with its requirements. When one designs a space for an activity, one selects and places the activity in the model (Koutamanis, 2014). Activities can be combined in time and space, producing novel solutions, or parsed into actions that are treated differently than in the brief. In all cases, what matters is that school management, teachers and students have a full understanding of how the design relates to their goals and requirements.

Participation of teachers and students at this stage is not unusual, but is limited by the ways information is processed in conventional practices (Blyth & Worthington, 2010; Koutamanis, 2014). They normally act only as informants, providing input that is interpreted by AECO professionals into technical data that may not always be legible for them. Brief implementation in BIM could make these interpretations more transparent and manageable for teachers, students and other involved stakeholders. Teachers and students could even be given joint authorship: the ability to directly enter and modify requirements on activities, especially with respect to educational aspects.

Precedents of other existing school buildings can be invaluable in briefing with BIM: They can be entered in the model so that the brief can be tested in what-if experiments. Teachers and students could see how it can be accommodated in real, acceptable school designs. Such precedent-based experiments would help teachers and students to visualise and analyse their insights, e.g., to envision enactment and spatialisation of learning activities. Furthermore, they would help to avoid stereotypes – a frequent and detrimental occurrence, where learning activities are reduced to standard solutions (Nordquist & Laing, 2015), retaining many irrelevant, unnecessary or even contradictory characteristics of these solutions. The longevity and perseverance of the Victorian classroom can be explained by such stereotypical thinking (Koutamanis & Majewski-Steins, 2011). Finally, they would establish procedures for the collaboration between AECO professionals and teachers and students in the development stage.

In the WP case, the initiative stage had a typically long duration and goals shifted. Halfway into the 1990s, the school decided to reconsider its existing buildings that dated from 1951 and 1968. The reasons were operational and financial, as Dutch policy was to subsidise school buildings per capita (number of students), and not on the basis of the floor area of its buildings. This meant that the school would have a financial deficit, as well as a surplus of floor area in the operation of its real estate. In 2000, the school and the local municipality decided to build a new school. As this would also create opportunities for educational improvement, it was warmly welcomed by the school and raised the level of ambition for the new building.

The school directors and a number of external advisers set up a vision for the future by looking back at the principles of the school, its fundamental approach to teaching, and how these could inspire the design of the new building. This vision was further discussed with the other members of the school management and the teachers, leading in 2003 to a participatory process that allowed teachers to think out of the box about innovative standpoints for the education offered by the school. The process involved brainstorming sessions where user working groups explored questions such as student group size and learning formats, combining experience with expectation in a clear vision about the school activities and their accommodation in a building (Dansen, Dorleijn, & Isselt, 2006). The results were integrated in a detailed brief containing the goals and requirements of the school.

There was every reason to be satisfied with the approach and results of this stage. The principled attitude and the assistance of external experts produced a clear expression of their intentions, which was shared with the AECO professionals responsible for the development. The only limitation was the conventional tools used to register the results: A conventional brief can be a very lengthy, detailed and eventually redundant document that defies direct or coherent interpretation. Understanding the main goals of the school posed no problems for AECO professionals in this case, but connections between these goals and requirements relied on extensive communication between AECO professionals and the school. If such communication was absent or ineffective, there emerged lacunae or conflicts that could affect the design, as in the case of the stair balusters.

5.2 | Development

Participation of school management, teachers and students in the development stage should amount to more than sessions in which designs are presented and discussed. With BIM as a tool for sharing information, all participants in a project could view the state of a design at all times. Meetings can then become moments of intensive analysis and joint decision-making that promote exploration and dialogue. Teachers and students can play an important role as joint *custodians* of the brief, ensuring that every activity and requirement is properly included in the design.

This interplay of design and brief can create feedback in both directions. Feedback to the design usually means that the design must be improved in order to better match the brief. In this case, teachers and students can educate AECO professionals by explaining to them the significance of what they need in the design, showing them how omissions or deviations from the brief affect the accommodation and performance of educational activities. Computer technologies of interactive visualisation and analysis help this communication by presenting information in an accessible and unambiguous manner. Feedback to the brief will lead to improvements of some of the goals, constraints or requirements, usually through a novel solution. Here, teachers and students have the opportunity to be educated by the AECO professionals, expand their knowledge of spatialisation, return to their didactic and pedagogical foundations and reconsider how these take place.

In short, the main theme of user participation in the development stage is the comparison of what was specified in initiative and the designs produced in response to that, especially between the abstract description of activities in the brief and expectations concerning behaviour (i.e., interaction between space and activities) when confronted with the designs. It should be stressed that even with the best intentions on both sides, it is not easy to find adequate and lasting solutions. For example, it is generally assumed that educational innovation leads to architectural innovation and that school designs that offer innovative spaces are deemed to better support teaching. However, schools may have trouble using such spaces because the school organisation may lag behind its ambitions (Campbell, Saltmarsh, Chapman, & Drew, 2013; Woolner, Mccarter, Wall, & Higgins, 2012) or because the school reverts to conventional teaching approaches (Sigurðardóttir & Hjartarson, 2016).

The design of the WP followed predictably conventional lines, with the architects and engineers putting the brief into form. The design teams included a representative of the school, whilst the user working groups of the initiative stage remained active and were frequently consulted. This interaction is exemplary of good participatory design and can ensure adequate communication between AECO professionals, clients and users. All parties involved had the feeling that teacher and student participation in the development stage was productively and efficiently organised.

Once again, the main limitations related to using conventional tools in these processes. Communication of the design on the basis of drawings and technical analyses, involved intensive mental processing of large quantities of information to understand how brief goals (e.g., openness of a classroom) were interpreted and how teaching and learning activities were to be deployed in the spaces described by the drawings. This was largely because the brief was linked to the design with conventional means. There was little, if any explicit connection between an activity requirement and the corresponding property of the learning space; for example. Going analytically into every detail was therefore simply not feasible and so conformance to the brief was only evaluated abstractly. For example, openness may be a goal that inspires designers to innovative solutions that negate many educational limitations of traditional classrooms, but at the same time it can have consequences for acoustics, air circulation and fire safety that may remain unnoticed.

In the WP case, the careful definition and correlation of goals and requirements in the brief helped the school to identify and discuss such matters with the designers. Unfortunately, decision making was not always kept transparent for school participants, e.g., concerning budgetary constraints on the capacity of the HVAC (heating, ventilation and air conditioning) system or the aforementioned issues with the stair balusters and photocopying machines.

5.3 | Realisation

In this stage, it seems that teachers and students have little to contribute. However, as information custodians, they still have to monitor changes as they appear in the model and keep track of how the design is implemented, so that they can react to any unwanted deviations from what was agreed in briefing or designing. Realisation also gives teachers and students time to prepare for using the building: Having had virtually experienced the form that will accommodate them, they now have the opportunity to look back at what they intended to do in the new building and refine their expectations. This may involve any number of organisational and educational issues, from making detailed and accurate plans for moving into the new building to training in the use of new facilities and new kinds of spaces.

In the WP school, the transition to realisation was facilitated by the inclusion of the main building contractors in the design team, which ensured that they understood the priorities and goals of the school. The design team remained responsible for inspections and progress evaluation. Once again, problems related to the lack of transparency in decision making. In this stage, it is not uncommon to apply changes to the design as a result of construction constraints, which may affect the goals and requirements of the brief. For example, the teaching areas in the WP were to have panelling in the lower part of the walls for ease of maintenance. Unfortunately, the type of panelling chosen by the architect proved infeasible. Instead, the walls were protected by a coating. The school agreed to that but during the operation stage the coating proved ineffective and consequently panelling was being introduced in an increasing number of spaces in the school.

5.4 | Operation

Operation forms the biggest challenge to both AECO professionals and teachers, students and school management. They may benefit from using BIM for all their information processing, as integrating property and facilities management information helps to identify technical needs and priorities, e.g., the failure of lighting. Integrating data relating to behaviour and performance, such as classroom occupation and use intensity or air temperature under different activities, is also easy and rewarding, as it provides a comprehensive picture of the school in use.

Whilst AECO professionals can use behaviour and performance data to look back at the design of the school building, teachers and students can do the same concerning teaching and learning activities. One of the key questions in the operation stage is the difference between what they imagined in the initiative stage, what they expected from development and what they are experiencing in the operation. Such comparisons can help teachers, students and school management to identify the reasons for possible disappointments and guide them towards better descriptions of their activities and needs (Sigurðardóttir & Hjartarson, 2016). In many cases, this leads to clearer descriptions and specifications of goals and requirements that should be in the brief in a new Initiative. Achieving a good match between form and activities generally requires a number of such cycles. Furthermore, like in the earlier stages, it is inevitable that only a small number of users from a school community is involved. In the operation stage there is no need for such restriction. Every teacher or student of a school can be part of post-occupancy analyses and evaluations.

In the WP case, unlike the abundance of information delivered by the AECO professionals in the initiative and development stage, the completion of the building was not accompanied by sufficient information on how it could be used, despite the many essential differences with the previous accommodation (Burke & Könings, 2016; Van Merriënboer et al., 2017, pp. 253–267). Users had to learn how to use the school by exploration and trial.

Added to that, there were technical shortcomings that took years to correct, in particular, the sun shading and panelling in the HVAC system. The combination of inadequate information and technical problems resulted in disorganised processes between the school and AECO, which reflected the distributed nature of warranties and accountability. Nevertheless, there was no breakdown in the collaboration that was established by the participative design of the building. Most problems were solved thanks to the efforts of the school and members of the design team, proving that they were not due to unwillingness or lack of professionalism, but that they could have been solved more easily or earlier with better means.

The most striking modification in the ten-year history of the school building of the WP derived from a general evaluation that took place a few years ago. It concluded that the building was largely satisfactory, with the exception of acoustics in the domains. Specialist consultants measured the acoustic performance of these spaces and developed a solution that involved placing acoustic panels in strategic positions. The school incurred the expense of these panels and performance improved significantly. What makes this modification relevant is that the greater acoustic requirements of the domains because of the openness goal were clearly specified in the initiative and development stage. It was only the solution proposed by the designers that proved inadequate. Lacking precise data, one can only speculate about the causes of the failure. What matters is that such causes could have been identified in an integrated information environment that would have improved transparency in the relations between form, activities, behaviour and performance.

Such an information environment can also be relevant for the next task of the school. An evaluation of its educational structure was planned in the academic year 2016–2017, including many organisational matters that relate to interaction with the building, such as scheduling. Understanding this interaction and the constraints of the building is important in the Dutch educational policy system and the one-off investment funding a school receives for its building for a period of 40 years. If modifications to the building could improve educational performance, the school must find the necessary financing within its regular operation budget. This can be facilitated by life cycle analyses of various scenarios in BIM, which help to justify investment in improvements against the lowering of operation costs or measurable improvement of performance. Connecting a model of the current form of the school building and teaching and learning activities to what was specified in the original brief and design could also present an invaluable learning opportunity: Describing the current situation and explaining it on the basis of its history would make predictions regarding both for the technical and the educational sides of school performance more transparent.

6 | CONCLUSION

A comparison of the potential of digital, integrated information tools, such as in BIM, and a successful conventional participatory design project such as the WP shows that appropriate information technologies can empower users such as school management, teachers and students to become full participants in the entire life cycle of a school building. Schools and policy bodies should realise that school buildings have a life cycle with a demanding and costly operation stage. Designing and constructing a building are only the beginning. Keeping track of the history of a building through technologies such as BIM empowers schools to have a clear understanding and reliable projections of their buildings, and how they relate to their educational vision. Additionally, schools should stimulate participation of users such as teachers and students in AECO processes as an important safeguard for both the smooth functioning of the school and educational performance or change. With technologies such as BIM, users can reach the core of AECO processes and make certain that what they need is fully and correctly interpreted in all stages of a school building's life cycle. Additionally, information technologies such as BIM serve as enablers of change: The availability of tools can increase interest among teachers and students in how and why the school building performs as it does, leading to wide and active user involvement in the operation of their own learning environment and the deployment of new initiatives.

This article described the potential application of BIM in school design in a thought experiment, by comparing it with the design process of an innovative school that created a school building without BIM, showing how this tool would have been of added value. Using information technologies such as BIM is neither a panacea nor a definitive solution. What they do is open up possibilities for fuller, and more effective and productive collaboration between different stakeholders, including users, to optimise the design of the physical learning environment that best supports teaching and learning. One should approach such technologies both constructively and critically, experience and evaluate them against one's own needs and aims. Further research should be undertaken to evaluate case studies of participatory school design processes in which either BIM is implemented to facilitate the design process. Additionally, exploring the impact of BIM within a participatory school design process could be studied at different educational levels, such as secondary education, higher education, and vocational training, since optimising the physical learning environment is crucial at any educational level.

BIM is becoming common practice in AECO and compulsory for most public buildings in most European countries and beyond (Cheng & Lu, 2015; Davies et al., 2015). As the retrospective analyses of the WP case suggests, schools could benefit from BIM to safeguard their interests and improve performance in design, construction and use processes. It is recommended that schools further explore the potential of visual information technology tools such as BIM, not only for technical and financial matters, but especially to support participatory design of their built learning environment with the involvement of teachers and students.

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