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Conceptual framework for improved management of risks and uncertainties associated with the performance of the building enclosure

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ABSTRACT
The building enclosure has a substantial impact on the overall performance of a building, especially in relation to moisture safety, energy use, environmental footprint and economy. Although the introduction of novel building technology can increase the risk of failures in terms of reduced building performance, failures can also result from the recurrence of past mistakes while using well established building technologies. This indicates that the dissemination of existing knowledge, often documented in project reports, handbooks or experience databases, is not always carried out in an efficient way. One way of addressing the issue is by increasing awareness concerning potential risks and uncertainties in the building process. The current paper presents a conceptual framework which has the broader aim of promoting risk awareness, improving the treatment of uncertainties and ultimately facilitating risk informed decision making during the modern design and construction process. The framework incorporates risk treatment with BIM based design and construction and could be supported by existing failure/damage and/or experience databases or knowledge systems.

KEYWORDS
Building performance, risk management, BIM, conceptual framework.

INTRODUCTION
There is currently an imbalance with respect to the treatment of risks and uncertainties in the design and construction of our built environment. While safety formats that aim at ensuring, and assuring, adequate safety against structural failures and malfunction are in place (e.g. CEN 2002), the treatment of risks and uncertainties related to the performance of the building envelope, indoor climate energy use, etc., lags behind. One important factor is that there are less severe consequences associated with building performance failures compared with structural failures. On the other hand, building performance risks are more long term and have a clear negative impact on durability, environment and the end users' economy. In addition, the predicted performance of a building, determined during design or through simulation, may in some cases deviate significantly from the actual observed behaviour of the building; e.g. the deviation of observed and predicted performance of so called green rated buildings (Lee & Hensen, 2015). These deviations highlight the underlying uncertainties which will require consideration in order to more appropriately treat building performance risks.

Building information modelling (BIM) is widely used by the architectural, engineering and construction (AEC) industry. There are a number of ongoing efforts to extend the traditional use of BIM to cover other aspects of building design and construction including engineering risk management (Zou et al., 2017) and building performance (El-Diraby et al., 2017). BIM is considered as having the potential to generate more design alternatives, enabling an optimization of, e.g., a building's energy performance (Habibi, 2017; Li et al., 2017). Another area of focus for research and development efforts is quantification of the sustainability or robustness of building design (Jelle et al 2013).

Efforts have been made to integrate a risk aware approach into the analysis of building life cycle aspects using BIM (Pruvost and Scherer, 2017). Design alternatives can be re-analyzed in the light of identified uncertainties and simulation results. Analysis of risks is often carried out by development of ontologies and the use of semantic web technology for representation of the risks (Ding et al., 2016). Main difficulties associated with an ontology and semantic representation approach are, however, that the complexity of the semantic representation of risk knowledge. There is a need for collaboration between the experts creating the BIM models and those working with risk interpretation; these types of approaches are often time-demanding.

This paper presents a conceptual framework for the treatment of building performance risks, with focus on the durability of the building envelope, using BIM. The framework has been developed taking into consideration the following aspects:

- Existing knowledge base concerning risks of conventional building solutions is vast.
- The dissemination of this knowledge to avoid failures may be poor or lacking.
- Risk awareness among AEC professionals may not be adequate in all cases.
- Uncertainties concerning building performance may be difficult to treat numerically.

To help address these issues, the framework aims to promote critical reflection rather than delivering detailed answers or metrics; provide support through all phases of the design and construction process, and; improve transparency and traceability of the risk management process in practice. In the current paper, theoretical aspects are highlighted while some discussions concerning the practical implementation of BIM risk management are provided.

INTEGRATING BIM & RISK MANAGEMENT

There is significant interest by researchers to integrate risk management in AEC through BIM and BIM-related technologies. A survey by Zou et al. (2017) reviewed a number of these efforts and identified some common approaches including the use of BIM to implicitly improve risk management, automatic rule checking as well as reactive and proactive IT-based systems to manage safety risks. In terms of application, a vast majority of the existing approaches focus on construction personnel safety risks (e.g. Ding et al., 2016). There are some exceptions, however, including Pruvost and Scherer (2017) who investigated risks in the building life cycle through an explicit consideration of uncertainties in energy simulations; i.e. quantified uncertainty modelling. A difficulty with applying this type of approach in practical cases is that it requires a stochastic model representation; i.e., a statistical description of the model parameters. Realizing such representations for all relevant risk scenarios may be difficult in practice due to a lack of reliable data and the nature of the uncertainties involved (e.g. the prediction of human behaviour in dwellings). Furthermore, the evaluation of the resulting quantified risk metric will require an objective risk based acceptance criteria and it is unclear how one can be obtained which is generally applicable for all building performance risks.

Although there is a great deal interest towards using BIM or BIM-related technologies to facilitate risk management, there are limitations of existing approaches to consider building performance risks. To start, unlike construction safety risks, which are the focus of many existing efforts, there is a discontinuity in the process of managing building performance risks. The former is often conducted by a dedicated team of practitioners while the latter is affected in varying degrees by the different process actors (architects, structural designers, HVAC engineers, etc) and can also be influenced by the end-users. There is nothing to ensure an effective knowledge transfer between process actors in terms of addressing these risks. In addition, design and construction decisions that affect building performance risks are not necessarily made in light of these risks. This may be due to a lack of knowledge or simply that they are overlooked or neglected as a result of focus on other integral aspects of the construction process; e.g. time pressure or economic constraints.

CONCEPTUAL FRAMEWORK

In reviewing building failures it is common that the unfavourable influences leading to failure were avoidable. Failures – generally defined as any unwanted deviation from design expectations – can often result from such influences being subjectively unknown, inadequately treated or overlooked during the design or construction process (Schneider, 1997; Breysse, 2012). This highlights a need for more effective knowledge transfer and management within the AEC community. In light of this, a conceptual framework for improving the management of building performance risks is considered which integrates risk relevant information from existing sources with BIM tools. The primary aim is to increase the awareness of risks by the process actors (architects, engineers, constructors) throughout the building process, especially during the early design stages, and facilitate the treatment of potential building performance risks during the entire design process. It is proposed that the framework should facilitate risk informed decision making through a cognitive loop as shown in Figure 1. Focus is on building performance risks resulting from poor or uninformed decisions made during the design and construction; a treatment of risks related to e.g. human behaviour in dwellings requires special attention.

The proposed framework intends on making rinformation concerning technical solutions with long term risks available in BIM-software in order to provide decision support for improved risk management. The following objectives are highlighted:

- Improve risk awareness and promote critical reflection.
- Provide access to existing risk relevant knowledge *throughout all project phases*.
- Improve transparency and traceability.
- Improve risk communication & knowledge transfer *throughout all project phases*.

It is envisioned that the framework shall be integrated with existing BIM platforms as an add-on or independent application. Design decisions concerning building solutions (facade materials, drainage, etc) shall consider potential building performance risks and this requires feedback to the process actors. A risk filter is thus required which can review construction objects within the BIM software and provide output, while citing source materials that describe potential risks, present possible causes and consequences, and describe suitable mitigation and avoidance measures. To enable this filtration, an IT database could be constructed which utilizes existing experience and knowledge concerning performance failures; i.e. a database containing relevant risk information. In contrast with earlier attempts (Ding et al., 2016) risk information shall be made available to construction objects structured according to existing, commercially available, building classification system(s) such as BSAB (https://bsab.byggtjanst.se/) or Uniclass (https://toolkit.thenbs.com/articles/classification).

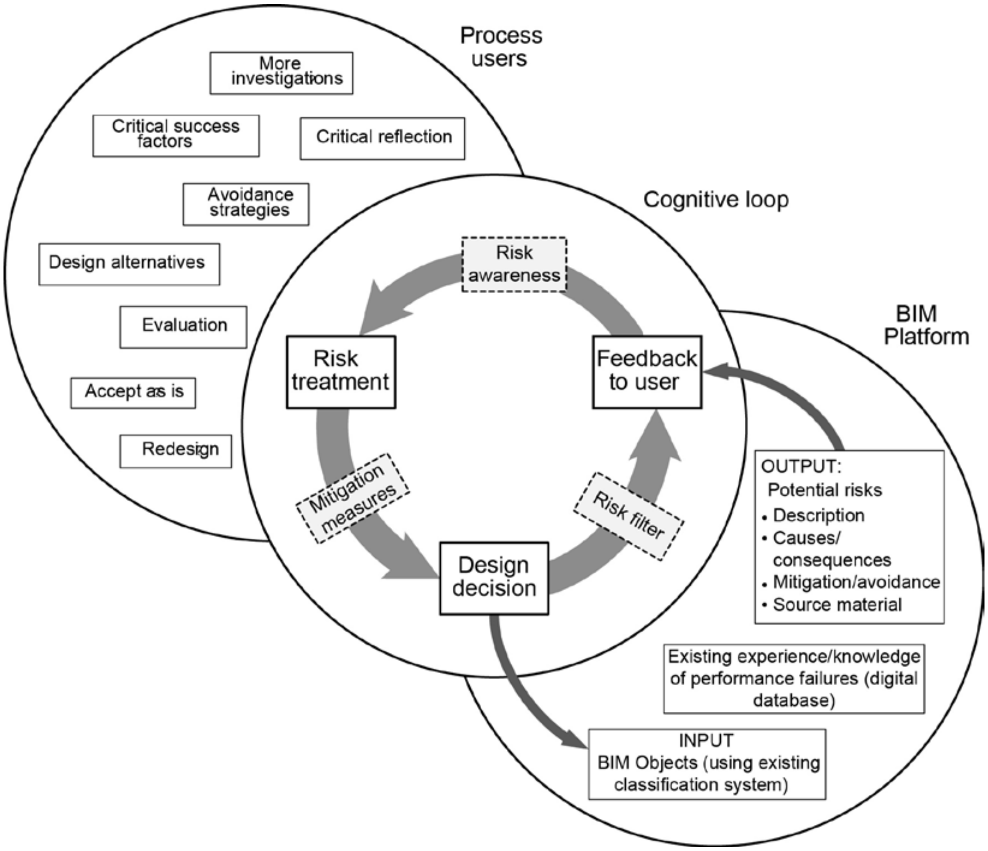

Figure 1. Illustration of Conceptual Framework showing a cognitive loop connecting the BIM platform with process users for integrated risk informed decision making

Commonly, risk relevant information is contained within textbooks or published papers (e.g. Douglas and Ransom, 2013; Molnár et al, 2016) although online or electronic databases may also be available (e.g. Imhof 2004). The relevance and reliability of information to be used as a basis for risk informed decision making has to be secured. In some cases, this type of data may be management by dedicated agencies with integrated quality control processes. One example from the Nordic region includes BYG-ERFA in Denmark (www.byg-erfa.dk), which is an independent organization collecting and disseminating quality controlled knowledge concerning building technology failures through traditional information channels such as print and pdf.

Feedback to the user shall be presented in terms of identified risk scenarios providing information concerning the following aspects:

- Description of potential risk (e.g. damage type)
- Potential causes and factors influencing initiation
- Possible consequences of the identified risk
- Possibilities for risk avoidance and mitigation strategies
- Link to source material and reliability of information

The proposed risk analysis steps might also serve as a structure enabling integration of the risk information into a digital knowledge database.

ILLUSTRATIVE EXAMPLE

In what follows, an illustrative example is provided which highlights the type of risk information that could be useful for improving the treatment of risks in the design of masonry veneers, see Table 1. The specific risk concerns frost damage of the bricks, that might occur due to the combined effects of high exposure to wind driven rain, frequent freeze-thaw cycles and poor frost resistance of the bricks.

Table 1. Risk relevant information for case: Frost Damage in Masonry Facades

Description	Clay brick veneer with frost damage. Brick exhibiting exfoliation & spalling.
Potential causes	High exposure to wind driven rain in combination with frost-thaw cycles. Poor frost resistance of the clay bricks.
Mitigation/ avoidance	Moulded bricks more frost resistant than extruded bricks; extrusion causes lamination parallel to external surface constituting zones of weakness. Deep-fired bricks more frost resistant than low-fired bricks Recommended to choose brick type considering intended conditions of usage.
Potential consequences	Degradation on large scale. Impared aesthetics. Demolition of veneer followed by replacement with more suitable bricks or another type of facade.
Additional relevant information	The upper parts of facades are more exposed than lower parts. Current European standards concerning frost resistance of clay brick EN 771-1 requires that veneers exposed to driving rain are built with bricks with high frost resistance (class F2); conforming to the provisions of this standard do however not guaranty complete security against frost damage.
Source material	*Damage atlas. Expert system for the evaluation of the deterioration of ancient brick masonry structures.* ISBN 3-8167-4702-7. *Avoid mistakes in masonry and render* (Molnár et al 2016). Reliability of source data: High

Typically, the architext will decide the brick type to be used in a brick veneer. Thus, the risk management system can issue a warning to the architect concerning the potential risk for frost damage. The architect is provided an opportunity to investigate whether the selected brick type, under the given exposure conditions, is prone to frost damage and determine whether the original design decision should be altered. A similar assessment can be carried out by the contractor or a building physics expert, if involved in the project.

CONCLUSIONS & DISCUSSIONS

The current paper presents a conceptual framework for the treatment of risks related to poor building performance considering modern building applications and specifically integration with digital tools such as BIM. The framework aims to improve the treatment of these types of risks to reduce potential impacts to facility owners and end users in general and the environment in special.

Although the framework from this paper addresses issues of improved risk management in building design on a theoretical level, an implementation plan is underway which has identified important issues concerning practical applications. These issues include the establishment and management of the risk relevant knowledge base, the classification of BIM objects to enable risk filtration, as well as the evaluation of the approach in practical cases. One important aspect of implementing the framework in practice is quality control. This is significant both in relation to the information which will provide the basis for risk management as well as the process of risk treatment in itself. The former could be achieved by having in place a technical review of risk information by experts within relevant fields of engineering. The latter should provide some mitigation concerning the risk of gross human error in whatever form. Further development of the framework shall assess the effectiveness of the framework in practical application and this process should highlight inherent factors for improved quality control in relation to risk management in the building process.

One anticipated difficulty associated with the implementation of the framework is related to cases of innovative, complex or uncertain (ICU) solutions; as strong focus on risk issues might have an inhibiting effect on introduction of ICU solutions. Thus, some opposition is expected from material suppliers, constructors, etc., if these parties/actors feel that the framework will hinder effectivization of the construction process. The issue of how risks associated with ICU solutions can be introduced with acceptable risk levels and under full transparency for all stakeholders must be considered explicitly. As a direct consequence, possibilities should be created for continouos updating of the risk relevant knowledge base while a risk neutral perspective may be initially taken with regards to ICU solutions until more data and experience are available.

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