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Potential shift of Integrated Design (ID) through BIM in Sustainable Building Renovation

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Abstract. Future building renovation concerns more holistic perspectives related to both integrations through the involvement of key stakeholders and fulfillment of sustainability in connection to a broader range of objectives and criteria facilitated by the renovation scenarios. This entails re-thinking, reviewing, and application of novel integrating methods and approaches through an integrated design (ID) schema, towards establishing a richer early design stage to deal with the multifaceted challenges in building renovation context. Through its technological capabilities (modeling techniques), shifting into Building Information Modelling (BIM) as a methodology for integration can be useful bringing more efficiency in (particularly the early design stage of) renovation projects by creating and adding values through the five strands of product, people, process, policy, and technology. On the basis of this underlying hypothesis, the aim of this paper is firstly to review the characteristics of ID, BIM, and their interactions on each other, and secondly to explore and address the potential shift of integrated design through BIM (ID+BIM) for sustainable building renovation. This contribution is relevant to building design researches and practitioners, who can use the resultant to better understanding and navigating the integrated design through BIM, and its potential shift in sustainable building renovation with multiple stakeholders.

Keywords: Sustainable Building Renovation; Integrated Design (ID); Building Information Modeling (BIM); Integrated Design through BIM.

1. Introduction
The term ‘holistic renovation scenario’ in this paper is adapted from [1]. It serves to underline a holistic approach where various renovation objectives (i.e. energy consumption, indoor thermal comfort etc.) linking to the sustainability in its full sense [2] are achieved in a balanced way, through the development of a renovation scenario. A ‘renovation scenario’ refers to a set of design changes that will be made to a building, e.g. replacing all north-facing windows with triple glazing, adding a new cladding system (i.e. composite panels), and HVAC equipment. Identification of renovation objectives and criteria, an indication of the renovation approaches [3], and necessarily how to deal with the complexity of decision-making within many involved stakeholders, are the key points and essential factors for the development of holistic renovation scenarios.

The new vision and tightened sustainability demand for buildings [4] have led to an increased demand for sustainable development of the renovation projects facilitated by renovation scenarios. However, investigations have documented that the efficiency of the building renovation industry still develops slowly and is low compared to other contexts [5]. New methods to support the processes within the conventional renovation process are therefore needed. This entails re-thinking, reviewing, and application of novel integrating methods and approaches through an integrated design schema, towards
establishing a richer early design stage to deal with the multifaceted challenges in the sustainable renovation context. One suggestion can be the use of integrated design (ID) through the application of BIM, that exists and being practiced by relevant practitioners in the building design context.

Besides many advantages of performing renovation design within an integrated design schema due to encompassing the sustainability tendencies, shifting into Building Information Modelling (BIM) as a methodology through its technological capabilities (modelling techniques) for integration can be effective in bringing richer early design stage for renovation projects by creating and adding values through various perspectives. Based on this underlying hypothesis, the aim of this paper is firstly to review the characteristics of existing integrated design (ID) methodologies, BIM, and their interactions on each other, and secondly to remark the potential of how shifting into the ID+BIM -that can also be supported via application of BIM-based Decision Support Systems (DSS)- can enhance the renovation context to meet the sustainable building renovation objectives and criteria in a broader sense. This is done through establishing and evaluating crucial seminal strands in the ID+BIM context in this paper.

The paper presents the results of a literature review towards establishing ID+BIM’s seminal strands, which is substantiated through conducting seven unstructured interviews of practitioners in renovation context on evaluating their importance on the improvement of the sustainable renovation context. The paper in section 1.1 provides the common existing barriers in renovation context. Sections 2.1 and 2.2 review the concept of BIM and ID via investigation of the existing critical literature in these areas, and then section 2.3 presents a brief discussion on how these topics may interact together towards establishing some seminal strands in the ID+BIM context. Thereafter, on the basis of the discussed theoretical frameworks as well as the application of established strands as an analytical lens, in section 3 the paper explores the potential of how shifting into the ID+BIM can enhance the renovation context to attain the sustainable building renovation. This is carried out through visiting and conducting seven unstructured interviews of real practitioners from four large scale architecture and construction consultancy companies located in Aarhus, Denmark. Finally, section 4 discusses the conclusion and further work. This contribution is relevant to building design researches and practitioners, who can use the resultant to better understanding and navigating the integrated design through BIM, and its potential shift in sustainable building renovation with multiple stakeholders.

1.1. Existing barriers in the renovation context

Experience from projects and research carried out over recent decades has identified numerous barriers that hinder the uptake of a holistic building renovation. BPIE [6] reported existing barriers in this context through categories such as ‘financial’, ‘institutional & administrative’, ‘awareness, advice & skills’ and ‘separation of expenditure and benefit’. Further, a list of five main constraints that building renovation projects face, from pre-retrofit to post-retrofit stages, were explored by Cattano et al. [7], including identification of pre-existing hidden conditions late in the design process, interactions between building systems, lack of experience with the methods and materials required to deliver successful sustainable renovations, and poor measurements.

Galiotto et al. [8] discuss retrofitting barriers that occur due to politico-economic barriers (which need to be addressed by policymakers and market developers), technical barriers (which need to be addressed by architects and engineers), and behavioral barriers (which are the direct impact of building owners and occupants). In relation to the last-mentioned barrier, the authors [8] emphasize the role of occupants’ behavior in building energy consumption, and reasons for behavioral barriers are argued, e.g. limited knowledge about the building renovation process [9] and its benefits among stakeholders, or lack of guidance from the government and responsible institutions etc.

The building occupants indirectly influence the pattern of energy demands due to the changes over time in occupancy schedules and usage patterns [10]. In connection to this, Booth and Choudhary [11] categorize the most common barriers in a building renovation as the pre-bound effect which is known as the divergence between modelled and actual energy consumption for the pre-retrofit, and rebound effect in which the post-retrofit energy consumption is higher than predicted, due to either technical issues such as incorrect design options, failures and mistakes during construction works, pre-existing
conditions (solar exposure conditions and orientation, historical and cultural heritage interest, local, many others) or more importantly changes in occupant behavior. The essence of the pre-bound and rebound effects lead to a substantial disparity between the predicted and actual energy savings. The authors in [12] consider that the removal of these barriers may reduce renovation costs and yield buildings that consume less energy and resources. Nevertheless, Yu et al. [13] state that understanding of building occupants’ behavior in a renovation field is not addressed adequately through the renovation process since the general focus in this field is still on technical goals i.e., buildings’ energy efficiency improvements. It seems essential that the design approach should integrate the effects of a building’s technical aspects with the users’ behavior representation, giving them the same importance [13,14]. From another perspective, Acre et al. [15] discuss that post-occupancy evaluation of renovated buildings, which is often used to assess the impact of energy renovation, fails to examine the social context correctly because many of the energy efficiency measures and technical issues in energy renovation remain abstract to the occupants.

2. Theoretical concepts
The literature review is divided into three sub-sections. The first two parts present BIM and integrated design, which are currently applied in many existing consultancy companies. The third part provides a brief description regarding the BIM and integrated design and how these topics may interact together.

2.1. Building Information Modeling
Building Information Modelling (BIM) is a method that focuses on generating and administrating building data [16,17]. In the year 2003, the Danish government launched a new political plan of action [18]. The goal was to increase the focus on how to optimize the AECO industry. The political initiative resulted in a project called ‘The Digital Construction’ to improve the interdisciplinary use of digital information within the industry. The use of BIM created the foundation of the project, and it is the main method for handling and generating digital data. As a result, the Danish government demanded that all governmental clients should make use of digital applications in their building projects, starting from the beginning of 2007. In the other hand, the economic potential of using digital data in the AEC industry is significant. A report from 2009, argues that digitalization can generate an economic potential of 17 billion DKK / year in Denmark [19]. Another research study from the National Institute of Building Sciences in the United States argues that digitalization in the AECO industry may result in savings in the range of 15.8 billion USD / year in the USA [20].

According to Krygiel et al. [21], BIM is an emerging methodology in the AECO industry since the intelligent digital three-dimensional model-based process of BIM can be used to plan, design, structure, manage, and analysis buildings. The BIM-model represents the foundation for the BIM-process. It functions as a database for a project and may contain information about the building geometry, spatial relations, building location, properties, quantities of building components etc. These can be extracted and used in applications for, i.e. energy simulations, acoustic conditions, facility management. These interactions between the BIM-model and other applications can be used throughout the whole lifecycle of the building, from the cradle to the grave, and all parties in the project can participate [22]. Succar [23] addresses BIM is a set of technologies, processes, and policies enabling multiple stakeholders to design, construct and operate a facility collaboratively. The communication between the BIM-model and other applications useable in a building construction project is the central concept of the BIM-process [20]. The digital interoperability makes the building construction process transparent for all the participants. This makes it possible to give continuous feedback on results in relation to energy, construction, maintenance etc., or to explore the relative effect of different design alternatives. The BIM-process depends on the ability to share information between applications, organizations, IT systems, and databases. Open file standards that consider the benefits of all applications in the process and not one software vendor may be the solution for achieving an optimal BIM-process [24]. This issue is compiled by the Industry Foundation Classes - IFC, that are the open and neutral data format for openBIM [25]. The IFC specification is developed and maintained by buildingSMART International as its "Data
standard". IFC has been being released since 2000 through various versions, from IFC1 to IFC4. Nowadays, IFC5 is currently in the early planning phase, and it is expected to include full support for various infrastructure domains and more parametric capabilities [26].

2.2. Integrated design schema
Integrated design is a method that has been evolved mostly during the last two decades, due to the new sustainability tendencies in the AECO industry. As such, the growing focus on sustainability is one of the areas that make integrated design highly relevant [27]. This method utilizes the strength of multidisciplinary design consultancies to optimize the building design and reduce its energy consumption [28]. Previous experiences of using the integrated design method in building construction projects show a relative potential reduction of energy consumption by 60 to 70 percent compared to a traditional building project [29]. Figure 1 demonstrates the difference between conventional/traditional design process versus an integrated design schema.

![Figure 1. Traditional design process versus integrated design (ID) schema in the AECO industry](image)

In an integrated design schema, iterations are performed in each sub-phase, and each iteration results in different design alternatives, which are discussed in an evaluation round [30]. By the evaluation round, one of the design alternatives is selected for further development based on the design goals established. Thus, the evaluation creates a milestone on the linear backbone of the design process and forms a transition between two design sub-phases. These milestones ensure a constant design progression towards the final goal (with reference to [31]). In essence, some characteristics may describe the integrated design process (according to [31]):
- Inter-disciplinary work from the beginning of the design process between all consultants
- Test of various design alternatives by use of simulation tools
- Development of well-formulated performance targets and design strategies
- A more active role of the client
- The architect as teamwork leader instead of the sole form designer

Integrated design can be understood as a collaborative method for designing buildings that emphasizes the development of holistic design [32]. The implication is clear: integrated design is holistic in that it involves all stakeholders from the earliest stages, each having input into what goes into making the decisions that will lead to the completed project. It is holistic in that it takes every team member's point of view into consideration [33]. The financial advantages of integrated design have been thoroughly researched and documented through large EU-financed projects such as Task 23 [31].
Concerning who benefits from integrated design, there is a perception that all sacrifice for the owner - that the owner has the most to gain, then the contractor, and lastly-if at all- the design team. In fact, given time, trust, transparency, and not a little effort on everybody's part, all benefit. The more who participate, the more who benefit- and the more benefits there are. With integrated design, the focus is on the owner - the owner's needs - and the end result, the completed building, optimized for a higher value and reduced waste.

Figure 2 illustrates the ability of an integrated design schema to significantly impact projects in the early design stages along with the fact that the cost of changes is the largest in the late design phases. This highlights the importance of integrating technical knowledge in the early design stages. Deutsch [32] states that because the stakeholders are together from the earliest project stages, decisions can be made from siting and orientation of the building to the specification of green components in a proactive and coordinated manner. The integrated design has its origin in the development of new buildings; however there are recent efforts to adapting and applying it for the renovation as well [33].

**Figure 2.** Integrated design effort - the blue curve indicates the cost of design changes. The green curve indicates the possibility of influencing the project (adapted from [34]).

2.3. Integrated design through Building Information Modelling (BIM)

On the basis of the precedent subsections, and towards providing a comprehensive categorial scheme to existing integrated design and BIM (ID+BIM) that encompasses its multifaceted perspectives, when we inspected our collection we observed that the ID+BIM’s descriptions are not mutually exclusive. They overlap and intertwine. When analyzed, as through a prism, the content of the descriptions forms five strands. One of these strands pertains essentially to the people as involved stakeholders in the process. Another strand pertains to the real design solutions and/or digital prototype (with reference to BIM-model), which we refer as the product. Third and fourth strands pertain to the role of process and policy on the people and upon the developing product. And the fifth strand pertains to the used technologies. Hereafter, we shall refer to these strands as the four P's + one T (4Ps+T) of ID+BIM (see Figure 3), i.e. (1) people, (2) product, (3) process, (4) policy, (5) technology.
- **People**: the collaborative schema between involved stakeholders including architect/ engineers/ contractors/ clients/ owners etc. that contributes to increasing the level of awareness and informed decision-making.
- **Product**: refers to the real design solutions and/or digital prototype of a project which contributes to more sustainable buildings.
- **Process**: encompasses an integrated process including iterative workflows for generating and leveraging building data to design and construct the building.
- **Policy**: the streamlined steps related to contractual, regulatory, and preparatory.
- **Technology**: the requirements concerning software, hardware, and computer network

ID+BIM can be understood as a collaborative method for designing buildings that emphasizes the development of holistic design. It strives to be holistic in that it involves stakeholders (architects, engineers, contractors, and clients) from the earliest stages, each having input into what goes into making the decisions that will lead to the completed project. It, therefore, strives to take every team member's point of view into consideration, and it is holistic in that these decisions are made with all the information shared at one time, up front and not in the more traditional linear fashion, each entity maintaining and controlling the distribution of its own locus of information (adapted from [32]). BIM technology allows the integrated design to flourish, encourages - and provides a vessel and conduit for - the sharing of information between the design and construction team [32]. As such, BIM enables integrated design and therefore makes it possible.

3. Potential shift of integrated design and BIM for sustainable building renovation

As discussed in section 1.1, the practice of building renovation faces various types of challenges and barriers, where economic, human behavior, and technical barriers seem to be dominating. There are several reasons for these barriers including variety of the involved stakeholders and their specific interests in the process [33], a wide range of available renovation approaches (e.g. insulation approaches, window replacement, HVAC systems etc. - see [3]), and broad number of objectives and criteria [or sub-criteria] (e.g. regarding energy efficiency, spatial quality, investment cost etc.) that needs to be met [2]. In this section, we use the ID+BIM+ strands as an analytical lens to explore and address the potential shift of ID+BIM for the improvement of sustainable building renovation context. To this end, we conducted seven unstructured interviews of real practitioners from four large scale architecture and construction consultancy companies, who are also involved in the ReVALUE (see revalue.dk) research project and have offices/branches located in Aarhus, Denmark. Three of the interviewees were BIM coordinators in their companies, two engineers, one experienced architect, and one owner. They have initially discussed their relevant knowledge about either of ID and BIM. Then, we questioned them about the potential of using these approaches in their work environment, focusing on their recent experiences in renovation projects. In the context of this study, the focus was on a scenario in which the design specification and overall plan form the foundation for a turnkey contract tender and associated competition process.

Looking into the renovation context from the 4P+T strands at the time of interviews was effective in terms of bringing focus into the discussions with the relevant practitioners, and it significantly helped in exploring the potential shift of the ID+BIM for the sustainable building renovation in more detail. Table 1 sums up these insights.
Table 1. The ID+BIM’s potential shift in sustainable building renovation as explored through the analytical application of 4P+T seminal strands

| Focus          | Implications of ID+BIM in sustainable building design                                                                 |
|----------------|--------------------------------------------------------------------------------------------------------------------------|
| **People**     | - improving the level of awareness, communication, and cohesion between the entire involved stakeholders                   |
|                | - establishing a more effective collaborative and interdisciplinary work culture, especially in Denmark that has a well-documented culture of trust |
|                | - moderating disputes and reduces adversarial relations between design team including architect and engineers, as well as owners and contractors |
| **Product**    | - encompassing the overall project goals including functionality, accountability, feasibility, which leads to attaining a more sustainable product |
|                | - strengthening the possibility that the owners’ project goals will be attained                                            |
|                | - enhancing the final constructed project quality because of shared goals, particularly with reference to investment cost and clients’ budget |
|                | - consolidating building elements toward a sustainable and synthetic whole                                                |
| **Process**    | - improving the program and project time frame by reducing schedule waste and time overruns                               |
|                | - contributing to shorter and informed decision-making on early design stages                                              |
|                | - streamlining data exchange and share of information between design stages and project phases (i.e. design, construction, operation and maintenance) |
| **Policy**     | - increasing the likelihood that the sustainability certification systems such as DGNB-DK will be used in the design process with the focus on earlier stages |
|                | - creating a secured job site within a further and better understanding of the real renovation practice and workflows by all |
|                | - increasing the chance of winning the project competitions                                                                |
|                | - streamlining the implementation and development of the technical standards based on the consensus of different parties   |
| **Technology** | - reducing the project costs through time frame optimization and systems coordination, decreasing modifications made in the context, loss of data, and reducing the need for rework during costliest and most prone to error |
|                | - improving the productivity of the design team, giving the accurate and right data, and while discussing with non-experts, i.e. owners/clients |

Figure 4 demonstrates the relative graphical positioning of the ID+BIM strands as explored through the analytical application of 4P+T seminal strands. The ID+BIM is enabling strategies to achieve sustainable building design through early intervention and the bottom-up consideration by stakeholders in how the design program, materials and systems, and components and products in a renovation project influence each other. Instead of engaging sustainability specialist working in isolation, ID+BIM implies a holistic, collaborative approach comprising of the insights and experiences of all teammates. ID+BIM has the potential to aid project stakeholders to provide the required geometrical and analytical data of an existing building 3D model to select and evaluate the proper type of renovation actions during the early design stage and to make decisions that have a significant impact on the life cycle of projects.

Figure 4. The relative graphical positioning of the explored ID+BIM strands for sustainable building renovation
This can significantly be supported by development and application of BIM-based hybrid Decision Support Systems (DSSs) to rapidly generate various scenarios and evaluate them against the essential sustainability Key Performance Indicators (KPIs), i.e. energy consumption, day-lighting parameters, indoor comfort [i.e. 35-36]. Ultimately, application of BIM-based DSSs within ID+BIM will bring an enormous potential to aid the design team together with the other stakeholders (motivating them) to comprehend and develop holistic renovation scenarios and to make informed decisions in a shorter period with focus on the early design stages, and thus significant impacts on considering/addressing the trade-offs between architecture and engineering principles for the sustainable building renovation.

4. Conclusion
This paper reviewed the characteristics of integrated design (ID) approach, BIM, and their interactions on each other, which are applied in many consultancy companies. The study established the ID+BIM’s 4P+T strands, and then used it as a tentative analytical lens to explore the potential of how shifting into the ID+BIM can enhance the renovation context. The study considers that ID+BIM can significantly influence in enhancing the current renovation process, by promoting the iterative decision-making and bring focus to the earlier stages of the renovation design process. This improves the level of awareness, communication, and cohesion between the entire involved stakeholders and their relevant demands the renovation of existing buildings. Likewise, it offers more productive teamwork and process from the used technology perspective. ID+BIM shifts the focus on the early design stages as well as promotes the iterative decision-making process, which leads to achieving more sustainable solutions for the renovation purpose. That will require changes in the culture and existing policies in the contemporary renovation practice. Accordingly, it can be concluded that ID+BIM serves at coping with the complexity within the renovation context, and as a result of this, it contributes in the time-saving, improvement of the accuracy and quality of the final decision, as well as encouraging stakeholders to accommodate holistic renovation scenarios in the early design stages of the renovation projects.

As the basis for our proposed 4P+T model as a tentative analytical lens, it presumably does not capture the full complexity of a sustainable renovation design process given its highly complex value profile and many heterogeneous stakeholders. Still, we argue that the seminal model offered may serve as a useful, analytical perspective and reflection method to facilitate the understanding of the explained complexity. The research in future concerns the exploration of ID+BIM methodology in real cases related to the several existing obstacles which may hinder the application of it or reduce its advantages.

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