On Building Information Modeling: an explorative study

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Abstract

Building Information Model (BIM) is now a well-established notion in the context of built environment management, which includes the construction industry and the facility management industry. At first sight, BIM represents the various tools that support formulation and usage of models of built environments. Vendors that develop and provide BIM technologies typically offer bold promises regarding the positive effects of the usage of BIM. These positive effects include increased efficiency, quality and safety, in the context of the whole lifecycle of a built environment. However, the main emphasis of that rhetoric is placed on the benefits gained from using BIM in the construction and maintenance of new built environments. As the overwhelming majority of built environments are made up of already existing constructions, rather than projected buildings, a key question is: what are the practices for the use of BIM for existing buildings? An explorative research study has been conducted to respond to that question. The main research methods employed included a comprehensive literature review and interviews with BIM experts. The key findings suggested here are: (a) that very little research addresses the actual practices of BIM usage for existing built environments, (b) BIM as such represents a rather complex, multi-dimensional phenomenon, that also introduces new complexities into the lifecycle of built environments, (c) BIM has many stakeholders of which some have conflicting relations with each other; (d) there is a need to conduct comprehensive and independent research into the domain of the use of BIM for existing built environments.
Foreword

In May 2013, a chance meeting took place between two of the authors of this text. One (Magnusson) had just completed his professorial installation lecture while the other (Haftor) was about to start his professorial installation lecture in the same lecture room. The first lecture was about Building Information Models and Modeling (BIM) while the second was about Information Logistics. When passing each other in the doorway, we exchanged brief greetings and remarked that we may have some common interest. Several weeks later, the two of us met and discussed BIM, which made us realize that our respective fields have a number of areas in common and that it would be interesting to explore them. We subsequently brought in two additional colleagues and thus established a multi-disciplinary team, with regard to buildings, their maintenance and conservation, and the information and information systems that support these activities. When the four of us met and discussed, we ended up wondering about the current practices and research with regard to the use of BIM for existing built environments. Consequently, we decided to run a part-time explorative research project, with the aim of answering that question. Given that we had limited resources available our method was limited to the review of literature and some interviews with experts in the field, in Sweden. In practice, one of us (Johansson) conducted the majority of the actual research, while the other three of us acted as supporters. We held several progress meetings to discuss our findings. When the study had been completed, we were somewhat surprised by the answers obtained, namely that there is no informed answer available as to the current practices and research with regard to the use of BIM for existing built environments. The reason for this is that very little empirical study has assumed that focus. The remarkable thing with this answer is that the BIM concept and its associated technologies are not especially new, and that its promoters and various technology vendors have put forward bold statements about the positive benefits from BIM. However, as far as our study could find, no research has been conducted that can tell us whether these statements are realized and sensible or not. However, this study has succeeded in identifying a number of details and inherent complexities about BIM and its use. One conclusion is that BIM could be regarded as a kind of neural system for any activities related to build environments, and in such a way transforms our understandings and practices within such an environment to the better. With this perspective, we are happy to invite the reader to peruse the following text.

August, 2014

the Authors
# TABLE OF CONTENTS

1. INTRODUCTION .................................................................................................................. 6

2. PURPOSE AND OBJECTIVE ................................................................................................. 7

3. METHODOLOGY .................................................................................................................. 9

4. CURRENT BIM PRACTICES ................................................................................................. 12
   4.1 This is Building Information Modeling (BIM) ................................................................. 12
   4.2 Some benefits aspired from BIM usage and practices ...................................................... 18
   4.3 BIM in the industry ........................................................................................................ 21
   4.4 BIM functions and promises for practitioners ................................................................ 23
   4.5 Practical BIM problems: Needs and Opportunities ......................................................... 27
   4.6 Potentials and hindrances for widespread adoption ......................................................... 30

5. RESEARCH FRONTIERS ....................................................................................................... 32
   5.1 Earlier and current BIM research ..................................................................................... 32
   5.2 Summary of research needs and their implications ......................................................... 36
   5.3 Proposed directions for BIM Research ............................................................................ 43
   5.4 Research Methodology and Design .............................................................................. 44

6. CONCLUSION ....................................................................................................................... 46

REFERENCES .......................................................................................................................... 48

LINKS AND WEBSITES ......................................................................................................... 62

THE RESEARCH TEAM AND SPONSOR ............................................................................... 71
1. **INTRODUCTION**

Information and communication technologies virtually dominate every part of our lives: private, professional, and civic. This seems to be true for the various manufacturing industries, such as the automotive or construction industries. Just as an engineer may produce a digital model of a car, where such a model may at a later stage guide the manufacturing, usage, and also recycling of that car; professionals construct models of built environments, to guide the planning, construction, usage and maintenance, and eventually recycling, of a building. The formulation and handling of these models is often associated with the label of “Building Information Models”, or simply “BIM”. Briefly, BIM may be regarded as professional tools for the creation and usage of models of built environments. The introduction of BIM technologies by various vendors is often associated with bold promises about the positive effects on the quality and efficiency of the various activities that constitute the lifecycle of a built environment. Most of that rhetoric, however, seems to address the use of BIM for the building of new constructions, rather than for existing built environments. A relevant question that emerges is: **what are the practices of the usage of BIM for existing built environments?** An attempt to answer that question triggered the explorative research project described here.

Rather surprisingly, the study’s findings suggest that little, if any, research has been conducted with focus on the usage of BIM for existing buildings in Sweden. The results suggest that BIM technologies offer many bold promises about the positive outcomes from its usage, yet little is known of whether these effects are realized or not. Further, BIM seems to be a rather complex phenomenon that also introduces additional complexities into the lifecycle of built environments, which also acts as a hinder for the adoption of BIM technologies, for built environment. This in turn seems to require multi-disciplinary approaches from both BIM professionals and its academics.

This text is organized as follows. The next section explicates the assumed **Research objective and its purpose** while the section after that summarizes the **research approach** employed. The findings produced by the study are presented in two principal sections, first **Current BIM**
Use of BIM for existing Buildings

Practices and then Proposed Research Frontiers. A section with Conclusions ends this text together with references and details of the research team.

2. PURPOSE AND OBJECTIVE

![Figure 1](image)

*Figure 1.* Illustrates the assumed focus of the study reported in this text; the use of Building Information Models (BIM) for existing Buildings.

This report presents the outcome of a finalized explorative research study into the use of Building Information Models and Modeling (BIM), for existing rather than projected buildings, with particular focus on Sweden (see Figure 1). While the project had several desired outcomes, one central objective guided the formulation this report:

- *To have identified frontiers, in both research and practices, with regard to the use of BIM technologies for existing buildings, with special focus on Sweden.*
More specifically, this implied a search for key features of current BIM practices, their successes, limitations, challenges and opportunities. Likewise, it implied a search for finalized research initiatives focused on BIM practices, and provided us with insights about their key characteristics, strengths and limitations. The main emphasis of this study, though, was to establish what we do know about BIM practices, and what their challenges are.

Several key factors motivate such an assumed focus of this exploration. Firstly, and in more general terms, promoters of BIM and its practices as a new technology have often presented BIM as a glorifying technology that will provide many benefits. The question is whether any of these benefits from using BIM have been realized or not, and what the associated challenges and opportunities are. Secondly, BIM ambassadors seem to have assumed a main focus on BIM use for the design and construction of new buildings. Both these assumptions are evident in available literature, and in numerous sources online (see bibliography). While such a focus has its merits, we need only to recall that the majority of the building stock (70 – 80 %) in western societies was built before the 1970s and is thus considered as existing buildings (OECD/IEA, 2009).

Therefore, ignoring the question of how to use BIM for existing buildings implies a radical reduction of the aspired potential effect of using BIM. Thirdly, there is an ongoing discourse regarding the actual process of the development of BIM technologies and associated practices (see the chapter on research), which is important. However, there also is a need for solid knowledge regarding the use of BIM itself, as such knowledge may potentially inform future BIM development practices with regard to the kind of BIM desired, or not.

Given the research objective as specified above, the research purpose assumed here is that the outcome of the study is:
• To serve as an intellectual guide for the formulation of a future research direction (e.g. program, initiative, projects), that addresses the use of BIM technologies for existing buildings, in Sweden.

Beside the key objective as declared above and the purpose of this study, several other objectives were aspired to, of which at least one deserves a mention, namely: to have established a well-coordinated cross-disciplinary research team, for subsequent research work. However, these “other objectives” lie outside the scope of this text.

3. METHODOLOGY

The research approach assumed here for achieving the objective specified above may be summarized in the following terms:

a. Literature Review: a careful search and review of existing literature, both academic and professional; this comprised a search, identification and retrieval of literature followed by reading, analysis and pattern recognition.

b. Expert Interrogation: identification of key experts within the assumed domain, interview and discussion related to the focus assumed here.

c. Multi-disciplinary Team: a crucial component was to put together a research team with members representing various disciplines related to the focus assumed here.

d. Driving Research Questions: given the objective detailed above, a set of driving questions were formulated, as a means to translate the assumed objective into
operational questions as instruments for data collection. Example of such central questions include:

- **The What:**
  - What is “BIM”? What does it stand for and for whom?
  - What are the constituting components and functions of BIM?

- **The Why?**
  - What are the key motivations for the development and deployment of BIM?
  - What are the key needs with which BIM is assumed to deal?
  - What are the key opportunities that BIM is assumed to explore?
  - Who are the key stakeholders (actors) involved in BIM?
  - What are the key stakes or interests for each BIM stakeholder?

- **Actual?**
  - How is BIM actually used?
  - What key problems, limitations and challenges arise from BIM usage? And what are the reasons for these?
  - What is the difference, if any, between the actual use of BIM versus the aspired ambitions, and driving motivations, for BIM use?
  - To what extent is BIM used for existing buildings?
  - What are the key hinders for successful BIM usage?
  - What are the key factors for successful BIM usage?

- **Future?**
  - What future development of BIM technologies and associated practices is likely to materialize and how may that influence the use of BIM for existing buildings?
  - What new knowledge is needed about BIM usage for existing buildings?

**Reference Framework:** the explorative study reported here was also guided by a conceptual body, with a set of assumptions and standpoints which may serve as a point of perspective or as a point of departure for the research work conducted. Indeed, any
research study, particularly one of explorative character like this one, has a Reference Framework, as understood here, however this is usually implicit, not articulated and reflected upon. The Reference Framework assumed here may be summarized as follows:

- This investigation is based on the so-called ‘holistic paradigm’, in the present context manifested in terms of (1) *Sustainable Building*, and (2) *Sustainable Integrated Conservation* (SIC) that combines humanistic and sustainability values and systems thinking, all applicable to BIM as a means for dealing with cultural heritage, and the natural and built environment at large. This is intended to improve the quality of life by protecting human health and encouraging *sustainable management* of natural, human and man-made resources. The focus is on *continuous adaptability* of the built environment, and on *enhancing its quality and diversity at all levels* (Fielden, 1982).

- Key activities of Sustainable Integrated Conservation include *monitoring, assessment, preservation, rehabilitation, adaptation, maintenance, and management* of built heritage and related assets, often in conjunction
  - with urban planning and design;
  - with environmental, social and material aspects;
  - with new construction technology and design;
  - with legislative issues;
  - with entrepreneurship, business, innovation; economy;
  - with humanities, arts and crafts, and
  - with education, training and research.

- An explicit recognition and assumption of *participatory and preventative practices, collaboration* and *synergetic learning* is made here, with the potential of anchoring the community’s *intangible inheritance* (e.g. Gustafsson & Rosvall, 2008; Horwitz & Aravot, 2008).

- *Sustainable building* includes all aspects of building performance, environmental, economic and social impacts. This requires integration of various kinds of knowledge and expertise in the inter-related fields of building
technology, conservation, environmental science, design and crafts, informatics, business, natural and social sciences, economy, business and health etc., where different models can help promote the sustainability of anticipated/planned activities, their impact and effects. The intention is to eliminate negative environmental impact through skillful, sensitive design, and to improve the efficiency of rapidly increasing impacts. From the perspective of existing resources, sustainable building means ensuring the continuing contribution of heritage to present and future generations through the dynamic management of change responsive to the historic environment (Johansson, 2012; Fielden, 1982).

- Architectural conservation and transformation in this context include preservation, renovation, rehabilitation and reuse of everything from individual buildings and objects to landscapes and streetscapes and urban revitalization of mass housing (Engelbrektsson & Rosvall, 2013).

### 4. Current BIM Practices

It is now time to provide a summary of the current BIM practices, as identified in this study. Recalling that the assumed focus is on BIM usage for existing buildings in Sweden, a more definitional elaboration will be provided to address the question of what is meant with the notion of BIM. This elaboration will then move its attention to why BIM is established; however when we answer the-what of BIM and the-why of BIM, the question of the-how of BIM will inevitably appear.

#### 4.1 This is Building Information Modeling (BIM)

In very basic terms, BIM may be regarded as a computer based database containing various models of buildings. In this context, the expression ‘models of buildings’ refers to some kind of representation of some part of a building, where that building-part is represented in terms of
selected attributes. Such a base of information about buildings is synonymous to a base of information about a machine, say a car, that is designed and then manufactured, or a customer database in a firm’s marketing function, where information about the customer is stored for various purposes.

BIM, being based on the use of Information and Communication Technologies, is able to conduct the basic information processing functions: to generate, store, transfer and transform information. The notion of ‘Building Information Model’, or just ‘BIM’, emerged in the 1970's and originates from semantic data models in the field of machine engineering. These models were originally designed for connecting logical and physical information about machines, and subsequently spread from the design and construction of machines into the design and construction of buildings (e.g. Wikipedia.org).

The first implementation of BIM was as a part of the Virtual Building concept and debut of ArchiCAD in 1987 (ibid). These concepts and applications were adapted, developed and modularized during the 1980's, enabling transferability of the technology and systems to the residential and commercial sectors. One example of early BIM-related models and development is the ‘Building Design System’, which was generated through a research project funded by the UK government in the mid-1970’s. Another example is ‘Really Universal Computer Aided Production System’ (RUCAPS), a computer aided design that was developed by John Davison and John Watts from the University of Liverpool (ibid).

Generally speaking, key constituting parts of a Building Information Model include (1) an object (a part of a building, a building, or group of buildings typically represented in 3 dimensions); (2) parametric interconnected data related to (1); and (3) meta-data (data about data, here definitions and specifications of (1) and (2), (see Figure 3; Magnusson 2013). In the context of this report, BIM may be understood as:
1. A set of technologies, processes and policies enabling multiple stakeholders to collaboratively design, construct and operate a facility, or group of facilities, and to sustainably manage them in the context of their environment (Succar, 2013).

2. A rich information model, potentially fed by multiple data sources, elements of which can be shared across all stakeholders and maintained throughout the life of a building from inception to recycling (Waterhouse, 2013).

3. A shared digital representation of physical and functional characteristics of any built object, and its environment, which forms a reliable basis for decisions (ISO/TC 59/SC 13).

In general, three major kinds of information are included in any given BIM: (a) Geometric, (b) Semantic, and (c) Topological information (Schlueter & Thesseling, 2009). Geometric information relates directly to the built form in three dimensions, semantic information describes the properties of components, while topological information captures the dependencies of components.

BIM is characterized by work-practices that employ digital models of buildings. The initial guiding idea was to develop a virtual building model to guide the building process; as the physical building is assembled, changes in the field are documented in the virtual model. An essential ingredient in BIM is that the object carries metadata. By using three to five dimensional digitization models, distinct phases of design are merged and the process becomes fluid, or well integrated, with an aspiration for an elimination of information loss between the activities constituting the work practice. BIM models consist of objects (i.e. representations of buildings and building elements such as walls, windows, columns, etc.), but also various types of information items, such as areas for specific rooms, zones, tenants, etc. This differs from traditional 3 Dimensional Computer Aided Design (3D CAD) which focuses only on the 3D graphical representation of a building. Current BIM technologies may provide
the design and geometry of a building; geographic information, light analysis, spatial relationships and characteristics of building materials (Magnusson, 2013) – see Figure 3 for an illustration.

The term ‘Building Information Model’, as such, first appeared in 1992 (van Nederveen & Tolman 1992). However, the terms ‘Building Information Model’ and ‘Building Information Modeling’ (BIM) began to be used more extensively from 2003 onwards (Autodesk, 2003). Nowadays, BIM represents a whole new paradigm, representing a turn away, or advancement, from the traditional practices of design and construction of buildings. It is not only considered as a way to make a profound impact on the professions, but is also regarded as an approach to assist the building industry in the development of new ways of thinking and practices. BIM may be considered as a ‘socio-technical system’, combining man-made technology and the social and institutional practices that develop and use that technology. In such a view, BIM is sometimes regarded as a unified system, or entity, consisting of different interacting aspects that are material, mental, and social (see Figure 2). The social aspects include different types of behavior, norms, cultural institutions and relationships. Indeed, these social aspects both utilize BIM hardware and are shaped by it (WSP Group, 2013: retrieved http://buildinginformationmanagement.wordpress.com, 2013-12-27).

More recently, the term BIM is used both as a verb and as a noun, that is Building-Information-Model and as Building-Information-Modeling. The latter recognizes that the practice of the formulation and usage of such models are highly interrelated. So, BIM accounts for the various human practices (i.e. activities, processes, norms and values) that ‘formulate building information models’ (Eastman, C., P. Teicholz, et al., 2011, p. Xi). Therefore, BIM requires a notion as a combination of technology and a set of work processes (WSP Group, 2013, pp. 6-7).
While the construction, maintenance and usage of models of buildings is almost as long as human writings, it is the digitalized building information models that offer such unparalleled opportunities to produce, store, share, and transform building information models, which again highlights the importance of the BIM practices. In these practices, an early ambition is that different actors share data through digital models in a coordinated, consistent workflow, during the building process as a whole, according to an integrated lifecycle (LC) perspective (Garagnani, 2013).

Another early ambition of digitalized BIM may be summarized in terms of the three C’s: (1) **Collating Information**, (2) **Incorporating Consistency**, and (3) fostering **Collaboration** and **Coordination** among different actors and professionals. An ambition with these three C:s in place is that building information and the process of building information can be managed **intelligently rather than in an ad hoc manner, arbitrarily and accidentally**. (http://www.corrs.com.au/thinking/insights/building-information-modelling-bim-a-construction-
As the design, construction, maintenance, use and then termination and recycling of any non-trivial building includes the generation of a significant volume of necessary information about the given building, BIM may be regarded as the neural system for building-related practices. In that sense, “BIM is a disruptive technology, which means it requires the change of practices. Thus, BIM is socio-cognitive: breaking the syntactic, semantic and pragmatic barriers between disciplines. This change is multi-dimensional and requires breaking the boundaries between research disciplines.” (ibid)

‘Computer Integrated Construction’ (CIC) can be defined as “the integration of corporate strategy, management, computer systems, and information technology throughout the project’s entire lifecycle and across different business functions” (Wikipedia.org). CIC and BIM are the most often used acronyms that represent the use of information and communication technologies in construction, however, CIC will be disregarded here as it has not been shown to have any significance for the research focus assumed here (Wong & Yang, 2010).

Finally, the ‘Industry Foundation Classes’ (IFC) data model is intended to account formally for building and construction industry data. It is a platform-neutral, open-file format specification that is not controlled by a single vendor or group of vendors. It is an object-based file format with a data model developed by buildingSMART (formerly the International Alliance for Interoperability, (IAI) to facilitate interoperability in the AEC industry, and is a commonly used collaboration format in Building Information Modeling based projects. The IFC model specification is now an official international standard (ISO 16739:2013). Because of its focus on ease of interoperability between software platforms, the Danish government has made the use of IFC format(s) compulsory for publicly aided building projects. The Finnish state-owned company Senate Properties demands that IFC compatible software and BIM be used in all their projects (Wikipedia.org)
Use of BIM for existing Buildings

4.2. SOME BENEFITS ASPIRED FROM BIM USAGE AND PRACTICES

As is rather common in most newly emerged technologies, many aspirations and promises are made and assumed with regard to the potential benefits of the usage of new technologies; this is also the case with BIM. An account of the various BIM benefits offered to professionals is summarized below. This should not be regarded as a perfect and finalized list of potential benefits however; rather it is an account of the commonly presented BIM benefits.

Figure 3. The figure illustrates the relation between Computer Aided Design technologies (CAD) that enable the formulation, storage and use of Building Information Models, that in turn enable a more intelligent, or sophisticated, work practice where buildings and their representations are key features. (Source: Wong & Yang, 2010, p.3).
Information sharing & integrity: For the professionals involved, BIM enables the simultaneous handling of information by different individuals in different professions. A purpose is to reduce the information losses that may occur when a new team takes 'ownership' of a project and/or building. Enabled by contemporary Information and communication technologies, BIM ensures that one official version of information of a building is held consistently over time. (Magnusson, 2012)

Integrated Project Delivery: BIM enables an entirely new way of designing and building, known as integrated practice, or ‘Integrated Project Delivery’ (IPD). This includes not only design and construction professionals and preservationists but also cost estimators and vendors, energy and code officials, and external reviewers. The practical use of BIM goes beyond the initial building planning and design phase, as it extends throughout the building's lifecycle and supporting processes including cost management, construction management, project management, facility maintenance and operation (see, http://www.helsinki.fi/cradle/news_archive/index.htm; retrieved 2014-01-22).

Lean construction: Lean construction is an industrial and managerial practice stemming from the popular lean manufacturing as originally developed by Japanese car manufacturing companies. At its core is that the only performance and resource activities utilized should be those that truly generate value for the output’s consumer, say a car buyer. To that end, a lean approach recognizes that there is a constant need for improvement, in order to identify a leaner way of conducting operations: in other words to increase the satisfaction of consumers and reduce resource utilization, or more concisely, to do the right thing in the right way, only. Lean extends from the objectives of a lean production system – maximize value and minimize waste – to specific methods and technologies. As a result, the process is designed to better reveal and support customer purposes. Work is structured to maximize value and to reduce waste. Efforts to manage and improve performance are aimed at improving total project performance, since this is more important than reducing the cost or increasing the speed of any particular activity. Lean challenges the belief that there must be trade-offs between time, cost, and quality. As the bringing about continuous improvement, in terms of what is done and how it is
done, requires extensive and accurate information about what is done and how it is done, BIM becomes something of a neural system of any building lifecycle, and may help make the building lean practice even more successful. (www.leanconstruction.org)

Safety: BIM places the effective use and exchange of information at its heart. Such information use may be preventative in that it aids in collision detection at the initial planning stage, identifying the exact location of discrepancies. This could lead to a more coherent safety and vulnerability representation and proactive risk assessment of cultural heritage, facility contents, qualities and potential threats, e.g. supporting the identification of vulnerabilities in building emergencies (Kapp, 2012).

Computer-aided facilities management (CAFM) refers to the use of information and communication technologies to effectively manage physical facilities in various ways. This can include long-range facilities management reporting, as well as more direct systems that actively manage aspects of facilities, such as lighting or heating and air conditioning equipment. Common features of computer-aided FM tools include systems that give information on floor plans and descriptions of physical space, as well as reporting on energy consumption. Computer-aided facilities management tools can use extensive databases and visual modeling tools, along with geographic information systems or services, to give project leaders and managers a bird’s eye view of a particular facility or building. In addition to providing these sorts of physical tools, computer aided facilities management systems can be part of long-term planning and auditing resources. For example, planners might use these sorts of tools to evaluate the depreciation of a facility or for other tax purposes. A wide range of CAFM-solutions has become extremely valuable to those who are tasked with efficiently managing the physical locations of a business or other entity. (www.techopedia.com, 05-02-14). Clearly, while information and communication technologies in general manifest a significant potential for an improvement of facility management, BIM may be regarded as a central component of such technology usage (Magnusson, 2012).

Facility management: is a profession that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, place, process and technology into a
coherent whole. The core competencies of Facility Management may include: Operations and Maintenance, Project Management and Quality, Real Estate and Property Management, Technology and Communication; Readiness for Emergency and Business Continuity; Environmental Management and Sustainability, Finance and Business, Human Factors, Leadership and Strategy (International Facilities Management Association, 2014). Clearly, successful management of any non-trivial building, such as an airport or a large hospital, requires a timely supply of a significant amount of accurate information (Haftor & Mirijamdotter, 2011), at the hands of various professionals. In this sense, well-established BIM practices have the potential to improve Facility Management immensely, in in a multitude of ways (Magnusson, 2012).

**Intelligent Buildings:** The expression ‘Intelligent buildings/homes’ encompasses a variety of technologies, spanning commercial, industrial, institutional, and domestic buildings, for example ‘Building Energy Management Systems’ (BEMS) and building controls. The notion of a smart building or home was born in the late 1970s, and refers in very general terms to structure and functions, systems and services, building and relationships for various ends, yet in general for an increased efficiency, performance and comfort manifested by buildings and homes. It is based upon the extensive application of various information and communication technologies that enable networked monitoring, control, and communication within and between buildings, of various parameters of the building and home. These technologies may include broadband, television, telephones, fire alarms, energy management, lighting control, air conditioning and access control, which allows buildings to be controlled intelligently (American Intelligent Building Institute, 2012; Greentech Advocates, 2013).

### 4.3. BIM in the Industry

The various BIM functions and promises for practitioners are outlined and their needs are highlighted in the text below. As mentioned earlier, the function of BIM is mainly focused on the production of new buildings while very little attention and effort are put into BIM initiatives for existing buildings.
Use of BIM for existing Buildings

BIM prevents errors by enabling conflict or ‘clash detection’ whereby the computer model provides visual highlights to the team showing where parts of the building (e.g. structural frames and building services, pipes or ducts etc.) may wrongly intersect. In the near future, this might include information about which parts are original to the building, and which parts have been added over time, making it easier to make proper judgments and decisions. For existing buildings and environments, additional issues may be relevant, such as documentation of structure and materials, geometric data for specific elements, such as details, floorboard and trim, etc. Dynamic information about the building, such as existing conditions, sensor measurements (e.g. moisture detection and energy efficiency) and control signals etc. can be incorporated within a BIM model to support analysis of building operation and maintenance, which in turn may serve as a basis for decisions, e.g. about rehabilitation/adaptation and reuse (Kapp, 2009).

Professionals, manufacturers and sub-contractors from every trade may input crucial information into a BIM before beginning construction, with opportunities to pre-fabricate or pre-assemble some systems off-site, make final adjustments and make a cost-effective rehabilitation and preservation and maintenance plan. Waste can be minimized on-site and products delivered on a just-in-time basis rather than being piled up on-site. Quantities and shared properties of materials can be extracted easily. Scopes of work can be isolated and defined. Systems, assemblies and sequences can be shown in a relative scale with the entire facility alone or a group (ibid).

Current and future BIM can leverage the capabilities of existing BIM software to provide a historical and navigable timeline that chronicles both tangible and intangible aspects and changes in the past with projections into the future. As discussed earlier, BIM is developed as a way of managing the full development lifecycle of a building project. Used to facilitate new designs, build changes and communication amongst contractors and design teams, BIM has proved to provide significant cost savings and efficiency gains. It has always been assumed that trying to model existing buildings and structures in Revit is time consuming and extremely costly, however this is attitude is changing. To fill this gap 3D laser scanning may be used for existing building modeling. By using the latest 3D laser scanning data capture techniques, surveys can be made in 3D and this information can be converted to accurate Revit models.
Many studies and initiatives have been carried out that can be linked to digitization of existing buildings (see: http://3d.si.edu/conference/index.html, retrieved: 28-12-13). For cultural heritage, 3D content is more and more often used with the latest 3D viewing platforms for visualizing and manipulating 3D data. Technologies include 3D printers and resulting prints, virtual reality goggles, and natural user interface (NUI) devices. (ibid). Current technology, e.g. laser scanning, photogrammetry, analytical 3D imaging, etc., make it possible to comprehensively assess a building’s geometry, existing conditions and specific needs; including e.g. air pollution and humidity levels, vibrations, cracking, corrosion processes, electricity consumption, energy efficiency and much more with different types of sensors. Analyses that are not included but could be incorporated are context analyses, physical loads, resistance to wind, fire, compatibility measures and concerns between the new structure and the old (i.e. in adaptations and renovations), intangible qualities and significance of a particular resource – and the role of high quality crafts. There are endless opportunities for collecting data that can be processed into information on the measures required to maintain the different qualities and values of a property (Johansson, 2008).

4.4. BIM FUNCTIONS AND PROMISES FOR PRACTITIONERS

Based on the research performed for this report, it seems certain that the demand for BIM and sustainable building technologies will continue to grow. BIM is not only beginning to change the way buildings function, how they look and the way they are built, but also how they are preserved, valued and understood – not as singular isolated units but as placed in a broader context, as part of a conglomerate of buildings and landscapes from different time periods (Johansson, 2008; Engelbrektsson and Rosvall, 2006). As BIM technology and practices continue to develop, efficient and intelligent technologies will become even more pervasive worldwide.
Use of BIM for existing Buildings

This point to increased business benefits of using BIM, such as *better quality of work and better profits, more accurate documentation, less rework, reduced project duration, fewer claims and the ability to offer new and more sustainable services*. Cost savings and operational efficiency, improved visualization and design quality, and client demand are cited as major drivers for the adoption of BIM. The majority of the world’s leading firms have already started their transition to BIM from traditional CAD systems, and the numbers of new technology providers developing add-ons to the systems have also increased. Companies are developing BIMs with various levels of detail, and the *modeling efforts* associated with generating BIMs vary.

The UK, United States, Australia and the Middle East have been identified as the top four markets that will provide the highest growth opportunities for BIM application-related software products and services (WSP Group, p. 29). In Europe, the building sector represents approximately 40% of EU:s total energy consumption. It is estimated that approximately 40% of all activities in the sector are related to rehabilitation, maintenance and reuse (Swedish Building and Planning, 2007; Swedish Environmental Protection Agency, 2008), and in 2050, as much

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**Figure 4.** Illustrates the outcome of an instance of Laser Scanning for BIM, in Brussels' Royal Quarter (Source: www.sparpointgroup.com)
as 70% of the existing building stock will remain. This means that the amount of activities in the area of architectural conservation, rehabilitation and management will increase (COM 2010). EU’s directive for enhanced near-zero energy buildings includes a strong focus on existing buildings and larger building stocks. In 2012, the BIM technology market stood at 1.8 billion USD, and it is expected to reach 6.5 billion USD by 2020. (European Parliament, 2010)

Based on the number of market studies and reports outlined in the bibliography, it is clear that BIM represents a new paradigm within the AEC/FM industries. A potential obstacle is that adopting and developing BIM is costly, but it is inevitable. Building owners are becoming an important driving force to its increased adoption. This development also applies to Sweden that has an extensive amount of historic buildings, gardens and habitats, industrial heritage and larger building stocks; including areas of mass housing. The qualities and cultural values that these environments represent should be protected, preserved and maintained while facing new requirements. A major problem, however, is that the building sector is too often focused on maximizing efficiency, space and usability at the expense of existing assets –emphasizing economic, functional, technical aspects and demands (Mason, 1998; de la Torre 2002).

However, in order to meet the future demands, the role of informatics, architectural conservation and high quality crafts skills and knowledge requires further attention.

As per the nature of socio-technological systems, the future of BIM is revolutionary. This lies in its development beyond 3D modeling and software; i.e. as a multi-disciplinary planning, design, analysis, construction, preservation/rehabilitation and facilities management process technology, that will lead to dramatic process changes. This means the shaping of social practices by expanding possibilities of achieving better communication and collaboration between different stakeholders and disciplines at an early stage, and throughout all stages of the building process. Once the basic infrastructure is in place, numerous work processes and technologies can be brought in, which will result in tighter integration. This may lead to more sustainable work practices creating an entirely new cultural and institutional environment.

In general, BIM may lead to improved quality and planning processes, energy efficiency, control, design, construction and management. Nowadays, improving energy efficiency is a
major driver for renovation and rehabilitation. In a near future, ‘eco-makeovers’ of larger building stocks will inevitably be carried out, involving laser scanning with measuring equipment to create a model for its shape to be incorporated into the BIM. BIM’s strength lies in its possibilities as a complex information management system. As it emerges and becomes more advanced, it will develop as an intelligent system consisting of a transparent set of methodologies, tools and work processes that are merged into a consistent and integrated whole, made accessible for all actors and parties involved - i.e. before, during and after the end of a project, and as part of the ecological process of continuous recycling (WSP Group, 2013). In this way, BIM is not only a rich 3D model; it is a complex information structure (6D and beyond). As more information is added, the data can be “mined” to identify and monitor the process and project’s performance.

If the information within a BIM is utilized in a more integrated manner, there are large profits to be made. For example, the client can find competitive advantage by providing customers with preventative long-term maintenance contracts, or find new bidding or business models for real estate sales. The buyer can also buy properties with a guarantee based on the concept of intelligent/ smart and/or ‘environmentally sound housing’, which means that property owners in the future may change their focus from being event-driven organizations to planning driven ones. Instead of dealing with daily errors, they would be able to focus on quality and sustainability requirements. More energy can be devoted to planning and cooperation, to preventive conservation, renovation/adaptation and maintenance. Then, the user would be able to both sell and buy quality assured accommodation - while the characteristics, specific qualities and values of the existing asset/-s remain. This will also create new business opportunities, jobs and employability for individuals. Moreover, this would ultimately lead to enhanced wellbeing and a better quality of life by ensuring that these different needs are met and that the qualities and values are properly preserved and maintained for future generations.
Use of BIM for existing Buildings

Given the above, current BIM functions and benefits can be summarized as opportunities:

- For collection of large volumes and variety of building related information;
- For laser scanning with measuring equipment, e.g. for energy efficiency;
- For storage and access of that information;
- For improved visualization and productivity due to easy retrieval of information;
- For analysis of that information for patterns or deviations identification;
- For increased coordination of construction documents;
- For integrative work practices such as planning;
- For innovative design;
- For architectural conservation and ECO-friendly environmental modeling;
- For more sustainable work practices;
- For effective resource utilization and coordination of activities in the lifecycle of a given building;
- For enabling innovative changes to the bidding process;
- For strategic leadership, entrepreneurship and innovation within an organization as well as on a broader scale.

4.5. PRACTICAL BIM PROBLEMS: NEEDS AND OPPORTUNITIES

In general, the construction industry is facing major challenges when it comes to developing and updating the existing standards and guidelines and different work patterns that ensure interoperability between the different phases of planning, design, production, preservation, rehabilitation and adaptation, maintenance and operation for SD, conservation and management. The connection between culture and technology represents one of the most important challenges. The emergence of sustainability practices is dependent on complex co-dependent and contextual knowledge, strategic interaction, collaboration, inter- and trans-disciplinary research. Environmental sciences and technology management are two such broad
and emerging fields where fundamental changes have taken place in the way research is performed. (Magnusson, 2012)

Sustainability has been very difficult to achieve – particularly with regard to quality, energy, costs, heritage aspects and related values. The situation is further complicated by the lack of relevant training, education and research/RTD, appropriate knowledge systems, methods, processes and skills. A major aspect is that the AEC and Facilities Management (FM) industries are discipline-driven and different actors dominate at different stages of the process. Many studies have raised concerns about this critical fact, which includes issues such as low quality, high costs, low profitability and a predominant lack of innovations (Johansson, 2008). Major parts of the processes are also project-based (Magnusson, 2013). The actors involved are part of a system that possesses poor information systems when compared to evidence provided by, for example, known control and efficiency theories (Bystedt, 2012). The challenge of providing the right information to the right actor, at the right time and place, and in the right format, is regularly manifested. There is a need to study problems from multiple dimensions and disciplinary perspectives, from a practical and a scientific viewpoint, in order to provide a sustainable impact and results, which also applies to the use of BIM.

Despite the considerable adoption of BIM for the design and lifecycle management of new buildings, very little research has been undertaken to explore the value of BIM for the re-design, conservation and management of existing buildings and environments (Fai et al., 2010). To a limited extent the focus has been on cross-disciplinary collaboration and integration, creating synergies between the new and the old (i.e. existing environment), between different disciplines, stakeholders and professionals, projects, methods and technologies, cultural and conceptual views etc. This applies to the construction process, in particular, but also to different kinds of planning and design processes, conservation, innovation and management on a broader scale. In general, a holistic approach to the field of BIM and facilities management (FM) is lacking.

A key problem is in the logistical management of information, and its intangible flows (Haftor et al. 2011). An important aspect is the ability to communicate and interact at an early stage and
Use of BIM for existing Buildings

in a continuous manner to strengthen and add value to the project and the investments made for an efficient use of resources. It's about being able to link different types of knowledge, technologies, methods, networks and initiatives with each other and create a common understanding of the knowledge and resources that are available at different levels, especially for small businesses, but also for other actors, such as larger firms. Otherwise there is a risk of duplication and/or unnecessary competition. The challenge is to merge different BIM systems in such a way as to maximize profitability and leverage existing qualities and strengths at each stage of the process.

It is a well-known fact that BIM will challenge relationships and current thinking – their effect on bidding, contracts and insurance (Magnusson, 2012). Also, it will support the integration of the architectural design-construction (AEC), preservation and maintenance/operation (FM) teams. Whilst such changes are expected, research indicates that this is not yet the case. One reason for this may be that the theoretical and practical basis of information handling and the concept of ‘value generation’ have not been fully understood. The quality of work is affected in a negative manner, which in turn has a negative impact on the built environment, and especially on the specific qualities and values it represents (Waterhouse, 2011). Problems include a lack of leadership, competence and feedback cycles, flow configuration, variability problems, collaboration and communication across cultural and organizational boundaries, ownership aspects, leadership and staying up-to-date, and a lack of evaluation and accumulation of improvement in processes (ibid). As a result, appropriate BIM systems and devices for intelligent information sharing; consensus-building and participatory decision-making are needed to a much greater extent than before.

According to long tradition, the master builder was specialized in the design, construction and maintenance of buildings. This included all stages of planning, design and management, the production and handling of hand-made drawings and construction documents. However, this has changed into high-tech digitized drawings and handling of documents. In addition, responsibility for the process has been transferred to the building owner and buyer who are responsible for operation and maintenance. The production phase is normally separated from the design phase as well as from the long-term conservation and management phase, which means that knowledge will be lost between the different phases. There is the question of
ownership and leadership at the various stages of the process. Lack of coordination and communication causes all kinds of errors and inefficiencies, structural and material damage. Generally, a more integrated and preventative approach is needed (Johansson, 2008).

4.6. Potentials and Hindrances for Widespread Adoption

Although the adoption of BIM has numerous potential benefits, it raises challenges with regard to organizational, communication and leadership aspects and the way in which BIM integrates the business processes of individual practices (Arayici & Coates, 2012). Benefits of BIM will only come through close collaboration, and different actors will need to work together as one. This will provide greater options for innovation and R&D. BIM will push this development, which will include a change in habits and routines to make cooperation natural, which in the long-term will change conceptual views. This would result in higher quality of work. It is expected that new forms of bidding and contracts will emerge. Digitalization and close collaboration challenge the prevailing system of intellectual ownership, which may emerge into parallel routes: 1) of increased specialization of BIM modeling and specialists and 2) of consolidation into giant firms. There is a prevailing need to develop a consistent holistic approach and to develop common standards and requirements, for concepts and terminology, information delivery, data storage formats, bidding and contract forms etc. Unfortunately, there is still a hazy notion about just what information and data are needed, when and how data will be stored, used, shared and kept up to date. It is an issue of organizational restructuring, and also of competence, and thus of education and training/R&D, but unless the gap between technology, end-users and their processes is over-bridged - BIM usage will continue to be limited (Wakefield, 2005).

Standardization is necessary if SB/AC aspects are to be integrated with BIM processes, which should include the definitions and semantics of the information used. In order to enable integration of SB/AC methodologies with BIM, the definitions of information contents should be further developed. Recently, the International Standard Organization (ISO) has established a framework for providing specifications for the commissioning of BIM. A number of other important initiatives have been carried out in the USA, in Europe and likewise in Australia; e.g. the North American National BIM Standard, NBIMS, the Finnish Common BIM Requirements,
COBIM, and the Australian National BIM Guide. It is applicable to any range of BIM and building-related facilities, from a “portfolio of assets at a single site or multiple sites, to assets at a single small building and at any constituent system, subsystem, component or element. The framework is applicable to any asset type, including most structures, infrastructure and public works, equipment and material” (ISO TS 12911:2012). These standards work mainly with principle methodologies rather than individualized processes.

_Workforce development_ is also critical to the decision to implement a new technology and approach; otherwise, desired outcomes cannot be achieved. A prerequisite for success is that the targets set can be translated into concrete action plans and patents, where innovation and continuing learning should go first. Many of the problems are caused by lack of relevant knowledge and skills, particularly at the intersection of different sectors and disciplines (Johansson, 2008, Johansson, 2005). With regard to the building sector in general, there is an increased need for continuing education and training at different levels, particularly from the viewpoint of leadership, sustainability and innovation/entrepreneurship, and R&D, as well as on the practical use of BIM and its future development. This means that the competence should be broadened and that the opportunities to work with BIM in existing environments should increase (Johansson, 2008; Gustafsson & Rosvall 2010; Dyrssen et al, 2011).

A first step would be to increase levels of awareness through formal education, which all professionals undertake to achieve their necessary minimum qualifications. Concept promotion of sustainable building, architectural conservation and BIM within higher education is vital, together with requests for syllabus integration and inclusion, as well as continued training and research/R&D, e.g. in the form of Continuing Professional Development (CPD) modules accessible for all actors and stakeholders, and for educators as well (UNESCO, 2005; Kassem, 2012). BIM will be a way to change all construction/architectural/built environment-oriented education, creating the need to integrate construction technology and design, urban planning, architectural conservation, traditional and modern building technology, natural and social sciences, economy, management, arts and crafts. This includes knowledge about architectural conservation technology and maintenance, where accurate documentation, assessment and depiction of existing resources and qualities are essential.
Use of BIM for existing Buildings

5. RESEARCH FRONTIERS

This section summarizes the research front in the area of the usage of BIM. To be very clear, one key finding from the study reported here is that there is very little academic research targeting the use of BIM for existing buildings. An account of the findings generated by this study is provided below.

5.1. EARLIER AND CURRENT BIM RESEARCH

‘Computer Integrated Construction’ (CIC) research efforts in the 1990’s focused on incorporating entire graphic data and non-graphic data throughout an organization or a project. In 1993, a Japanese CIC project exploited a full scale, on-site automation combining information and robotics through all the stages of design, procurement and construction (Miyatake & Kangari, 1993). Another important research project was carried out by Chinowsky and Reinschmidt in 1995, where “qualitative spatial reasoning” was developed in order to embed the design knowledge into the graphic objects. Another research project, funded by the Korean government developed fully integrated CIC-systems using real-world projects. This encompassed the full spectrum of construction business functions, including planning, sales, design, estimation, scheduling, material management, contracting, cost control, quality, safety, human resource (HR) management, financing/accounting, general administration and R&D. This project fully utilized state-of-the-art technologies coupled with newly researched management methodologies. It was successful in terms of technical capability and a holistic approach, however, practical effectiveness was not proven to be economically feasible (Cho, 2000).

The research carried out by Chinowsky and Reinschmidt (1995) was further developed by Taylor and Bernstein in 2009, focusing on patterns of visualization, coordination, analysis and supply chain integration as a BIM trajectory. A holistic BIM framework focusing on the issues of practicability for real-world projects has been proposed by several researchers and research groups since then; the first was proposed by Succar (2009), followed by another by Jung and
Joo (2011). These two frameworks can be further developed and delineated so that the practical use of BIM effectively incorporates different BIM technologies in terms of their different properties, relations, standards and utilization across different construction business functions, considering various project, organizational and industry perspectives. In 2013, Succar published a Ph.D. dissertation on the same topic. See Table 1 for an overview.

Table 1. Summary of early research efforts on BIM.

<table>
<thead>
<tr>
<th>Source</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miyatake, Y. &amp; Kangari, R. (1993)</td>
<td>A full scale, on-site automation combining information and robotics all through the stages of design, procurement and construction</td>
</tr>
<tr>
<td>Chinowsky, P.S. &amp; Reinschmidt, P.S. (1995)</td>
<td>“Qualitative spatial reasoning” was developed in order to embed the design knowledge into the graphic objects.</td>
</tr>
<tr>
<td>M. Cho (2000)</td>
<td>Presents fully integrated CIC-systems using two real-world projects. This effort encompassed the full spectrum of construction business functions, including planning, sales, design, estimating, scheduling, material management, contracting, cost control, quality, safety, human resource (HR) management, financing/ accounting, general administration and R&amp;D. This project fully utilized state-of-the-art technologies coupled with newly researched management methodologies.</td>
</tr>
</tbody>
</table>
Current BIM research is mainly being conducted in Europe (Scandinavia, Germany and France), and at present, the United Kingdom (UK) is the leading region of BIM research. A significant amount of research is also carried out in Asia, Australia and the United States. In the last few years, several research initiatives have added new dimensions to the usual 3D BIM approach, progressively including information about 1) construction time (BIM 4D), 2) costs estimation (BIM 5D) and 3) lifecycle management (BIM 6D). At the Universities of Salford and Stanford/CIFE and the University of Reading some research has been performed with focus on hospitals. There is a group at the University of Washington (U.S.) including studies conducted on behalf of the U.S. Army Corps of Engineers on “Developing Best Practices for Capturing As-Built Building Information Models (BIM) for Existing Facilities”. In Italy, Dr. Matteo Lo Prete at Politecnico di Milano has presented a Ph.D. dissertation entitled Synergies between management and valorization of Cultural Heritage though Models Based on BIM Technologies. This doctoral research specimen deals with questions on how to create digital models of existing buildings with different techniques (Lo Prete, 2013). The amount of BIM literature is constantly growing, especially in terms of academic papers in peer review journals and magazines.

In Australia, academic research is being conducted at Deakin University, the University of Newcastle and the University of Sydney, in collaboration with Kyung Hee University in Seoul, Korea, focusing on developing a theoretical framework of technical requirements for using BIM as a multi-disciplinary collaboration platform (Singh et al, 2011). In Marseille, France, some progress has been made in the development of a specific free Autodesk Revit plug-in, nicknamed GreenSpider, examining how point clouds collected during high definition surveys can be processed with accuracy in a BIM environment, also for historic buildings. This research highlights the critical aspects and advantages deriving from the application of well-established parametric techniques such as e.g. laser scanning and photogrammetry to real world domain representations (Garagnan, 2013).

The British government has taken an initiative to make BIM obligatory for public projects, and in the United States, the General Services Administration has introduced requirements for the use of BIM. Even in the Nordic countries multiple client organizations have taken the initiative to start introducing BIM, e.g. Statbygg in Norway. Senatfastigheter in Finland and
Use of BIM for existing Buildings

Domænebestyrelsen for Bygninger, Boliger og Forsyning in Danmark. In Sweden, a number of government clients/managers have agreed to jointly develop common guidelines for BIM. At Luleå University, Professor Thomas Olofsson is leading a research project on industrialized building processes, which includes issues related to BIM. At Chalmers University of Technology in Gothenburg, a number of master theses have been produced on the topic and use of BIM.

Three ongoing European projects of which two are HESMOS (http://www.hesmos.eu) and ISES are currently addressing all this, including a number of aspects of BIM for energy-efficient design and sustainable lifecycle management, including BIM-integrated air-flow analysis, which is integrated with the ongoing Eurostar project SARA. Their management calls for an extended BIM-based information framework, ICT platforms providing open access to advanced methods, flexible and holistic involvement of a broad range of end users in the overall process. This also includes the development of an energy-extended BIM platform (eeBIM), an enhanced Information Delivery (IDM/MVD) “BIM to energy” process and a set of advanced energy analysis, simulation, monitoring and cost estimation tools for various lifecycle phases, from early design to facility management, refurbishment and retrofitting, bound together in a common, interoperable BIM-based Virtual Energy Lab platform accessible via the Internet.

The third project is a newly-started large European Integrated Project (IP), known as eeEmbedded (Collaborative Holistic Design Laboratory and Methodology for Energy-Efficient Embedded Buildings). This project will develop an open BIM-based holistic collaborative design and simulation platform, a related holistic design methodology, an energy system information model and an integrated information management framework for designing energy-efficient buildings and their optimal energetic embedding in the neighborhood of surrounding buildings and energy systems. A new design control and monitoring system based on hierarchical key performance indicators will support the complex design collaboration process. Knowledge-based detailing templates will allow energy simulations in the early design phase, and BIM-enabled interoperability based on a novel system ontology will provide for a seamless holistic design process with distributed experts, and a seamless integration of simulations in the virtual design office (energy-performance, CO2, CFD, control system, energy system, climate change, user behavior, construction, facility operation), thus extending it to a real virtual design lab. The
partners of these three European projects represent a broad mix of academic institutions. These projects are hosted by Institut for Construction Informatics, TU Dresden in collaboration with BIM consultants and software vendors such as Nemetschek, RIB, DDS, SOFiSTiK, and industry partners from design (Obermeyer Planen + Beraten, Leonhardt, Andrä & Partner, Granlund Oy etc.) and construction (Royal BAM group, TRIMO Engineering, STRABAG AG). See Table 2 and Table 3 for an overview.

5.2. SUMMARY OF RESEARCH NEEDS AND THEIR IMPLICATIONS

In general, there is a need for a more integrated approach to research and practice at the intersection of different disciplines, sectors, business functions and initiatives. The research and development work carried out on BIM so far has had a significant focus on new buildings. What happens to existing resources is little researched or discussed today, especially in terms of management and maintenance. In recent years, many firms have seen the majority of their construction work switch to retrofit and refurbishment projects instead of new build, so the demand for research in this area is growing. As a consequence, there is an urgent need to find out how to better integrate BIM research with facilities management, historic building technology, architectural conservation, and high quality construction practice (traditional and modern), combined with entrepreneurship and strategic leadership in using BIM.

There is a need for increased integration of already existing systems, technologies and tools etc. that are independent and functioning well: for energy efficiency; moisture detection; daylight and artificial lighting; simulation of safety; accessibility and space; laser scanning; GIS; and for being able to combine information about new and existing buildings/environments, and most importantly - the context. The challenge will be to put all necessary information into ‘one’ model; keeping it transparent and up-to-date and making it independent and accessible for a wider audience. This is because SB/SIC need a new type of information compared to a traditional process. In this context, holistic understanding and the transition between the different phases and stages of the building process is of key importance. Formulating comprehensive interactive frameworks of BIM for sustainable urban planning, construction, preservation/rehabilitation, maintenance and management (FM) jointly would effectively
facilitate the strategic utilization of BIM. This applies not only to individual buildings, but also to larger building stocks, whole cities, streetscapes, landscapes and infrastructure.

Table 2. Summary of current BIM research.

<table>
<thead>
<tr>
<th>University</th>
<th>Research Focus</th>
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<tbody>
<tr>
<td>University of Salford (UK)</td>
<td>New dimensions to the usual 3D BIM approach, progressively including information about 1) <em>construction time</em> (BIM 4D), 2) <em>costs estimation</em> (BIM 5D) and 3) <em>lifecycle management</em> (BIM 6D). The research is partly led by Prof. Dr. Lauri Koskela, Theory Based Lean Project and Production Management, School of the Built Environment: <a href="http://laurikoskela.com/papers/">http://laurikoskela.com/papers/</a> A Ph.D. dissertation was presented by Dr. Bilal Succar in 2013: “Building Information Modelling: conceptual constructs and performance improvement tools”, see references.</td>
</tr>
<tr>
<td>University of Reading (UK)</td>
<td>BIM applied to hospitals (see above)</td>
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<tr>
<td>Stanford/CIFE (USA)</td>
<td></td>
</tr>
<tr>
<td>University of Washington (USA)</td>
<td>Best Practices for Capturing As-Built Building Information Models (BIM) for Existing Facilities</td>
</tr>
<tr>
<td>Politecnico di Milano (Italy)</td>
<td>Synergies between management and valorization of Cultural Heritage though Models Based on BIM Technologies. How to create digital models of existing buildings with different techniques.</td>
</tr>
<tr>
<td>Deakin University (Australia)</td>
<td>Development of a theoretical framework of technical requirements for using BIM as a multi-disciplinary collaboration platform.</td>
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<tr>
<td>University of Newcastle (Australia)</td>
<td></td>
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<tr>
<td>University of Sydney (Australia)</td>
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<tr>
<td>Kyung Hee Univ. in Seoul (Korea)</td>
<td></td>
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<tr>
<td>Garagnan, S., Marseille (France)</td>
<td>University unknown. Examining how point clouds collected during high definition surveys can be processed with accuracy in a BIM environment, also for historic buildings.</td>
</tr>
<tr>
<td>TU Dresden (Germany)</td>
<td>An open BIM-based holistic collaborative design and simulation platform, a related holistic design methodology, an energy system information model and an integrated information management framework for designing energy-</td>
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37
efficient buildings and their optimal energetic embedding in the neighborhood of surrounding buildings and energy systems.

<table>
<thead>
<tr>
<th>University</th>
<th>Focus Area</th>
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<tbody>
<tr>
<td>Aalto University (Finland)</td>
<td>BIM for facilities and organizational management (FM/OM) is one of their current focus areas aiming to introduce the state-of-the-art approaches, and identify the key research and practical challenges, in using BIM for later stages of the project lifecycle. The BIMforLEAN project aims at strengthening the Finnish research capability in integration of lean construction and BIM. To realize this, Prof Lauri Koskela from the University of Salford (UK) is invited to Aalto University as a FiDiPro Professor. The overall objective is to identify, demonstrate and expand the positive synergies between BIM and lean construction as well as to develop novel practical solutions leveraging such synergies. Their research focus is on three areas: 1) linkages between BIM and lean construction; 2) mobile computing for construction; and 3) interaction between commercial, organizational and design/production system arrangements in construction projects.</td>
</tr>
<tr>
<td>Luleå University (Sweden)</td>
<td>Research on industrialized building processes, which includes issues related to BIM</td>
</tr>
<tr>
<td>Chalmers University of Technology (Sweden)</td>
<td>A number of master theses on the use of BIM. Department of Civil and Environmental Engineering Division of Construction Management Research Group Name: Visualization Technology.</td>
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</table>

More research is needed to understand how to use of BIM systems for cross-domain tasks such as the achievement of efficient planning, investigation, assessment, documentation, and lifecycle energy and cost performance of new and existing resources. This requires consideration of *multiple information sources* and *resources generated* which are maintained and exploited by various stakeholders over a large number of years (6D BIM). Such information may for example include documentation of existing conditions; communication, collaboration and decision-making processes; energy and climate data; occupancy/activity data; manufacturer data regarding materials, pre-fabricated or equipment components; a stochastic approach for reliability; sustainability; assessment and research methodologies; potential risks and future maintenance; architectural quality and heritage aspects and much more.
Table 3. Other key BIM research initiatives.

<table>
<thead>
<tr>
<th>Actor / Group</th>
<th>Description</th>
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<tbody>
<tr>
<td>British Government, BIM Task Group (UK)</td>
<td>The Government Construction Strategy was published by the Cabinet office 2011. The report announced the Government’s intention to require: collaborative 3D BIM (with all project and asset information, documentation and data being electronic) on its projects by 2016. Essentially the UK Government has embarked, together with industry, on a four year program for sector modernization with the key objective of: reducing capital cost and the carbon burden from the construction and operation of the built environment by 20%. Central to the BIM Task Groups ambitions is the adoption of information rich Building Information Modeling (BIM) technologies, process and collaborative behaviors that will unlock new more efficient ways of working at all stages of the project lifecycle.</td>
</tr>
<tr>
<td>The General Services Administration (USA)</td>
<td>Requirements for the use of BIM, similar to the BIM Task Group, UK (see above).</td>
</tr>
<tr>
<td>Statsbygg (Norway) Senatfastigheter (Finland)</td>
<td>Has jointly published the report: “Statsbygg Building Information Modeling Manual - version 1.2”. Includes generic requirements for Building Information Modeling (BIM) in projects and at facilities.</td>
</tr>
<tr>
<td>Domænebestyrelsen for Bygninger, Boliger og Forsyning (Denmark)</td>
<td>“Digitalisering af Offentlig Byggesagsbehandling” (“Digitization of Public construction works”) was a three-year digitization project aiming to demonstrate how it was possible to carry out a construction project with digital data. The project has won an Innovation Award in Denmark. The prize was established by Kommunalteknisk Chefforening (KTC).</td>
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</table>

It should be noted that BIM does not provide any shortcuts in the process; it simply states the deficiency of information (Kapp (2009, p.13). There is a need to further investigate the construction of BIM systems and the information flows that incorporate both technological and quantitative assets (intelligent objects, energy and performance data etc.) and qualitative assets (traditional/modern skills, techniques, photographs, oral communication, histories,
sounds, acoustics and lighting etc.) Lifecycle Assessment (LCI/LCA), energy assessment, service life assessment, preservation and maintenance manuals, optimization of refurbishment and sustainability rating are important methods in design for SB/SIC and the sustainable use and refurbishment of buildings. In order to rationalize the use of these methods and to support the use of sustainable methods during the design processes, the methods should be integrated with BIM processes. To become more cost-effective and efficient, BIM needs to be developed so that more of the work is carried out jointly at the early stages of a process, to become more preventative and planning-driven when preparing for the next phase.

A key factor is the object’s interaction with its intended use, and its users. This is still an under-represented aspect in current BIM systems and IFC models. Currently, many user-related decisions are based on a set of average user requirements and on the assumption that the future buildings will have to adapt to the needs of the majority of users. There is a need to include use and users’ semantics in current BIM representation, and to integrate it with the virtual simulation of the ‘building use phenomenon’. The objective is to provide visualization, to be combined with a written description, of how the existing or future buildings will actually be preserved, adapted, renovated, (re-)used and experienced, before commencing construction. This allows designers to test and evaluate the impact of their decisions on the new or existing building and future users’ life and activities at an early stage. How decisions are made over time is also important. This may include information about specific problems, limitations and needs/constraints, intentions and arguments etc., which should be included in the BIM model as well. This may improve the quality of the final product by solving critical issues and reducing both time and costs.

It is evident that creating information technology tools is only one necessary step on a much more complex path to the improvements being sought. There is a complex relationship between modeling technology, building systems and services, management and organization of actors over the lifecycle of the built environment (BIM research group, Aalto University, Finland). Hence, it is clear that BIM requires more than software to be effective; i.e. the capability and willingness of all parties to interact and collaborate more closely, at all stages of the process - even if it may seem too complicated, expensive or time consuming at first. Institutions and governments must participate, encourage and invest in research/R&D,
education and training (WSP Group, p. 10-12). Knowledge and experience in inclusion and leadership are crucial factors for management of the BIM system as an inter-connected whole, which today is handled by special BIM managers – and to be expanded to include all design professions, building owners etc. who will need to learn about IL, BIM, architectural conservation sustainable building principles, as it overlaps other disciplines, including the role of FM, traditional and modern building technology/crafts.

It is asserted that the cultural heritage sector should be able to play a more proactive part in future BIM development instead of being passive or re-active to its consequences, and ongoing developments (Johansson, 2008). More and more people agree that it is time to stop regarding cultural heritage conservation as an obstacle for economic growth. On the contrary, cultural heritage is nowadays considered a prerequisite for regional and sustainable development. In the context of BIM, it is asserted that the cultural heritage sector has a strong and important role: to promote creativity, innovation and competitiveness – also for the development of intelligent/smart buildings (Dyrssen et al, 2007; Gustafsson, 2010). New research on BIM should move beyond new build to managing the broader range of facilities and built assets (including landscapes and infrastructure), providing preventative conservation/maintenance/renovation/rehabilitation and adaptive reuse. Because of enabling the sharing of information and because of the great variety of objects, BIM can support the management of information needed for sustainable building practices and conservation. For example, the need for rigorous building investigation, documentation and verification at a preliminary stage is extremely important. For a sustainable result, all design professionals (architects, planners, engineers, preservationists etc.), material producers, manufacturers, building owners, economists, facilities managers and craft specialists should be involved. A research question that emerges is: Can BIM research be joined with cultural heritage research and scientific insight, artistic understanding etc., as part of a more integrated and holistic approach?

Existing buildings and environments are all historic resources, and they were not developed in a virtual world. Their conditions and parameters are real. The passage of time allows buildings to evolve and transform – what is typically preserved is often unique architectural components that were crafted exclusively. Existing resources are always unique: their materials, details,
technique, contents and surroundings. Unlike new build, architectural heritage adds an entirely new level to the design process—that of existing qualities and conditions, not only heritage value per se. Some materials deserve to be preserved and/or maintained, but some may be recycled and reused, however, not all. It is a matter of informed judgment and finding a balance in each case. Architectural heritage is often seen as being essentially material (tangible), but it also has non-material (intangible) dimensions of crucial importance for sustainability and high quality outcomes that need to be considered when using BIM.

Summary of key aspects and their implications:

1. **There is a need to further include building owners, use and users’ semantics in BIM research and development.** A key factor is the object’s interaction with its intended use, and its users. This is still an under-represented aspect in current BIM systems and IFC models. The objective is to provide visualization, preferably combined with a written description, of how the asset should be continuously managed, assessed, preserved, adapted, renovated and maintained, (re-)used and experienced, before beginning its construction.

2. **There is a need to further investigate the construction of BIM systems and the information flows,** which should incorporate both technological and quantitative assets, as well as qualitative assets.

3. **More research is needed for the use of BIM systems for cross-domain tasks** such as the achievement of efficient planning, investigation, assessment, documentation, lifecycle energy and cost performance of both new and existing resources. New research should move beyond new build to managing the broader range of facilities and built assets - including infrastructure and landscapes. There is an urgent need to better integrate BIM research with facilities management (FM), historic building technology, architectural heritage conservation, and high quality construction practice (traditional and modern crafts), combined with entrepreneurship and strategic leadership.
4. To become more cost-effective and efficient, BIM needs to be developed so that more work is carried out jointly by different actors and professionals at the early stages of a process, throughout the project’s various phases: from an integrated lifecycle perspective, i.e. to becoming more preventative and planning-driven.

5.3. PROPOSED DIRECTIONS FOR BIM RESEARCH

The intended research should be multi- and interdisciplinary in system design and modeling, and include theories, roles, competencies and phenomena such as *complementarities* and *intersections* as part of a more comprehensive methodological approach (Ennen & Richter, 2010). The intended research should offer a *holistic model framework*, with an emphasis on sustainability and *management* of built environments. This model should be applicable to individual buildings (new and old), to groups of buildings, landscapes and streetscapes, to larger building stocks and infrastructure subject to change – and concern all stages of the building process, including conservation and management (involving all potential parties; e.g. designers, planners, preservationists, economists, crafts). Such a framework is not available today and is yet to be developed.

The intended research should preferably be based on the theoretical framework of SB and SIC, in order to develop BIM as a multi-disciplinary collaboration platform. A *broad multi- or cross-disciplinary approach*, transcending the borders between sectors, academic and non-academic institutions, enterprises and disciplines will be necessary, to improve the functional, managerial and economic realities of BIM. The research should provide *theoretical and practical considerations* as to how the basic objectives of SB/SIC can be achieved. This would extend from a ‘*lean production system*’ to a ‘*value creating system*’, promoting architectural heritage, sustainability, innovation, education, learning and R&D. Since the subjects of sustainable building and conservation are inter-linked, it is asserted that both objectives can be realized through an *innovative and precautionary approach*, incorporating a more preventative and integrated course of action/R&D. The research effort should remain *local*, but be conducted in collaboration with different researchers and research groups abroad (Cole & Lorch, 2003).
5.4. Research Methodology and Design

An appropriate research methodology must explore the BIM modeling process in depth, considering both quantitative and qualitative information from many different actors, disciplines and perspectives. This means questioning the functions, purposes, structures, and processes of existing BIM models and frameworks, interfacing systems and interactions, methods and tools used by different stakeholders. This implies that the composition and very nature of existing BIM systems, their structure, content, components and design, is questioned.

A systemic holistic approach combined with trans-disciplinary and embedded case studies (i.e. for real-world modeling) is proposed for developing a comprehensive BIM framework and approach (Scholtz et al., 2006). In coming research papers/proposals/applications, the following issues may be covered in parallel: 1) New buildings to be projected in an existing environment; and 2) Existing buildings and environments documented in the form of a comprehensive integrated BIM model (including the use of laser scanning/‘point clouds’, terrestrial surveying, photogrammetry, existing drawings, visual inspection and assessment etc.).

The main issues to be further explored, as proposed here, are:

- What information is needed to fully implement BIM?
  - To whom will information handling be a priority?
  - Who owns the information?
  - Who needs what information?
  - How can the information be trusted to be accurate and up-to-date?

- What knowledge and technology is available today?
  - How can different theories and activities contribute to sustainable building and conservation as a whole?
  - What are the key opportunities?
  - What are the key success factors for the realization of these opportunities?
Use of BIM for existing Buildings

- What are the main characteristics of BIM business models and technology?
  - What are the limitations and challenges?

- How is knowledge and data collected and sorted today to provide useful information?
  - What knowledge, systems, methods and tools are missing?

- What are the general causes of the lack of information in the process?
  - How can delivery of relevant building information be obtained?

- How would a future BIM model be configured?
  - What components, systems, methods and tools should be included in the BIM process?
  - What type of information should be included?

- What specific BIM services can be designed so that information is correctly handled throughout the various stages of the process?
  - What is the future of such services and who will be the owners of the services?

- What would characterize a future BIM business model?
  - Who will pay? Who will find new ways to profit?
  - How can the services be cost effective, and what will be the consequences?

- What is the future quality and value of these models and solutions to the environment, to industry and society at large?
  - To what extent can environmental principles and ethics be used in these BIM models and their development, and how?
6. CONCLUSION

The assumed research focus presented here includes the various aspects of the usage of Building Information Models and Modeling practices for an existing built environment, with a special interest for Sweden. An explorative research study has been conducted to that end, and is reported here. The objective of that study was to identify the frontiers of research and practices with regard to the assumed focus and it included a comprehensive review of academic and professional literature and interviews with selected BIM experts in Sweden. The key results of the study may be summarized in the following terms:

- **Big Expectations**: Much professional literature and some academic literature regard BIM as a “silver bullet” that will solve all kinds of problems related to the whole lifecycle of built environment.

- **No Evidence**: The conducted study could not identify a great deal of research addressing the use of BIM; the few studies that are available do not confirm the Big Expectations assumed for the positive effects of the use of BIM.

- **Complexity**: While the usage of BIM promises to deal positively with the various complexities inherent in the lifecycle of any built environment, paradoxically the introduction and use of BIM as such also seems to introduce new kinds of complexities challenging a successful use of BIM for existing buildings.

- **Many Stakeholders**: It is clear that as any non-trivial built environment has many stakeholders with their various sometimes conflicting interests, the introduction of BIM usage also introduces additional stakeholders that are specific and unique to BIM and its usage.

- **BIM is more than software**: While vendors of the various BIM software packages and associated accessories such as 3-D scanners, do promise many benefits originating
from BIM usage, it is much more than a software package. BIM usage includes resources such as people with their roles, competencies and interests, it includes various practices with their activities and processes, it includes social institutions with their formal and informal norms, it includes economic actors such as firms, public organizations and NGO:s, and includes the actual built environment that BIM is supposed to serve. All this appears to necessitate a comprehensive approach that is not limited to only a few disciplines; is they professional or academic.

- **Research is needed**: Perhaps the clearest outcome of the study reported here is that there is a need for comprehensive research into the use of BIM for existing built environments, both in Sweden and elsewhere. Put simply, this is because:

  o On the one hand the BIM industry and its professionals have put forward many bold positive effects which can be assumed to be produced by the use of BIM.

  o On the other hand there is no independent professional research to confirm or otherwise the actual vs. the assumed consequences of the adoption and use of BIM.

  o This gap must be closed for several reasons, of which the key ones seem to be:

    - We need to know, rather than assume, whether we should use BIM, or not, and why and how?
    - We need to know, rather than assume, what are the key reasons preventing the successful usage of BIM?
    - We need to know, rather than assume, the factors that promote successful use of BIM?

This suggestion for a future research agenda into the use of BIM for existing built environments concludes this report.
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THE RESEARCH TEAM AND SPONSOR

The research reported here was generously sponsored by the Department of Informatics at Linnaeus University, Sweden.

The research team was constituted by four members, as follows:

- **Erika Johansson PhD**
  - Senior Researcher, Department of Informatics, Linnaeus University, Sweden;
  - acted as the researcher and was responsible for conducting the majority of the research;

- **Darek M. HAFTOR PhD**
  - Professor in Informatics, Department of Informatics, Linnaeus University, Sweden;
  - acted as the sponsor representative and as the research leader;

- **Bengt MAGNUSSON PhD**
  - Adjunct Professor in Informatics, Department of Building Technology, Linnaeus University, Sweden;
  - acted as senior advisor with special focus on BIM technologies and their usage;

- **Jan ROSVALL PhD**
  - Professor Emeritus, Chalmers University of Technology and University of Gothenburg, Sweden;
  - acted as senior researcher with special focus on conservation of built environments.
Use of BIM for existing Buildings

Presentation of each Researcher

Dr. Erika JOHANSSON earned her Ph.D. degree at Chalmers University of Technology in 2008. As a Fulbright scholar and American Scandinavian Foundation (ASF) fellow and a professional trainee, she was a resident of the USA for five years, where she pursued studies and research for her licentiate and doctorate degree at Columbia University, Graduate School of Architecture, Planning and Preservation (GSAPP) in the City of New York. She holds academic qualifications in environmental science and conservation research, and an international career directed towards sustainability and development of intersectional leadership, collaboration and competence development in the broader area of sustainable building, conservation and development with an emphasis on cross-sector innovation, learning and R&D. She has pursued comprehensive academic-industry training, inter- and trans-disciplinary research providing a broad understanding of architectural conservation, construction and sustainability-oriented issues, including organizational and collaboration aspects, educational/R&D needs and analyses, research and work methodologies, participatory action-based research, emerging technologies, informatics/ICT, entrepreneurship, innovation and management. As an architectural conservator, she has experience of the design, execution and management of projects, including investigation and assessment of built structures, preservation, renovation/rehabilitation/adaptation, energy efficiency, documentation, procurement and maintenance. Dr. Johansson has worked on a number of different conservation projects in Sweden, UK and the greater New York City (Manhattan) area. She has experience of directing, leading and managing multi-disciplinary teams and working with actors from different backgrounds; expertise in strategic planning and development in a broader sense along with in-depth technical skills in conservation.
Dr. Darek M. HAFTOR is the PostNord Professor of Informatics, with special focus on Information Logistics, at Linnaeus University, Sweden. He has spent almost fifteen years in industry, initially as an analyst and a consultant and subsequently as a manager at a multinational corporation. That work exposed him to various aspects of operations development, followed by strategic management activities. Dr. Haftor has a keen interest in business development as facilitated by information and various information and communication technologies. His professional work has brought him all over Europe and also to the Middle East. He has studied a variety of disciplines, from mathematics, statistics and computer science, through business administration, industrial organization, and psychology to social theory and philosophy, at various schools throughout Europe and North America. Dr. Haftor was awarded a doctorate in Industrial Organization and Management from Chalmers University of Technology, Sweden. He has held academic positions at several universities in Sweden, has taught MBA classes internationally, and has held several board member positions for academic organizations and their journals. His academic and managerial work has been recognized, including receiving ‘The Sir Geoffrey Vickers Memorial Award’ from the International Society for Systems Sciences and also ‘The President’s Achieving Excellence Award’ from Wyeth Corporation, both in the USA. Dr. Haftor’s research results include a ‘Systemic Enterprise Modeling Language’; a ‘Normative Ground-Motive Analysis’ model of pre-theoretical assumptions, a model of ‘Semantic Complexification in Human Affairs’, and a novel ‘Profit Equation’ that accounts for cognitive time distortion. In broad terms, Dr. Haftor’s current research focuses two frontiers: 1) Information Economy and its Digital Business Models, and 2) on normative foundations, inherent in any design and development of organized effort.
Dr. Bengt MAGNUSSON is Adjunct Professor in Building Technology with special focus on BIM technologies, at Linnaeus University, Sweden. Dr. Magnusson is by profession a Structural Engineer and obtained a Ph.D. at Chalmers University of Technology, Sweden, with work targeting probabilistic design of load-bearing structures in the serviceability limit state. Prior to his PhD, he had earned a Licentiate of Engineering degree, also at Chalmers, with work that addressed probabilistic analysis of the load-bearing capacity of strengthened masonry lintels in reconstruction of old buildings with structural masonry walls. Among other scientific achievements, Dr. Magnusson has developed computer programs for studying energy efficient buildings, FFT analysis of wind loads, and a number of other engineering problems. He has directed a large number of reports addressing structural issues for wooden structures. During the last 20 years Dr. Magnusson has acted as a senior consultant at Advanced Engineering Computation AB (AEC) in Gothenburg, Sweden, a daughter company to COWI A/S, Denmark, which is a leading European engineering company. Dr. Magnusson has been active in the practical implementation of CAD, BIM and GIS at a number of Swedish organizations, private as well as public. Dr. Magnusson has thorough knowledge and expertise in the field of construction technology and BIM; creating and utilizing information in design, construction and management of buildings and infrastructure.
Dr. Jan ROSVALL has since the 1960s, together with his wife Associate Professor Emerita Nanne Engelbrektsson, instigated and continuously developed a comprehensive interdisciplinary academic infrastructure and multidisciplinary discourse in Conservation of Cultural Heritage - Built Environment at the University of Gothenburg (GU), Sweden - the very first of its kind in Europe, resulting in a complete workforce of more than one thousand qualified employees, teachers and doctors/Ph.Ds. The discourse employs a wide range of methods, and investigates a broad array of objects and large-scale projects, from the preservation and restoration of artifacts, monuments, ordinary town and urban ambiances, and cultural landscapes. In his proactive leadership role, Professor Rosvall has had a profound impact on the development of the conservation field both in Sweden and internationally. He has contributed to epistemological and ethical considerations, cross-disciplinary and cultural reflection and a broadening of views, policy change and development. Through his positions at the Department of Conservation GU and GMV Centre for Environment and Sustainability, Chalmers/GU he has been acknowledged as an international scholar and guest professor for many years: e.g. at Heritage Malta and University of Malta, University of Naples, Politecnico di Milano, University of Seville (Europe), and at Baylor and Cornell Universities (USA). His academic teaching and research has included 1) theory and principles of conservation; including assessment, documentation and systemic modeling, communication and management, heritage design, arts and crafts; and 2) theory, methods, principles, history and ideas of Western art, architecture and urbanism. In 1996 he was appointed the very first Visiting Professor in Conservation ever at the Swedish Classical Research Institute in Rome. In addition, he was responsible for launching the multi- and transdisciplinary NMK Postgraduate Enterprising Research School at Chalmers/GU in 2001. He currently holds a position as senior advisor at the Department of Conservation, Uppsala University (Campus Gotland) and was awarded the title Professor Emeritus at Chalmers/GU in 2010.