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10 QUESTIONS CONCERNING SUSTAINABLE BUILDING RENOVATION

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Ten Questions concerning Sustainable Building Renovation

Abstract

In countries all over Europe the need for building renovation is receiving increased attention. One reason for this is an ageing building stock. Another reason is the need for more environmentally sustainable buildings with reductions in energy consumption and greenhouse gas emissions to limit the harmful climate impact. There is at the same time a need to upgrade many buildings to improve the quality of life – social sustainability, for instance improve indoor climate; and to increase productivity in the building process to ensure affordable housing – economic sustainability.

Low productivity and frequent conflicts in the construction sector have led to an increasing interest in new forms of collaboration between the different stakeholders involved in construction projects. Development of strategic partnerships concerning a portfolio of renovation projects are seen as a promising way to achieve more sustainable building renovation for some large building clients and for companies with a high maturity in collaborative practice.

There is a large number of tools for design decision support and systems for sustainability certification of buildings, but there are not many tools and systems dedicated to building renovation. Measuring the different dimensions of sustainability is a challenge. Regulations play a central role in opening the markets for sustainable building renovation through incentive schemes, building

codes, etc. Although traditional approaches to energy renovation emphasize more efficient heating and lighting systems and better insulation, there is a tendency to address the challenge more holistically by emphasizing social targets.

Keywords: Building; Renovation; Sustainability; Partnerships; Targets; Measurements.

1. Introduction

The need for renovation of buildings is receiving increased attention in many European countries [1]. There are many reasons for this, but essentially it comes down to a fundamental need to make building renovation more sustainable. Thus, it is important to improve the way we carry out building renovation. The authors of this paper are engaged in research and development on this topic in close collaboration with companies from the whole value chain in the Danish construction industry and we know that many researchers and companies are involved in similar activities in other countries. To support our common knowledge building, this paper creates an overview and state of the art of the existing research-based knowledge on Sustainable Building Renovation (SBR). This is done by presenting and discussing current research and by answering 10 questions.

There is a lot of research and development that focus on inventing and designing new technical solutions and developing new methods to calculate, simulate and dimension the physical and technical aspects of new and renovated buildings. On the other hand, there is much less research on how to manage and carry out the process of building renovation even though this is essential to improve the productivity, effectiveness and user satisfaction of renovation [2]. To make building

renovation more sustainable, it is important to have a holistic approach on sustainability and include both the social, economic and environmental aspects. These issues have been some of the leading considerations behind the formulation of the 10 questions. The paper provides answers to the questions to create a common overview of SBR; mostly from a European perspective.

2. The 10 questions (and answers) concerning Sustainable Building renovation

2.1 Question 1: What are the typical issues that initiate the need for a SBR?

A European research project concerning SBR investigated the drivers for energy renovation in three European countries – Cyprus, Denmark and Sweden [1]. The drivers naturally vary for different types of buildings and organisation in each country. In table 1 they are grouped in the main factors: Durability/building physics, Economy, Environment, Comfort and Other. It was common for all three countries that energy renovation is mostly undertaken as comprehensive refurbishments, where upgrading the building in a more general sense has become necessary. Renovations only concerning energy efficiency mostly concern measures with limited payback time.

There have been many studies aiming at identifying barriers for building renovation and many proposals to categorise them have been made. Over all the barriers can simply be divided into two main categories: economic and informational barriers [2]. Lack of the financial incentives and life cycle perspectives are the most significant economic barriers, while too little political consciousness, lack of common direction amongst the main stakeholders and lack of overview, where to prioritise, are the most important informational barriers.

A recent study [3] presents an overview of barriers based on 13 literature references resulting in the following five categories of barriers; (1) Institutional and political barriers; (2) Market and economical barriers; (3) Financial barriers; (4) Technical barriers, and (5) Behavioural and social barriers.

Table 1: Identified drivers for energy renovation for three European countries [1]

	Cyprus	Denmark	Sweden
Durability/building physics	Moisture	Deterioration	Maintenance
Economy	Cost, income	Payback time	Cost
Environment	Energy savings, Eco-friendly products	Energy savings, local energy production	Energy savings
Comfort	Indoor air quality	Indoor climate	
Other	Building aesthetics	Branding, CSR	

2.2 Question 2: What is meant by SBR?

SBR is in this paper understood as renovation of existing buildings that results in upgraded buildings, which are more sustainable in terms of environmental, social and economic aspects after the renovation than before [4] – or at least in relation to two of these aspects. The meaning of sustainability is associated with the consideration of the interdependence of society, environment and economy in complex sustainability thinking based on the definitions from the United Nations with the three sustainability dimensions: social, economic, and environment [4]. For assessing

sustainability of investment projects, Haavaldsen et al. [6] recommend differentiating between the three levels: operational relating to project output, tactical relating to target groups, and strategic relating to greater society.

Thuvander et al. [7] present a large list of commonly used terms to describe building changes and concludes that there is no generally used term. This paper will like Thuvander et al. [7] use the term 'renovation'. Building renovation is according to Àstmarsson et al. [8] the process of fixing or replacing existing parts of the building to improve its performance; either to its original state or better. However, renovation means renewal and is not identical with maintenance and replacing old parts with similar new parts. With renovation it is common to upgrade the building standard to be closer to the current standard rather than the standard at the time the building was originally built.

The standard of buildings produced develops over time and mostly increases, so that new buildings in general have a higher standard than old buildings. Energy requirements is a striking example. Over the last decades, the requirements to reduce energy consumption of buildings have gradually become much stricter in building regulations in most countries. Furthermore, the amount and sophistication of technical building installations or services have increased drastically. A reflection of this has been a comprehensive literature on intelligent buildings [9]. Thus building renovations provide the possibility to change building design/lay-out, functions, architectural expression etc. to match users' current and/or future needs. Combining multiple disciplines introduces complexity to building renovations, and because of that, interdisciplinary expertise is required to deal with most renovation projects [10].

The focus in this paper is on comprehensive renovation projects, which among other things involve a major improvement in energy performance. Such renovations are encouraged in European energy policies and are also called ‘deep renovation’, for instance in EU’s Horizon 2020 programme for research and innovation [11]. A main argument for deep renovations are that they are a necessity to achieve radical improvements in energy efficiency.

However, recent research has observed a trend of housing associations moving towards applying partial or over-time renovation strategies; for instance in Sweden as well as other locations. The positive side of partial renovations is that it can provide opportunities for dealing with social issues, respect for architecture and cultural identity, and limit use of resources. They also allow for later inclusion of new technological innovations and thereby possibly achieving even higher levels of energy efficiency in the long run, while all-at-once deep renovations might lead to lock-ins to the current less efficient technologies [12]. This is an area that needs further investigation.

2.3 Question 3: Who are the main stakeholders in SBR?

The main stakeholders in SBR can be divided in the demand side and the supply side. Who is involved in a specific project varies according to type of building, complexity and national traditions. The demand side consists of the owners and the users and those who represent them as facilities managers, building clients, client consultants and administrators in deciding on doing and involved in ordering building renovation. The supply side consists of the providers of design and construction services (architects, consulting engineers, contractors) as well as material and equipment providers. Besides the main stakeholders, there are often a number of secondary

stakeholders involved in SBR like authorities, financiers, and neighbours. The demand side is the most interesting, when one search for motivation and barriers for initiating SBR.

An analysis from Denmark confirmed that building owners and users often have different interests, but this also varies depending on type of buildings [10]. Public schools and listed buildings are usually part of a political agenda since they get a lot of attention from the inhabitants every day. Energy renovations in social housing in Denmark are highly dependent on residential democracy. It means that the majority of the residential voters have to support the idea; otherwise it will not be realised.

Principal-Agent Problems [13] in terms of Landlord/Tenant Dilemma [8] is present in the building sector in many countries and is considered to be one of the biggest barriers for energy renovation projects. The landlord provides the tenant with housing, appliances and installations, and the tenant pays the energy bill. The landlord is therefore not interested in investing too much money in energy efficiency, while the tenant wants to lower the energy costs, and this is where the dilemma occurs. The legislation in this field is very complex and the maximum rent is regulated by law in some countries, which can be an obstacle for energy renovations because the maximum possible rent in most cases is insufficient for financing renovation investments.

2.4 Question 4: What characterizes the process of SBR compared to the process of new building?

In the construction industry it is often assumed that renovation projects merely are a special type of new construction projects. They are often organised in the same way even though mostly with a more traditional division of labour and contract forms, and less standardisation. However, there are a number of differences between the process of new building projects and the process of renovation

projects. Jensen et al. [4] identify seven characteristics, which distinguish the process of building renovation from the process of new building project:

1. There is an existing building and it is possible and necessary to make a pre-evaluation of the building's design, condition and performance in the planning of renovation.
2. There are also usually existing users and most of them will remain users after the renovation, so it is possible and relevant to collect their experiences and views on the buildings in a pre-evaluation and their needs and preferences in the briefing process during the planning of renovation.
3. It is possible to set performance target for the building after renovation related to the performance before and calculate the expected performance improvement. In new buildings, the expected performance has to be related to more general benchmarks like requirements in building codes or benchmarks for other more or less similar buildings.
4. There is an existing building design and architectural expression, which has to be taking into consideration and limits the freedom for possible new design solutions. This is of particular importance, if the building is listed or categorized as worthy of preserving by authorities.
5. It is usually necessary to open up some of the existing building surfaces, which very often leads to surprises compared to drawings and other documents from the original building design and in relation to condition of building materials and installations.
6. It is usually much more important to involve and inform the users during the construction process than in new building projects; both because it is their building before, during and after renovation and because they will experience disturbances and perhaps even relocation during the renovation project.

7. It is possible in a post-evaluation after the renovation is finished to measure and make a direct calculation of how the building performance and user satisfaction has been improved compared to the situation before, if a proper pre-evaluation was made.

In literature, there are a number of different models of renovation processes, for instance Thuvander et al. [7] and Nielsen et al. [14], and in spite of many differences they have in common a strong focus on the decision making process. A main difference between the process of SBR and new building projects is the preliminary investigation of the existing building, which is the whole basis for developing design solutions in SBR, where new building projects have the building site as a basis [7].

2.5 *Question 5: What are emerging phases, forms of procurement and organisation for SBR?*

The typical phases in SBR very much resembles traditional phases in construction; pre-design, design, construction and handover. There are however a number of considerations, which are unique to renovation and to building projects with a focus on sustainability. A building project with a sustainability focus must take into account a number of factors, and not only consider them in the design, but also be ready to do quality control and commissioning to ensure that the sustainability targets set for the project are realized. Sustainability is a broad topic and the project organization must articulate, prioritize and execute sustainability targets that can be environmental, social or economic in nature. The project can use internally defined sustainability goals or utilize building rating systems, see further in section 2.7.

The procurement process for building projects with a sustainability focus can take several forms as with other building projects. The traditional form with “Design-Bid-Build” approach separates the pre-design and design from the construction and handover. A “Fixed Price” strategy can be used by the building client to transfer the risk to the contractor, or if the building client wants to assume all the risk, a “Cost Plus” contract can be made [15]. Apart from the traditional forms of contracting, which usually is provided by local governments or officially sanctioned bodies, bespoke construction contracts can also be used. This has been reported in the UK, where 51% of the respondents to the NBS National Construction Contracts and Law Survey 2015 reported having used bespoke contracting [15]. Bespoke contracts are tailored to the task, but they results in relatively expensive projects and are not suitable in a wide range of circumstances. They are made by legal teams specialized in construction contract law in the specific country, where they are applicable.

This traditional procurement process can be broken up into a number of discrete operations. While this way of procuring comes with a number of advantages, the drawbacks are high transaction costs and low levels of coordination. A number of initiatives have been instigated to overcome these shortcomings and can be grouped under the umbrella term Relational Contracting [16]. In relational contracting emphasis is put on creating trust and collaborative teams and has led to schemes such as: Integrated Project Delivery, Partnering and Strategic partnerships/alliances. The creation of trust in relational contracts entails using a wide range of strategic, tactical and operational tools, for instance alignment of goals and values, bi- or multi-lateral governance, transparency in budget allocation and expenses, holistic risk assessment and allocation, systematic workshops, and education of staff in handling partnerships [4,16,17].

2.6 Question 6: What examples exist of new forms of partnerships for SBR?

Conditions vary greatly from country to country, when it comes to the sophistication and variety of partnerships being used in the construction industry. For the last two decades sophisticated strategic partnerships have been used in the UK; most noticeably by central and local government building clients. These practices of strategic partnerships or alliances have spread to several other countries and have yielded positive results with regards to a great number of parameters, including budget certainty, completion time and client satisfaction [17].

When establishing an organisation to execute a SBR, it should be arranged in such a way that it can handle the many barriers facing such a project [18]. One of the main barriers to both sustainable new buildings and renovations concerns the targets or mitigating strategies. There is a general lack of knowledge in relation to this, which means that the building brief usually does not contain such targets and mitigations or that they are not brought into the building operation phase [19].

When evaluating the most cited research on barriers to sustainable building and challenges regarding renovation projects, it seems that strategic collaboration employing framework contracts can be beneficial [4]. A strategic collaboration, also called a strategic partnership or alliance, consists of a building client, who enters into a long-term contract with a consortium consisting of architects, consulting engineers and contractors. In such a collaboration, it is possible to have early involvement of experts and contractors in the pre-design and design phase. This enables the state of the non-renovated building to be assessed better and ensures that sustainability criteria and

technologies are implemented correctly. When the team in a strategic collaboration works well, it will over time be able to implement improved solutions, which benefit from better communication and cross-disciplinary understanding. In a framework contract with several projects, it is possible to implement novel solutions and learn how new technologies, processes and methods can be implemented across projects to further improve sustainability parameters.

The core strength of the strategic collaboration is the companies' priority of resources on a strategic level, the interconnection of systems and communication and the use of teams, which can collaborate and learn across multiple projects. However, such implementation is not without difficulty and requires both a mature building client and mature consortium [20]. Implementation and development of a mature client side has been found to be possible both through a national top down approach with a mandate to government building clients about using strategic collaboration and through a bottom up approach with individual building client [4]. The top down approach has been effective in the UK at pushing the concept of strategic collaboration, but it has by no means resulted in universal adoption [15,21]. The bottom up approach found in Sweden and Denmark has yielded positive results for the involved building clients and consortia, but it is not broadly adopted in the two countries [17].

Several models have been proposed to support and mature the consortium and each company in the consortium to enable them to participate in strategic collaborations. One such model can be found in Johansen et al. [22], where Key Attributes (KA) are used to highlight both the positive aspects of strategic collaborations - values, and the difficult aspects – complexities, see Fig. 1. The model

identifies a stair with five steps that may categorise a company's maturity level in this respect. This also offers ideas or guidelines about the next step.

Fig. 1. Strategic Collaboration in Construction Maturity Model (Adapted from [22])

2.7 Question 7: What tools exist for target setting and evaluation of SBR?

There are many decision support tools and several systems for sustainability measurements and certifications of buildings. The decision support tools are tools and methods that can help decision makers such as professional building owners to make more informed decisions, when dealing with SBR. The decision support tools are mainly used in the early stage of renovation projects (pre-design and design phase) and are primarily focusing on performance estimation, criteria weighting and design alternatives generation [14]. Some of the most widely spread decision support tools are

EPIQR (residential buildings), TOBUS (office buildings), XENIOS (hotels) and INVESTIMMO (residential buildings).

There are several international standards that address sustainability in buildings. These standards can be used for setting the goals for planning and building construction. CEN's Technical Committee 350 (CEN/TC 350) covers a suite of European standards covering the assessment of sustainability for construction products, buildings and the wider built environment. These standards are relevant for the assessment of integrated performance of buildings over their life cycle. EN 15643 [23] covers sustainability assessment of buildings (part 2 - environmental, part 3 - social, and part 4 - economic performance). while EN 15978 [24] provides calculations for the environmental assessment of buildings [25].

Previous studies have shown that the earlier sustainability assessment is conducted, the greater is the potential to effectively influence building performance. However, evaluation of building performance is typically not performed until the design development stage or later due to several barriers: data availability, lack of building designer expertise, and lack of quantified environmental targets and inability to measure performance against these targets [26]. Risholt et al. [27] suggest that sustainability assessment of building renovations should be based on a lifecycle analysis applying three types of indicators; performance indicators, economic indicators and social and usability indicators. This is in line with Mjørnell et al. [28,29], who present a tool to evaluate different renovation alternatives based on environmental, economic and social life cycle assessments.

A critical review of 16 different building environmental assessment tools disclosed that half of the tools can be used for existing buildings, but only 5 of those are suitable for assessment of building renovations [30]. A more recent study found 8 building assessment methods of relevance for assessment of building renovation [7]. Criteria-based certification systems like BREEAM, LEED and DBNG are complex rating tools in which the assessment is made applying certification scheme specific weights to different criteria [31]. Their purpose and evaluation methods are different, and they vary in scope, structure, format, complexity and in the sustainable energy performance indicators used. They also lack some vital indicators that can be used to assess the sustainable performance of building envelope such as material efficiency, energy efficiency, economic efficiency [32]. However, the certification systems also show some common features: they are mainly environmentally driven, based on indicators of building performance, and score based [33].

Besides international standards and certification systems, there is a broad variety of decision support tools relating to sustainable renovations. For example, Nielsen et al. [14] identified 43 decision support tools applicable in SBRs. However, only 9 of identified tools include the aspect of goal setting, while only 5 tools provide explicit guidelines for evaluation of design alternatives. RENO-EVALUATE [10] is one of the tools that can be used for goal setting. Post Occupancy Evaluation (POE) tools like for instance Building Use Studies [35] can be used for evaluating final results of renovation projects. Several overviews and comparisons of various POE tools have been published [36,37,38].

2.8 *Question 8: How can sustainability targets be measured for SBR?*

The targets for SBR are measured through a combination of different parameters originating from environmental, social and economic dimensions of sustainability. Although measuring the different dimensions of sustainability is a challenge, several tools and databases with various degrees of maturity exist.

Environmental targets for SBR aim at reducing resource consumption and negative environmental impacts. The targets are measured through parameters such as consumptions of energy, water and waste, emissions of CO₂ and other pollutants, as well as environmental life cycle assessments of the whole building before and after renovations. Studies show that 80-90 % of negative environmental impacts occur during building use stage, while 10-20 % of impacts are related to building construction and end-of-life stage [39,40]. Furthermore, studies show that a majority of negative environmental impacts from building use are caused by building operating energy [41,42]. Thus, reducing operating energy and increasing the share of renewable energy consumption are typically main environmental targets within SBRs.

Life cycle assessment (LCA) is an internationally acknowledged method for assessing environmental performance of products. LCA principles are outlined by international standard ISO 14040 [43] and the requirements and guidelines are given in ISO 14044 [44]. This assessment method requires large data sets and is time demanding, but very useful in highlighting the most environmentally friendly products. In SBRs, LCA software tools like GaBi and openLCA can evaluate environmental impacts of different renovation solutions or single building components. Pons et al. [45] have identified 10 environmental impact assessment tools for buildings.

Social targets focus on subjective evaluations in terms of user satisfaction, and objective evaluations in terms of indoor climate and health parameters before and after renovation. Such targets are sometimes called non-energy benefits (NEBs) [2]. For example, improving indoor climate quality may not directly have feasible financial effects or reduce negative environmental impacts, but the research shows that improving indoor climate quality in office buildings reduces sickness amongst employees and provides increased productivity [46]. Social targets are described in EN 15643-3 [23] and can be measured through indicators for the following social performance categories: accessibility, adaptability, health and comfort, loadings on the neighbourhood, maintenance, safety/security, sourcing of materials and services, and stakeholder involvement. There are, as mentioned in section 2.7, attempts to develop social life cycle assessment, but there is a lack of standardised methods for such assessments [28].

Economic targets consider financial parameters like operational cost, rental cost, asset value and life cycle cost before and after renovation. Payback time is often the most important parameter when considering SBRs [2]. It is usually only calculated by considering the initial investment and the direct annual operational cost saving without taking indirect costs and the time value of money into account. Therefore, it is a simplified calculation, while calculations based on life cycle cost (LCC) of net present value can give more precise results. LCC methodology refers to standards ISO 15686-5 [47] and EN 16627 [48].

Sustainability targets are often assessed through criteria-based certification tools, which in some cases also rely on LCA and LCC credits. For example, DGNB includes LCA and LCC credits, while BREEAM incorporates LCC credits. If the property owner or building user asks for it, a

specific certification can be achieved after building renovation, depending on building performance within environmental, economic and social parameters.

2.9 *Question 9: What institutional factors enables and inhibits SBR?*

The realization of SBR are enabled and inhibited by a wide range of institutional factors. The inhibiting factors include handling cultural heritage buildings combining original practices and solutions and cost-effective and energy-efficient mainstream solutions [49]. Furthermore several issues relate to financing [50] like high capital cost, unclear return on investments, fair sharing of benefits and costs between tenants and landlords and regulated limits for increasing rents decreasing the risk of renoviction, where landlords use refurbishment projects to boot out long-time tenants that cannot afford the substantial increase rent.

On the enabling side, regulation and policymaking play a central role in opening the markets for SBR through incentive schemes, building codes, certification schemes, etc. These initiatives not only relate to national states but are also developed and implemented at subnational and supranational level. The drivers at the subnational levels are primarily cities or regions. An example is the emissions trading Cap-and-Trade policy [51] successfully implemented by Tokyo Metropolitan Government using market mechanism to allow the most cost-effective renovations to take place among the very large buildings in the city [52].

At the national level, the focus is on traditional initiatives such as building codes and regulation of energy prices. However, also new concepts emerge here like the Dutch EnergieSprong, which began as a government funded innovation program for the social housing sector [53], but now has

spread to countries like Germany, France, Italy, UK, US and Canada [54]. This approach is based on highly-industrialized retrofit processes and the conversion of the energy bill into a financial source to support refurbishment of the building stock with long-term performance guarantees [55].

The national governments might even further be influenced by “supra-national” requirements most notably exemplified by shared directives in the European Union (EU). Key EU legislation like the Energy Performance of Buildings Directive (EPBD) [56], together with the Energy Efficiency Directive (EED) [57], the Renewable Energy Directive (RED) [58], the Ecodesign Directive [59] and Energy Labelling sets a framework for long-term improvements in the energy performance of Europe's building stock.

Determining the most effective set of policies to significantly improve the existing building stock is a key challenge for energy policy makers around the world. Here it is not just important to consider the building in itself, but to see the building in the wider energy system. The increasing share of renewable energy in the grid creates a need not just for more efficient systems, but also more flexible consumption practices and technologies [60,61]. A recent review by IPEEC Building Energy Efficiency Task Group categorize four generic policy instruments [62]:

- Performance based renovation targets and requirements
- Building energy codes/ standards applied to existing buildings
- Mandatory energy performance disclosure, sometimes linked to upgrade requirements
- Voluntary standards that become mandatory with financing from certain sources

In practice the actual policies are a configuration of the abovementioned policy instruments targeting the specific sub-, supra- and nation context taking into consideration areas like (historical) building types, key industry capabilities, and fiscal systems. Despite the different contextual factors, the policies that appear to deliver the most significant activity in building energy renovation are the following [62]:

- Comprehensive improvement targets, supported by underlying policies and initiatives including regulations, financing, and information campaigns aimed toward various stakeholders.
- Disclosure of energy performance, with mandates tied to improving the performance of the poor performers.
- Linking financing and other supportive policies to deeper savings, through tiered incentives where very deep renovations are rewarded.
- Some role for a “renovation facilitator” to navigate different policies and stakeholder groups needed for implementation of deep renovations.

2.10 Question 10: What are typical and emerging concepts and technologies for realising SBR?

With regards to technology to be used for SBR, the amount and sophistication of building materials, technical installations or services have escalated over the past decade. Table 2 identifies and evaluates some the most common technologies for SBR, inspired by the hierarchical process towards zero carbon refurbishment by Ma et al. [63] supplemented with recent sources like Pacheco-Torgal et al. [64]. Here we only look at the technologies for the building omitting the wider energy supply like gas and district heating.

Table 2. Building technologies for SBR categorized by their main function [64]

Main function	Technology	Benefits	Challenges
Heating and cooling demand reduction	Thermal insulation materials	<ul style="list-style-type: none"> - Simple and practical components - Well proven technology - Saves energy - Improved indoor climate 	Health and safety challenges during installation
	Paned windows and glazing	<ul style="list-style-type: none"> - Better indoor climate using natural lighting - Letting the outside in - A source for heating 	<ul style="list-style-type: none"> - Optimal solution very dependent on geographical location and orientation - Must be potentially be supplemented with solar shades
	Air tightness	<ul style="list-style-type: none"> - Minimizing heat loss - Inexpensive and effective - Better comfort by reduced draught 	<ul style="list-style-type: none"> - Potentially source for humidity and subsequently mould - Difficult to achieve 100% airtightness
	Reflective materials	<ul style="list-style-type: none"> - Simple and effective - Reduce the summer heat-island phenomenon. - Make buildings and cities comfortable places to live. 	<ul style="list-style-type: none"> - Reflections influence stakeholders around the building
Energy efficient equipment and low energy	Thermal storage capacity	<ul style="list-style-type: none"> - Principle well known - Saves energy - Improved comfort 	<ul style="list-style-type: none"> - Phase Change Materials - represent an immature technology

technologies		<ul style="list-style-type: none"> - Decreasing temperature fluctuations 	
	Smart heating systems	<ul style="list-style-type: none"> - Improved comfort - Saves energy - Better energy utilization - Automatic temperature adjustments - Relatively low cost of implementation 	<ul style="list-style-type: none"> - Potentially complex integrated systems - Sometimes incompatible with user behaviour
	Lighting	<ul style="list-style-type: none"> - Low cost - Long lifecycles - Moving towards SMART solutions 	<ul style="list-style-type: none"> - Fast development compared to other technologies - More advanced systems
	Heat recovery	<ul style="list-style-type: none"> - Considered more efficient than natural ventilation - Can ensure better air quality and indoor climate 	<ul style="list-style-type: none"> - Requires maintenance
Renewable energy supply	Solar Air Collectors (SACs)	<ul style="list-style-type: none"> - Simple and effective - Heat producing - Ventilation by fresh air - Ideal for small buildings 	Limited adoption on larger buildings
	Photo Voltaic (PV)	<ul style="list-style-type: none"> - Multifunctional - Electricity producing - Part of the envelope - Rapidly decreasing costs - High durability 	<ul style="list-style-type: none"> - Still limited adoption in SBR - Design challenges with integration. - Depending on location and orientation

	Solar thermal	<ul style="list-style-type: none"> - Primarily suitable for preparing hot water and to providing space heating. - Simple well-proven technology 	-
	Heat pumps	<ul style="list-style-type: none"> - Air source heat pumps are considered as better options for building refurbishment due to its ease of installation and less space requirement comparing with ground source heat pumps. 	<ul style="list-style-type: none"> - Requires maintenance - Potentially large systems (ground)

The technological development of new building technologies increases the solution space for SBR and sets requirements for the processes connecting the specific challenges with technological solutions. Fuelled by the increasing digitalization, existing and new process technologies promise to help decision makers navigate the complexity and epistemic uncertainty of the specific projects. The reduction of epistemic uncertainty through collection of data for existing buildings has traditionally been supported by “destructive practices”. Here parts of the building are destroyed to uncover important information about the structural principles, thermal bridges and current state of building materials, including moisture and mould. However, new technologies have made the collection of data about buildings easier and non-destructive. This includes thermal cameras for tracking thermal bridges and insulation patterns, and moisture measurements or indications based on electromagnetic induction methods [65].

Furthermore, new 3D scanning techniques create 3D models of existing structures [66]. While these currently represent advanced technologies, the current improvement of the sensors and extra cameras in mobile phones suggest that 3D scans in the future might be a feature in our hands [67].

3. Conclusions

In the first stage of developing this paper we formulated 10 questions concerning the proposed topic of Sustainable Building Renovation (SBR) and provided an answer in one sentence to each question. We conclude the paper by giving our reconsidered one sentence answers.

1. The typical issues that initiate the need for SBR can be grouped in the main factors: durability/building physics, economy, environment and comfort.
2. SBR is renovation of existing buildings that results in upgraded buildings, which are more sustainable in terms of environmental, social and economic aspects after the renovation than before – or at least in relation to two of these aspects.
3. The main stakeholders in SBR can be divided in the demand side, consisting of the owners and the users and those who represent them, and the supply side, consisting of the providers of design and construction services as well as material and equipment providers.
4. The main characteristic that distinguish building renovation from a new building project is that there is an existing building and often existing users and one needs to make a pre-evaluation of the building and the experience of using it, which can be used as a starting point and a baseline for a post-evaluation.
5. The typical phases, forms of procurement and organisation for SBR resembles the traditional situation for new building projects, resulting in high transaction costs, but there are a number of

initiatives to overcome these shortcomings, which can be grouped under the umbrella term Relational Contracting with an emphasis on creating trust and collaborative teams.

6. For the last two decades sophisticated strategic partnerships have been used in the UK - often based on the use of framework contracts covering a portfolio of renovation and/or new building projects, and these new forms of collaboration have spread to several other countries.
7. There are not as many tools and systems for decision support dedicated specifically to building renovation and there is a lack of simple tools for target setting and evaluation of SBR, but several international standards address sustainability in buildings.
8. The targets for SBR are measured through a combination of different parameters originating from the dimensions of sustainability – both separately, for instance in environmental, social and economic life cycle assessments, and jointly in comprehensive building certification systems.
9. Regulation and policymaking play a central role in opening the markets for SBR through incentive schemes, building codes, certification schemes, etc., but there are also a number of inhibiting factors including handling of cultural heritage buildings.
10. The amount and sophistication of building materials, technical installations and services have escalated over the past decade and some of the most promising areas of development are related to heating and cooling demand reduction, energy efficient equipment and low energy technologies, renewable energy supply as well as digital tools and diagnostic methodologies. However, much of the development is still in the laboratory.

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Biography

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References

- [1] Gohardani, N, Björk, F, Jensen, PA, Maslesa, E, Kanarachos, S and Fokaides, PA. On Stakeholders and the Decision Making Process Concerning Sustainable Renovation and Refurbishment in Sweden, Denmark and Cyprus. *Archit Environ* 2013;1(2);21-28.
- [2] Jensen, PA, Maslesa, E, Gohardani, N, Björk, F, Kanarachos, S and Fokaides, PA. Sustainability Evaluation of Retrofitting and Renovation of Buildings in Early Stages. *Proceedings of 7th Nordic Conference on Construction Economics and Organisation, NTNU*, 12-14 June 2013.
- [3] Meijer, F, Straub, A and Mlecnik, E. Consultancy centres and pop-ups as local authority policy instruments to stimulate adoption of energy efficiency by homeowners, *Sustain.* (forthcoming)
- [4] Jensen, PA, Johansen, JB and Thuesen, C. Prerequisites for Successful Strategic Partnerships for Sustainable Building Renovation. *Proceedings of 9th Nordic Conference on Construction*

Economics and Organisation (CEO 2017), Chalmers University of Technology, 13-14 June 2017.

- [5] UN. Institutional framework for sustainable development. 2012 Available at: <https://sustainabledevelopment.un.org/topics/institutionalframeworks-international-cooperation/> [Accessed 16 November 2016].
- [6] Haavaldsen, T, Lædre, O, Volden, GH and Lohne, J. On the concept of sustainability – assessing sustainability of large public infrastructure investment projects. *Int. J Sust Eng.* 2014; 7(1);2-12.
- [7] Thuvander, L, Femenías, P, Mjörnell, K and Meiling, P. Unveiling the Process of Sustainable Renovation, *Sustain.* 2012; 4(6); 1188-1213.
- [8] Ástmarsson, B, Jensen, PA and Maslesa, E. Sustainable Renovation of Residential Buildings and the Landlord/Tenant Dilemma, *Energy Policy* 2013;63;355-362.
- [9] Clements-Croome, DJ. *Intelligent buildings: design, management and operation.* Thomas Telford, London. 2004.
- [10] Jensen, PA and Maslesa, E. Value Based Renovation – A Tool for Decision-making and evaluation, *Build Environ* 2015; 92;1-9.
- [11] EU. Horizon 2020 - Work Programme 2016 – 2017. European Commission Decision C(2016)4614 of 25 July 2016.
- [12] Femenías, P, Mjörnell, K and Thuvander, L. Rethinking deep renovation: The perspective of rental housing in Sweden, *J Cleaner Production* 2018;1-11.
- [13] IEA. Mind the gap. Quantifying Principal-Agent Problems in Energy Efficiency. International Energy Agency. 2007.
- [14] Nielsen, AN, Jensen, RL, Larsen, TS and Nissen, SB. Early stage decision support for sustainable building renovation – A review, *Build Environ* 2016;103;165-181.

- [15] NBS. National Construction Contracts and Law Survey 2015;1–33.
- [16] Kumaraswamy, MM, Rahman, MM, Ling, FE and Phng, ST. Reconstructing Cultures for Relational Contracting. *Journal of Construction Engineering and Management*, 2005; 131(10).
- [17] Kadefors, A, Thomassen, MA and Jørgensen, MN. Long term strategic collaboration in the construction industry - case studies from Denmark and Sweden. A pre-study. Realdania, Copenhagen, 2013.
- [18] Häkkinen, T and Belloni, K. Barriers and drivers for sustainable building, *Build Res Inf* 2011;39(3):239–255.
- [19] Sodagar, B, Fieldson, R and Gilroy-Scott, B. Design for Sustainable Architecture and Environments, *Int. J. Environ. Cult. Econ. Soc. Sustain* 2008;4(4);73–86..
- [20] Meng, X, Sun, M and Jones, M. Maturity model for supply chain relationships in construction,. *J Manag Eng* 2011; 27(2);97–105.
- [21] National Audit Office. Improving Public Services through better construction, 2005.
- [22] Johansen, JB, Jensen, PA and Thuesen, C. Maturity Model for Strategic Collaboration in Sustainable Building, *Proceedings of ARCOM Conf, Cambridge* September 2017;259–268.
- [23] CEN. EN 15643 Sustainability of construction works - Sustainability assessment of buildings. 2017.
- [24] CEN. EN 15978 Sustainability of construction works – assessment of environmental performance of buildings. 2011.
- [25] Anderson, JE, Wulfhorst G and Lang W. Expanding the use of life-cycle assessment to capture induced impacts in the built environment, *Build Environ* 2015; 94; 403–416.
- [26] Russell-Smith, SV, Lepech, MD, Fruchter, Rand Littman, A. Impact of progressive sustainable target value assessment on building design decisions, *Build Environ* 2015; 85; 52–60.

- [27] Risholt, B, Time, B and Hestnes, AG. Sustainability assessment of nearly zero energy renovation of dwellings based on energy, economy and home quality indicators, *Energy Build* 2013; 60; 217–224.
- [28] Mjörnell, K, Bass, A, Lindahl, M and Molnar, S. A Tool to Evaluate Different Renovation Alternatives with Regard to Sustainability, *Sustain* 2014;6;4227-4245.
- [29] Malmgren, L and Mjörnell, K. Application of a Decision Support Tool in Three Renovation Projects', *Sustain* 2015;7;12521-12538.
- [30] Haapio, A and Viitaniemi, P. A critical review of building environmental assessment tools, *Environ Impact Assess. Rev* 2008; 28(7); 469–482.
- [31] Russell-Smith, SV, Lepech, MD, Fruchter, R and Meyer, YB. Sustainable target value design: Integrating life cycle assessment and target value design to improve building energy and environmental performance, *J Clean Prod* 2015;88:43–51.
- [32] Mwasha, A, Williams, RG and Iwaro, J. Modeling the performance of residential building envelope: The role of sustainable energy performance indicators, *Energy Build* 2011;43(9);2108–2117.
- [33] Conte E, and Monno, V. Beyond the buildingcentric approach: A vision for an integrated evaluation of sustainable buildings, *Environ Impact Assess Rev* 2012;34: 31–40.
- [34] Malmgren, L, Elfborg, S and Mjörnell, K. Development of a decision support tool for sustainable renovation – a case study, *Struct Surv* 2016;34(1);3-11.
- [35] Bordass, B, Leaman, A and Paul, R. Assessing building performance in use 5: conclusions and implications", *Build Research & Information* 2001;29(2):144-157
- [36] McDougal, G, Kelly, JR, Hinks, J and Bititci, US. A review of the leading performance measurement tools for assessing buildings, *J Facil Manag* 2002;1(2);142-153.
- [37] Preiser, WFE and Vischer, J. (Eds.) *Assessing Building Performance*, Elsevier 2005.

- [38] Riley, M, Moody, C and Pitt, M. A review of the evolution of post-occupancy evaluation as a viable performance measurement tool, BEAN Conf 2009, BEST Research Centre, Liverpool John Moores University, UK.
- [39] Cabeza, LF, Rincón, L, Vilariño, V, Pérez, G. and Castell, A. Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review, *Renew Sustain Energy Rev* 2014;29:394–416.
- [40] Passer, A, Ouellet-Plamondon, C, Keneally, P, John, V and Habert, G. Impact of future scenarios on building renovation strategies towards plus energy buildings, *SBE16 Zurich* 2016; 124;2.
- [41] Nemry, F, Uihlein, A, Colodel, M., Wetzel, C, Braune, A, Wittstock, B, Hasan, I, Kreißig, J, Gallon, N, Niemeier, S and Frech, Y. Options to reduce the environmental impacts of residential buildings in the European Union-Potential and costs, *Energy Build* 2010;42(7) 976–984.
- [42] Blengini GA and Di Carlo, T. Energy-saving policies and low-energy residential buildings: An LCA case study to support decision makers in Piedmont (Italy), *Int J Life Cycle Assess* 2010;15(7);652–665.
- [43] International Organization for Standardization. ISO 14040 Environmental management -- Life cycle assessment -- Principles and framework. 2006.
- [44] International Organization for Standardization. ISO 14044 Environmental management -- Life cycle assessment -- Requirements and guidelines. 2006.
- [45] Pons, O and Aguado, A. Integrated value model for sustainable assessment applied to technologies used to build schools in Catalonia, Spain, *Build Environ* 2012;53;49–58.
- [46] Huang, Y-C, Chu, C-L, Chang Lee, S-N, Lan, S-J, Hsieh, C-H and Hsieh, Y-P. Building users' perceptions of importance of indoor environmental quality in long-term care facilities,

Build. Environ 2013; 67(0);224–230.

- [47] International Organization for Standardization. ISO 15686-5 Buildings and constructed assets - Service-life planning - Part 5: Life-cycle costing. 2008.
- [48] CEN. EN 16627 Sustainability of construction works. Assessment of economic performance of buildings. Calculation methods. 2015.
- [49] A. Martínez-Molina, I. Tort-Ausina, S. Cho, and J.-L. Vivancos, “Energy efficiency and thermal comfort in historic buildings: A review,” *Renew. Sustain. Energy Rev.*, vol. 61, pp. 70–85, 2016.
- [50] R. P. Taylor, C. Govindarajalu, J. Levin, A. S. Meyer, and W. A. Ward, *Financing Energy Efficiency*. The World Bank, 2008.
- [51] Grubb, M. Emissions trading: Cap and trade finds new energy, *Nature* 2012;491(7426):666–667.
- [52] Nishida, Y, Hua, Y and Okamoto, N. Alternative building emission-reduction measure: outcomes from the Tokyo Cap-and-Trade Program, *Build. Res. Inf.* 2016;44(5/6);644–659.
- [53] P. Jacobs, K. Leidelmeijer, W. Borsboom, M. van Vliet, and P. de Jong, “Transition Zero,” 2014.
- [54] EnergieSprong, “No Title,” 2018. [Online]. Available: <http://energiesprong.eu>. [Accessed: 17-Jun-2018].
- [55] Micelli, E and Mangialardo, A. Recycling the city new perspective on the real-estate market and construction industry, *Green Energy Technol.* 2017;115–125.
- [56] EU. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast), *Off. J. Eur. Union* 2010;13–35.
- [57] European Parliament. Directive 2012/27/EU, *Off. J. Eur. Union* 2012; L315/1(October):1–56.
- [58] EU. Directive 2009/28/EC, *Off. J. Eur. Union* 2009;140(16); 16–62.

- [59] European Council. Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products (recast), Off. J. Eur. Union 2009;10–35.
- [60] Bulut, MB, Odlare, M, Stigson, P, Wallin, F and Vassileva, I. Buildings in the future energy system - Perspectives of the Swedish energy and buildings sectors on current energy challenges, *Energy Build.* 2015;107;254–263.
- [61] Boermans, T, Papaefthymiou, G, Offermann, M, John, A and Comaty, F. The role of energy efficient buildings in the EUs future power system, 2015.
- [62] IPEEC Building Energy Efficiency Task Group. Existing Building Energy Efficiency Renovation, 2017.
- [63] Ma, Z, Cooper, P, Daly, D and Ledo, L Existing building retrofits: Methodology and state-of-the-art, *Energy Build.* 2012;55;889–902.
- [64] Pacheco-Torgal, F, Granqvist, C-G, Jelle, BP, Vanoli, GP, Bianco, N and Kurnitski, J. Cost-Effective Energy Efficient Building Retrofitting: Materials, Technologies, Optimization and Case Studies, Elsevier Ltd. 2017.
- [65] Hola, J and Schabowicz, K. State-Of-The-Art Non-Destructive Methods For Diagnostic Testing Of Building Structures – Anticipated Development Trends, *Archives of Civil and Mechanical Engineering*, 2010;10(3);5-18.
- [66] Lehtola, VV, Kaartinen, H, Nüchter, A, Kajaluoto, R, Kukko, A, Litkey, P, Honkavaara, E, Rosnell, T, Vaaja, MT, Virtanen, JP, Kurkela, M, El Issaoui, A, Zhu, L, Jaakkola, A and Hyypä, J. Comparison of the selected state-of-the-art 3D indoor scanning and point cloud generation methods, *Remote Sens.* 2017;9(8).
- [67] Schöps, T, Sattler, T, Häne, C and Pollefeys, M. Large-scale outdoor 3D reconstruction on a mobile device, *Comput. Vis. Image Underst.* 2017;157;151–166.

- Seven characteristics distinguish building renovation from a new building project
- There are not many tools and systems dedicated to planning building renovation
- Strategic partnerships can be a promising way to achieve more sustainable building renovation
- Regulations play a central role in opening the markets for sustainable building

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