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ENVIRONMENTAL ASSESSMENT OF BUILDINGS

Appu Haapio

TEKNILLINEN KORKEAKOULU
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Abstract

Since the building sector started to recognise the impact of their activities on the environment in the 1990s, environmentally related issues have been an extremely popular research area. However, the research has partly been incoherent and inconsistent; researchers have excessively been focusing on their own topics neglecting possible collaboration, including the collaboration in interdisciplinary fields. The field of building environmental assessment tools is vast. The use of the tools is diverse. They are almost taken as a given; their contents have not been critically analysed. How the definitions of the assessment tool affect the results has been neglected. The interest lies excessively with the end results, without further clarification.

The aim of this study is to clarify the field of building environmental assessment tools by analysing the current situation and future challenges. The relationship between environmental assessment and service life planning is critically analysed. Many building environmental assessment tools require an estimation of the building's lifetime. The service life of a building, however, has not been emphasised within the tools; rather it is taken as a given without further analysis. Therefore, the service life planning needs to be included in the environmental assessment of buildings.

The existing methods and tools should not be underestimated. However, they should not be considered the sole possibilities. New ideas and interdisciplinary discoveries should also be welcomed in order to keep up-to-date; something worth researching may appear. If the new aspects are neglected, there is a possibility that "the high quality building" of today will be "the low quality building" of the future.

The results of this doctoral thesis improve the understanding of the environmental assessment of buildings, the service life planning, their relationship, and also the factors affecting them. The results can be utilised in the development of the environmental assessment of buildings and service life planning. Furthermore, the results are beneficial for standardisation work, and research in the interdisciplinary fields.

Keywords environmental assessment, building, service life, maintenance, obsolescence

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Tiivistelmä

1990 luvulla rakennussektorin huomio kiinnittyi toimintojen ympäristövaikutuksiin. Siitä lähtien ympäristötutkimus on kasvattanut suosiotaan huomattavasti. Tutkimusaiheet eivät välttämättä ole olleet yhtenäisiä tai toisiaan tukevia. Oman aihealueen tutkimusta on painotettu liikaa, ja samalla yhteistyömahdollisuuksia on laiminlyöty. Myös poikkitieteellinen yhteistyö on kärsinyt. Lukuisien, hyvinkin erilaisten, rakennusten ympäristöarviointityökalujen käyttö on kirjavaa. Työkaluja ja niiden ominaisuuksia pidetään itsestäänselvyyksinä, eikä niiden sisältöä analysoida kriittisesti. Työkalujen rajauksien vaikutusta tuloksiin ei ole pohdittu riittävästi. Kiinnostuksen kohteena ovat vain viivan alle jäävät numerot; tulokset.

Tutkimuksessa analysoidaan rakennusten ympäristöarviointityökalujen nykyistä tilannetta ja tulevaisuuden haasteita. Ympäristöarvioinnin ja käyttöikäsuunnittelun suhdetta analysoidaan kriittisesti. Rakennusten ympäristöarviointityökalut tarvitsevat usein arvioin rakennuksen eliniästä. Rakennuksen käyttöikää ei kuitenkaan ole korostettu ympäristöarviointi-työkaluissa. Käyttöikä on ennemminkin otettu valmiina suureena analysoimatta sitä sen tarkemmin. On välttämätöntä sisällyttää käyttöikäsuunnittelu rakennusten ympäristöarviointiin.

Olemassa olevia menetelmiä ja työkaluja ei pidä aliarvioida, mutta niitä ei sovi pitää ainoina vaihtoehtoina. Uusille ja poikkitieteellisille ideoille pitää antaa mahdollisuus, niistä voi syntyä jotain uutta. Mikäli uusia näkökulmia ei hyödynnetä, on mahdollista, että nykyinen hyvä esimerkki ”laatutalosta” on tulevaisuudessa huono.

Tämä väitöstutkimus avaa näkemyksiä rakennusten ympäristövaikuttamiseen ja käyttöikäsuunnitteluun, niiden väliseen suhteeseen sekä niihin vaikuttaviin tekijöihin. Tutkimustuloksia voidaan hyödyntää rakennusten ympäristöarvioinnin kehit-tämisessä ja käyttöikäsuunnittelussa. Lisäksi, standardisointityö ja poikkitieteellinen tutkimus hyötyvät tuloksista.

Asiasanat ympäristöarviointi, rakennus, käyttöikä, kunnossapito, vanhanaikaiseksi jääminen

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Helsinki, 29th February, 2008

Appu Haapio

LIST OF PUBLICATIONS

The thesis is based on the following scientific papers, which are referred to in the text by their Roman numerals:

I Haapio, A, Viitaniemi, P, 2008. A critical review of building environmental assessment tools. *Environmental Impact Assessment Review*, doi: 10.1016/j.eiar.2008.01.002

II Haapio, A, Viitaniemi, P, 2007. Environmental criteria and indicators used in environmental assessment of buildings. In *Proceedings, CIB World Building Congress 2007, Construction for Development*, 14-17 May 2007, Cape Town, South Africa.

III Haapio, A, Viitaniemi, P, 2008. Environmental effect of structural solutions and building materials to a building. *Environmental Impact Assessment Review*, doi: 10.1016/j.eiar.2008.02.002

IV Haapio, A, Viitaniemi, P, 2008. Service life of a building in environmental assessment of buildings. In *Proceedings, 11th DBMC International Conference on Durability of Building Materials and Components*, 11-14 May 2008, Istanbul, Turkey.

V Haapio, A, Viitaniemi, P, 2008. How workmanship should be taken into account in service life planning. In *Proceedings, 11th DBMC International Conference on Durability of Building Materials and Components*, 11-14 May 2008, Istanbul, Turkey.

AUTHOR'S CONTRIBUTION

Appu Haapio is the corresponding author of the papers I-V.

ABBREVIATIONS

AEC professionals	architects, engineers, and constructors
CEN	European Committee for Standardization
EPD	environmental product declaration
ISO	International Organization of Standardization
LCA	life cycle assessment
LCR	life cycle resource
LCW	life cycle waste
REPA	resource and environmental profile analysis
SC	subcommittee
SETAC	the Society of Environmental Toxicology and Chemistry
TC	technical committee

TABLE OF CONTENT

1 INTRODUCTION

Life Cycle Assessment (LCA) is a methodology for estimating and assessing the environmental impacts of a product throughout its life cycle; from the extraction of the raw material through manufacturing and use to final disposal, i.e. *from cradle to grave*. The idea of environmental life cycle assessments was conceived in Europe and in the USA in the late 1960s and early 1970s. According to Hunt and Franklin (1996), the formal analytical scheme that was to become LCA was first conceived by H.E. Teasley, Jr., the employee of Coca-Cola Company, in 1969. In the early 1970s, during the energy crisis, the interest in energy laid in economical reasons rather than in ecological issues. Teasley, however, understood the interrelation between energy resources and material use. His study on the beverage container aimed at quantifying the energy, material and environmental consequences of a package over the life cycle (Hunt and Franklin 1996).

The historical term for the environmental life cycle studies, *Resource and Environmental Profile Analysis (REPA)*, was used from 1970. The term LCA first came to into use in the USA as late as 1990. The first article of the complete presentation of LCA methodology, published in a peer reviewed scientific journal was the study by Hunt, Sellers and Franklin (1992). (Hunt and Franklin 1996) Most of the LCA studies were confidential during the 1970s, and early 1980s. The public interest in LCA was also low until the late 1980s, when environmental awareness rose. There was a need for a more sophisticated approach to complex environmental issues. In 1990, the Society of Environmental Toxicology and Chemistry (SETAC) initiated defining LCA and developing a general methodology for conducting LCA studies, and the International Organization of Standardization (ISO) followed soon after. (Rebitzer er al. 2004; Russell et al. 2005) Azapagic (1999) has compared these two methodological frameworks.

In the 1990s, industrial sectors, including the building sector, started to recognise the impact of their activities on the environment. Public policy and a growing market demand for environmentally sound products and services forced the building sector to focus on the environmental performance of buildings. When aiming to reduce environmental impact, a yardstick for measuring environmental performance was needed (Crawley and Aho 1999). Since a building may comprise over 60 basic materials and ~2000 separate products, all with different service lives (Kohler and Moffatt 2003), managing a proper LCA for a building is challenging, and does not always serve its purpose. Separate environmental indicators were developed for the needs of relevant interest groups. The first real attempt to establish a comprehensive means of simultaneously assessing a broad range of environmental considerations in buildings was the Building Research Establishment Environmental Assessment Methods (BREEAM) in 1990 (Cole 2005; Crawley and Aho 1999; Grace 2000). Since then, the development of the building environmental assessment tools has been very active (Paper I). Some of these tools are LCA based, and some are frameworks or rating systems (e.g. IEA Annex 31 2001, Paper I). The success of the tools, however, may have dwarfed all other mechanisms for instilling environmental activities (Cole 2005).

1.1 Research challenge

Since the building sector started to recognise the impact of their activities on the environment in the 1990s, environmentally related issues have been an extremely popular research area. However, the research has partly been incoherent and inconsistent; researchers have excessively been focusing on their own topics neglecting possible collaboration, including the collaboration in interdisciplinary fields.

The research challenge is to define the existing topics, and to analyse their connections. In order to be able to utilise the research results as widely as possible, the relationships between different topics need reviewing. Moreover, it is challenging to specify the topics which need further research. A sandbox is an excellent example. The sandbox is *the research area of environmentally related issues*. The sand pits are *the researchers' topics*. Once *a researcher* starts shovelling a sand pit, the image of the other sand pits and their locations in the sandbox fades. After a while, it is impossible to describe the size or locations of the other sand pits. If the sandbox is viewed from the bird's-eye perspective, the comprehensiveness of the *research topics* can be studied. Furthermore, the existing canals and the possibly forthcoming canals, *the collaborations,* should be analysed.

1.2 Framework of the study

The field of building environmental assessment tools is vast. The use of the tools is diverse. They are almost taken as a given; their contents have not been critically analysed. How the definitions of the assessment tool affect the results has been neglected. The interest lies excessively with the end results, without further clarification.

The framework of this doctoral thesis is presented in Figure 1. The current situation of the environmental assessment of buildings needs to be analysed *(identification).* Based on this analysis, a common objective is defined. The common objective is *a vision;* what the future should be like. When aiming towards *the vision*, changes are needed in the old habits and working methods, and new areas are included in the research. How the changes are approved, is *challenging*. This process may have obstacles *(challenges).* These *challenges* should be identified and analysed. It is essential to rise to *the challenges*. All the *challenges* cannot be overcome, but these limitations have to be recognised, and their influence on the outcome has to be analysed. In order to concretise the development process, *the challenges* should be converted into research topics, and those responsible for these *challenges* should be identified *(division of tasks).*

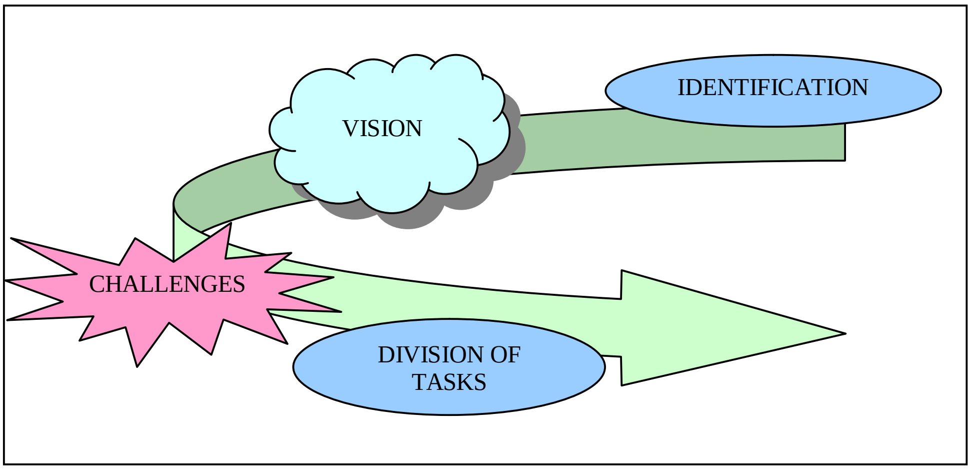

Figure 1 Development process for environmental assessment of buildings

1.3 Aim of the study

The aim of this study is to clarify the field of building environmental assessment tools by analysing the current situation *(identification,* in Figure 1) and the future *challenges*. The relationship between environmental assessment and service life planning is critically analysed *(challenges)*. Many building environmental assessment tools require an estimation of building's lifetime. The service life of a building, however, has not been emphasised within the tools; rather taken as given without further analysis. Therefore, the service life planning needs to be included in the environmental assessment of buildings.

Furthermore, how workmanship and maintenance should be taken into account in service life planning is discussed *(challenges)*. The quality of the construction influences the maintenance of the building, the life cycle costs, and also the environmental impact. Therefore, the skills and levels of workmanship should be emphasised more in service life planning.

These *challenges* are converted into research topics *(division of tasks)* in order to establish a comprehensive viewpoint for the environmental assessment of buildings *(vision)*.

1.4 Results

The results of this doctoral thesis improve the understanding of the environmental assessment of buildings, service life planning, their relationship, and also the factors affecting them. The results can be utilised in the development of the environmental assessment of buildings and service life planning. Furthermore, the results are beneficial for the standardisation work, and research in the interdisciplinary fields.

1.5 Content of the study

In the first section, the research area is introduced, the framework and the aim of the study are stated, the utilisation of the results is briefly discussed, and the content of this study is listed. The second section focuses on the environmental assessment of a building and building environmental assessment tools.

The third section focuses on service life planning. In the fourth section, the service life in the environmental assessment of buildings is discussed. In the fifth section, the results from this study are highlighted, and the future of the environmental assessment of buildings and service life planning is discussed. Furthermore, future research topics are suggested.

2 ENVIRONMENTAL ASSESSMENT OF A BUILDING

In the 1990s, public policy and a growing market demand for environmentally sound products and services forced the building sector, among other industrial sectors, to focus on environmental performance; how the buildings were designed and operated. When aiming to reduce environmental impact, a yardstick for measuring environmental performance was needed (Crawley and Aho 1999). The specific definition of term building performance is complex, since different actors in the building sector have differing interests and requirements (Cole 1998). Economic performance, for example, interests investors, whereas the tenants are more interested in health and comfort relating issues.

The Building Research Establishment Environmental Assessment Method (BREEAM) was the first real attempt to establish a comprehensive means of simultaneously assessing a broad range of environmental considerations in buildings. BREEAM, the first commercially available environmental assessment tool for buildings, was established in 1990 in the UK (Cole 2005; Crawley and Aho 1999; Grace 2000). Since then, the development of the building environmental assessment tools has been active, and the tools have gained considerable success (e.g. CRISP 2004; IEA Annex 31 2001; Paper I; Reijders and van Roekel 1999). Cole (2005), however, suspects the success of the tools has dwarfed all other mechanisms for instilling environmental awareness.

Furthermore, the standardisation of issues relating environmental building has increased. The International Organization for Standardization (ISO) and the European Committee for Standardization (CEN) have been active in defining standardised requirements for the environmental assessment of buildings. (Paper II) ISO Technical Committee (TC) 59 Building construction and its Subcommittee (SC) 14 Sustainability in Building Construction have recently published three standards / technical specifications:

§ ISO/TS 21929-1:2006 *Sustainability in building construction – Sustainability indicators – Part 1: Framework for development of indicators for buildings*. It is based on a premise that *"sustainable construction brings about the required performance with the least unfavourable environmental impact, while encouraging economic, social and cultural improvement at a local, regional and global level"*. (ISO 2006a)

§ ISO 21930:2007 *Sustainability in building construction -- Environmental declaration of building products*. The standard describes the principles and framework for the environmental declaration of building products, including consideration of the reference service life of building products. The prime purpose of an environmental product declaration (EPD) of a building product is to provide information for the assessment of the environmental performance of buildings. (ISO 2007b)

§ ISO/TS 21931-1:2006 *Sustainability in building construction – Framework for methods of assessment for environmental performance of construction work – Part 1: Buildings*. (ISO 2006b) The standard defines a framework for methods of assessment for the environmental performance of buildings.

CEN TC 350 *Sustainability of construction work* develops voluntary horizontal standardised methods for the assessment of the sustainability aspects of new and existing construction works and standards for the environmental product declaration (EPD) of construction products. (CEN 2005) TC 350 is developing the standards under three working groups (CEN 2007; Paper II):

§ WG 1 *Environmental performance of buildings*. Framework for assessment of integrated building performance (under approval).

§ WG 2 *Building life cycle description*. Assessment of environmental performance of buildings – calculation methods (under development).

§ WG 3 *Product level*. Environmental product declaration – product category rules (under development).

2.1 Building environmental assessment tools

Building environmental assessment has become a popular research area in the past decades. There have been several international projects in the field; REGENER (1997), BEQUEST *Building Environmental Quality for Sustainability through Time* (BEQUEST 2001), IEA Annex 31 *Energy Related Environmental Impact of Buildings* (IEA Annex 31 2001), CRISP *A European Thematic Network on Construction and City Related Indicators* (CRISP 2004), and PRESCO *European Thematic Network on Practical Recommendations for Sustainable Construction* (Peuportier and Putzeys 2005).

Numerous tools have been developed by various institutes to assist the environmental assessment of buildings. Cole (1998, 1999, 2004, 2005), Cooper (1999), Crawley and Aho (1999), Ding (2008), and Edwards and Bennett (2003) have, for example, discussed building environmental assessment methods. Erlandsson and Borg (2003), Forsberg and von Malmborg (2004), Haapio and Viitaniemi (Paper I), Reijders and van Roekel (1999), Seo et al. (2005), and Todd et al. (2001) have compared building environmental assessment tools.

2.2 Criteria and indicators in environmental assessments

Building environmental assessment tools are not all commensurable. The comparison of the tools and their results is difficult, if not impossible (Paper I). Different tools have been developed to assess new and existing buildings, residential buildings (single family, multi unit), office buildings and other types of buildings.

Different building environmental assessment tools use different criteria in the environmental assessment of a building, and different indicators to correspond to these criteria. Sometimes, criteria and indicators are not differentiated; but rather confusingly used as synonyms. Criteria are characteristics that are considered important and by which success or failure is judged. Indicators are quantitative, qualitative or descriptive measures, which when periodically evaluated and monitored, show the direction of change. (ISO, 2002b) Indicators are measures corresponding to the criteria (characteristics). A criterion may consist of more than one indicator. (Paper II) Qualitatively expressed criteria and indicators are open to wider interpretation by assessors, and therefore less certain. The simultaneous use of qualitative and quantitative indicators forces to weight the indicators or to use a scoring system. Otherwise adding indicators with different units is impossible.

In addition, the nature and the units of indicators may differ (Gerard et al. 2000). The results give a different picture depending on the used units; concrete construction waste, for example, has high mass and low volume compared to wood (Trusty and Meil 2002). As an example given by Haapio and Viitaniemi (Paper II), $10m^3$ of concrete construction waste is ~24000kg in weight, and $10m^3$ of wood construction waste is ~5300kg in weight. On the other hand, the volume of 1000kg of concrete construction waste is ~$0{,}4m^3$, and the volume of 1000kg of wood construction waste is ~$1{,}9m^3$. From the viewpoint of image, concrete construction waste benefits if the amount of waste is expressed in unit of volume (m^3), and wood construction waste benefits from using the unit of mass (kg). The situation could be avoided by using both units; mass (kg) and volume (m^3).

On the other hand, is *waste* a sufficient environmental criterion? Or should it be divided into sub criteria, such as *biodegradable waste, waste for combustion* and *waste for landfill site*, which are measurable indicators? These issues need to be considered broadly, because they have different dimensions. The combustion of waste, for example, produces energy and later, reduces the need for fossil fuels. (Paper II) Moreover, the reusability of building products should be analysed thoroughly. The products may be reused elsewhere, or after their primary purpose of use, they may be recycled and used as raw material for new products. Sato et al. (2005) introduced life cycle resource (LCR) and life cycle waste (LCW) indices for assessing resource sustainability. For example, after their service life, used wooden building products can be used as raw material for other products (e.g. chip board), or as an energy source substituting non-renewable energy resources.

Furthermore, the transportation of construction waste needs to be taken into consideration. The volume as well as the mass of the waste set requirements for the transport vehicles. Chopping the construction waste into portable parts requires energy. Chopping may also need special equipment or machinery. These issues need to be included in the discussion. (Paper II)

2.3 Differences within building environmental assessment tools

Building environmental assessment tools emphasise the life cycle of a building differently; some tools cover the whole life cycle whereas other tools are more focused on the maintenance and the use of buildings. Even if the tools cover the same phases of the life cycle in the assessment, they may cover the phases differently. One tool uses several criteria for a phase while the other uses only a few criteria for the same phase in question. Moreover, the tools may use the same criteria, but different indicators to correspond to these criteria. (Paper I; Paper II)

Cole (2005) points out that the interpretation of the results can vary considerably depending on the assessor. Different building environmental assessment tools use different criteria, indicators and units. This may mislead the users of the tools. As an example, the results presented per surface area (m^2) do not always tell the whole truth. Also the volume (m^3) has to be considered, because the height of the spaces may vary (Junnila 2004). The surface area (m^2) of the building can be measured from the outside (including the walls) or from the inside (excluding the walls). Therefore, how the measurements are taken influences the results. Energy consumption, for example, is often expressed as giga joules (GJ) per unit area of surface. The energy consumption is smaller if the building’s surface area is measured from the outside, and bigger, if the surface is measured from the inside. And yet – the building is the same. (Paper I)

Some building environmental assessment tools utilise well known databases in calculations, the others rely more on guidelines and questionnaires (Paper I). Due to different data sources and collection methods, the comparison of the environmental impact of materials is impossible (Trusty and Meil 2002). This impedes the comparison of the results of the buildings' environmental assessments. In addition to the results (graphs, tables, reports) some of the tools hand out different labels and certificates. Instead of certificates and reports, consumers and some designers would, however, prefer building product labels, which would facilitate the decision making (Kohler 1999). The producers of the building components would also welcome the labels with content.

How should users know which building environmental assessment tool is suitable for a certain building? And which tool gives the most reliable results? The uncertainties or the margin of error is not mentioned within the results of the tools. (Paper I) On the other hand, users may choose a tool which best suits their purpose based on the results. If users start promoting tools based on the desired results, the reliability of the environmental assessment of buildings has vanished. Evidently, the current situation of the building environmental assessment tools is confusing. According to Haapio and Viitaniemi (Paper I), the use of tools is not obvious; where and when they should be used, who should use them, and how the results from the assessment should be utilised. They suspect, these issues have reduced the use and utilisation of the tools. Ding (2008) sees the inflexibility, complexity and lack of consideration of a weighting system as major obstacles to the acceptance of the tools.

The development of the building environmental assessment tools is challenging in the future. It is more practical to have a tool which clarifies around 80% of the significant issues, than a tool which clarifies around 90% of irrelevant environmental issues. (Paper II) As Ding (2008) points out, *"Striking a balance between completeness in the coverage and simplicity of use is one of the challenges in developing an effective and efficient environmental building assessment tool."*

2.4 Integration of the assessment tools and design tools

Currently, most building environmental assessment tools are used towards the end of the design process to evaluate the environmental results. Often, these assessment tools are used by an external user (Lützkendorf and Lorenz 2006), such as AEC professionals (architects, engineers, and constructors), producers, investors, consultants, tenants, authorities, and researchers (Paper I).

The building environmental assessment tools are not used simultaneously with the design tools. Consequently, the later the assessment in the design process is done, the fewer possibilities it has to influence the design itself. The design of the building is largely specified by different regulations, building codes and standards. In addition, different actors in the building sector have different requirements for the buildings. Different building components and structural solutions can meet these regulations and requirements, but optimising and comparing these different solutions is challenging. Optimising one solution may not be the ideal solution for the whole building; changing a building product in one place may cause changes elsewhere. A window with the best U-value, for example, is not always the best solution in northern Europe. In cold weather, water may condense on the surface of the window's glass, causing problems if the condensed water stays there for too long or is absorbed into the structures.

The integration of the assessment tools and design tools would facilitate the situation. Lützkendorf and Lorenz (2006) are expecting it to happen in the future. However, the integration of the tools is challenging. The variety of the building environmental assessment tools is wide; LCA based tools, rating systems, technical guidelines, assessment frameworks, checklists and certificates (e.g. Boonstra and Pettersen 2003; IEA Annex 31 2001) The tools cover different phases of the building's life cycle and take different environmental issues into account. Where the LCA based tools use databases, the environmental assessment frameworks rely more on guidelines and questionnaires.

2.5 Framework of the environmental assessment of buildings

The framework of the environmental assessment of buildings is presented in Figure 2. The existing building environmental assessment tools are used to assist the assessment. *The existing tools* differ from each other; e.g. they rely on different databases, they are designed for different users, they emphasise the life cycle of a building differently, and they hand out different certificates.

Different types of buildings are assessed. *The assessed buildings* can be new, or existing buildings, or under renovation. Furthermore, different *existing tools* are designed to assess different types of buildings. The building can be used as a residential building or as an office building. Environmental assessment of buildings is based on different *criteria and indicators*. They can be qualitative or quantitative. Different *existing tools* rely on different criteria and indicators.

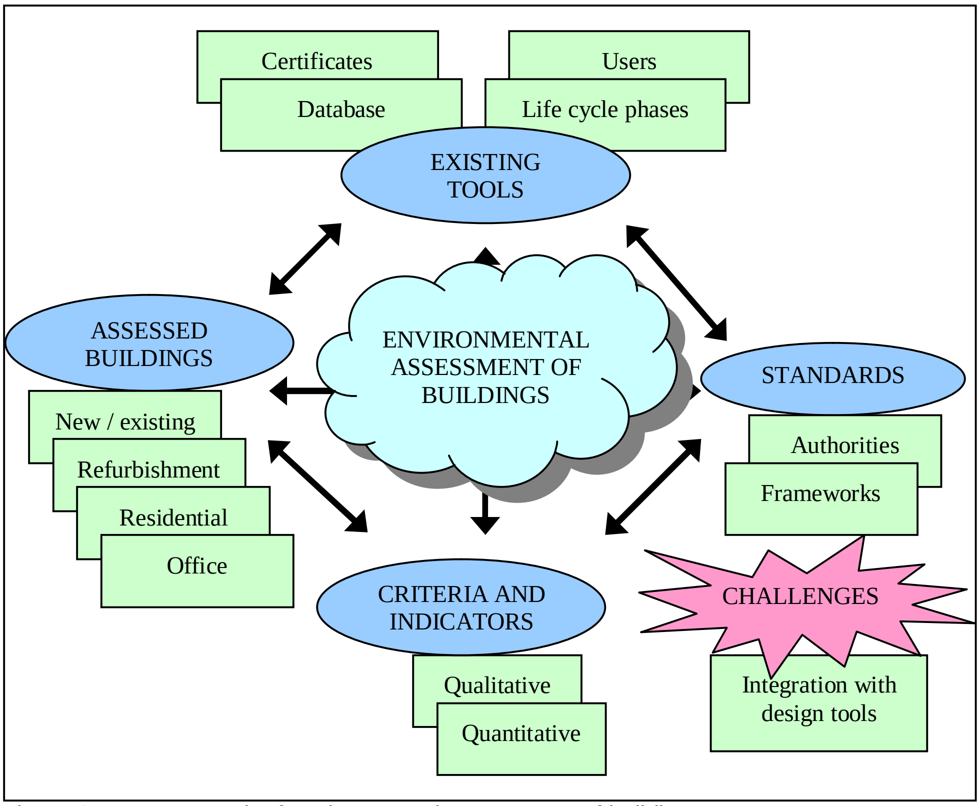

Figure 2 Framework of environmental assessment of buildings

Furthermore, *the standards* set frameworks for the criteria and indicators, and also for the environmental assessment of buildings. Currently, *the existing tools* are not used simultaneously with the design tools. As mentioned earlier, the later the assessment in the design process is done, the fewer possibilities it has to influence the design itself. This is a challenge for the future. The integration of design tools and building environmental assessment tools would facilitate the current situation.

3 SERVICE LIFE PLANNING

The standardised requirements for service life planning have been prepared by ISO Technical Committee (TC) 59 *Building construction* and its Subcommittee (SC) 14 *Design life*, in ISO 15696 series *Building and constructed assets – Service life planning.* ISO 15696 series consists of the following parts:

- Part 1 (ISO 15686-1:2000): *General principles* focuses on describing the process of service life forecasting (ISO 2000). The standard gives general information, and a framework for the service life planning. However, it does not provide specific guidance on how to perform it. ISO 15686-1 is the umbrella document of the ISO 15686 series (ISO 2001). An updated version, ISO/CD (Committee draft) 15686-1 is currently under development.

- Part 2 (ISO 15686-2:2001): *Service life prediction procedures* focuses on describing the procedures that facilitate service life predictions of building components (ISO 2001). The standard is more of a framework than a specific description of the techniques of service life prediction.

- Part 3 (ISO 15686-3:2002): *Performance audits and reviews* focuses on describing the approach and procedures of service life performance audits (ISO 2002a). Audits are undertaken to provide a reasonable assurance that the required service life performance will be achieved.

- Part 4 (ISO 15686-4): *Data requirements* is under preparation (ISO 2004a). However, Part 4 is not mentioned on the homepage (ISO 2007c).

- Part 5 (ISO/DIS 15686-5.2): *Life cycle costing* is under development, but a draft of the standard is available. Part 5 focuses on describing the procedures for performing life cycle cost analyses of buildings. (ISO 2007a)

- Part 6 (ISO 15686-6:2004): *Procedures for considering environmental impacts* defines how to assess relative environmental impacts of the design options. Furthermore, it identifies the interface between service life planning and environmental life cycle analysis. Nevertheless, the standard does not take a position on the balance between environmental and other aspects. (ISO 2004a)

- Part 7 (ISO 15686-7:2006): *Performance evaluation for feedback of service life data from practice* focuses on describing the principles for service life performance surveys and evaluation emphasising technical recommendations. (ISO 2006c)

- Part 8 (ISO/DIS 15686-8:2006): *Reference service life and service-life estimation* is under development, but a draft of the standard is available. The standard provides guidance on modifying reference service life. A factor method can be utilised in such modification. (ISO 2006d)

- Part 9 (ISO/NP 15686-9): *Guide on the inclusion of requirements of service life assessment and service life declaration in product standards* is under development. (ISO 2007c)

- Part 10 (ISO/WD 15686-10): *Levels of functional requirements and levels of serviceability – Principles, measurement and use* is under development. (ISO 2007c)

The length of the service life is not precisely known in advance. Consequently, the objective becomes to make "*an appropriately reliable forecast of the service life using available data*" (ISO 2000). The forecasting of the service life of a building (or a component) is to assure whether it can be expected to exceed the required design life with adequate reliability. The standard ISO 15686-1 gives the following definitions regarding forecasting service life (ISO 2000):

- **Service life planning** is "*a design process which seeks to ensure, as far as possible, that the service life of a building will equal or exceed its design life (i.e. intended service life (deprecated)) while taking into account (and preferably optimizing) the life cycle costs of the building.*"

- **Service life** is *"a period of time after installation during which a building or its parts meets or exceeds the performance requirements"*

- **Reference service life** is *"service life that a building or parts of a building would expect (or is predicted to have) in a certain set (reference set) of in-use condition"*

- **Predicted service life** is *"service life predicted from recorded performance over time"*

- **Estimated service life** is "*service life that a building or parts of a building would be expected to have in a set of specific in-use conditions, calculated by adjusting the reference in-use conditions in terms of materials, design, environment, use and maintenance*".

3.1 Forecasting service life

Forecast service life is based on either prediction or estimation. The procedure of service life prediction is described in the standard ISO 15686-1 clause 8, and detailed in the standard ISO 15686-2. The standard ISO 15686-1 clause 9 provides a method, a factor method, for estimating service life. (ISO 2000, 2001) Ideally service life should be predicted according to the standards ISO 15686-1 clause 8, and ISO 15686-2 (Davies and Wyatt 2004). Where the ideal cannot be achieved, estimations using the factor method, described in ISO 15686-1 clause 9, might be required. A clear distinction between predicted and estimated service life should be made when forecasting service life (ISO 2000).

In the prediction of service lives, the evidence from previous use, the knowledge of service lives of similar components, the tests of degradation in specific conditions, and combinations of these, are utilised. In an ideal prediction, service life is expressed as a function of the in-use condition (environmental condition under normal use). (Paper IV) There are two methods of testing degradation; long-term exposure, and short-term exposure, and usually they are used in combination (ISO 2000, 2001). Ideally, a service life prediction based on exposure tests normally provides the reference service life for a factored estimation (ISO 2000).

The purpose of the factor approach is to provide a rough-and-ready means of estimating service life (Davies and Wyatt 2004). As stated in ISO 15686-1, "*The factor method does not provide an assurance of a service life: it merely gives an empirical estimate based on what information is available*" (ISO 2000). The factor method is based on a reference service life, and a series of modifying factors (ISO 2000, 2006d).

3.2 Agents influencing the service life

Service life is “*the period of time after installation during which a building or its part meet or exceed the performance requirements*” (ISO 2000, 2004b). In forecasting the service life of a building (or a component), the objective is to establish whether it can be expected to exceed the required design life with adequate reliability. (ISO 2000) In forecasting service life, there are critical issues which need to be taken into consideration:

- Agents of degradation
- Dose and intensity
- Combination of agent

There are several factors, or agents, which affect the service life of building materials and components during their lifetime. In the standard ISO 15686-1 Annex C (taken from ISO 6241), these agents of degradation are classified by their nature (ISO 2000):

- Mechanical agents (i.e. snow loads, vibration from traffic)
- Electromagnetic agents (i.e. solar / UV)
- Thermal agents (i.e. heat, fire)
- Chemical agents (i.e. air humidity, ground water, bird droppings)
- Biological agents (i.e. bacteria, moulds, termites).

After identifying the agents, it is important to assess the dose and the intensity of the agents. They are often evaluated over a reference period of time, for example, a year. Westberg *et al*. (2001) point out the degradation agents can be considered one by one, but also the combination has to be taken into consideration. One agent may create a favourable environment for another agent. Therefore, the recognition of the combination is vital. (Paper V) The durability of building materials relates closely to the service life of building materials. (Paper V) However, as Brischke et al. (2006) point out, durability and service life are not synonyms. Service life is “*the period of time after installation during which a building or its part meet or exceed the performance requirements*”, and performance is “*the qualitative level of a critical property at any point of time considered*” (ISO 2000). Durability is a property leading to a certain service life, but it is influenced by different agents in service (Brischke et al. 2006).

3.3 Pre-installation factors influencing service life

There are several factors, which may affect the service life of building components, even before their service life begins, before they become a part of the building. This important subject area has been less addressed in research. According to Haapio and Viitaniemi (Paper V), these factors are called pre-installation factors. They use a window as an example:

- The design of a window might be faulty. For example, a vertically low and horizontally wide window is challenging for the hinges if they are on the vertical side of the window frame. Or there might be mistakes in the measurement – the window frame is too small for the window opening.

- The quality of the raw materials might not meet the requirements. The moisture content of the wood might be too high, or there might be too many knots in the wood material.

- The manufacturing processes might cause damage to the window frames. The hinges and the fasteners might not be installed properly. The insulating tape might be tightened too much in the corners.

- The components are not stored properly during the manufacturing processes or at the construction site. For example, an excessive moisture content of wooden frames during the manufacturing and installation may cause cracking of the frames later on. Furthermore, rough handling of the products may damage them; i.e. cracks on the window frames can expose them to moisture.

- The installation of the window might not meet the requirements. The moisture content of the surroundings of the window opening might be too high during the installation. Later on, the wooden window frames may crack. Also, the installation instruction may have been neglected.

The pre-installation factors reducing the service life of the window, mentioned above, are similar to the pre-installation of other building components. The different phases of the life cycle; design raw material production, manufacturing, storage, and installation, influence the service life of the building component greatly. All these pre-installation factors cause the reduction of the service life of the building component, even before it begins. (Paper V)

However, sometimes the damage appears later, during the use of the building. A faulty design of the window does not necessarily appear immediately after installation. Heavy rain, for example, may emphasise oversights in the installation of the window. Problems occur if rain water stays on the horizontal surface. A faulty product might have to be replaced with a new one. Due to this, the environmental load of production is already doubled. Also, there are environmental loads from the disposal of the faulty product. Furthermore, the faulty product and its replacement might have caused damage to the surrounding products, or even to the structure of the building, and reduced their service lives as well. (Paper V)

There is no point predicting or assessing the service life of building materials or components, if the pre-installation factors are not taken into consideration. They greatly affect the service life of a building. Due to these factors, the building materials or components may never reach the predicted service life. The possibility was lost somewhere in the phases of design, raw material production, manufacturing, storage, or installation. If the pre-installation factors are not taken into consideration, the significance of the service life planning is minor. (Paper V)

Considering the influence of the pre-installation factors on the service life of the building components, the comparison of the different raw materials becomes less significant. If the component does not reach the predicted service life due to the pre-installation factors, there is no point in comparing the service lives of components with different raw materials. A thorough analysis on the pre-installation factors and their impact on the components and their surrounding is vital. It is essential to analyse the pre-installation processes in order to pinpoint the black spots of the processes. The focus should be on how to avoid, or at least minimise, the possible damages to the building components during the pre-installation processes. Development of the processes might also be required. (Paper V)

3.4 Service life performance audits

ISO 15686-3 (2002a) focuses on describing the approach and procedures of service life performance audits. Audits are undertaken to provide a reasonable assurance that the required service life performance will be achieved. ISO 15686-3 (2002a) provides a choice between formal independent audits and less formal internal review procedures. Both service life performance audits and reviews emphasise the pre-briefing, briefing and design stages of the construction projects. The emphasis of the construction, operation, refurbishment and disposal stages is secondary. The distinction between core and secondary audits is not intended to be definitive. (Paper V)

However, the distinction does not seem justified. For example, the purpose of an audit at the construction stage is *"to assess whether correct or intended materials / components have been used and installation instructions have been properly implemented"* (ISO 2002a). If these two aspects are not assessed, it lessens the credibility of the service life performance audits. The use of incorrect materials or unqualified installation may reduce the predicted service life as well as cause damage to the surroundings. (Paper V)

The instructions for maintenance and refurbishment should always be analysed within audits. Inadequate instructions may cause damage to the constructions during the use of a building. The tenants and the owners of the buildings are also responsible for the condition of the building. It is their responsibility that the use of the building is correct and that possible damages are repaired on time; before they damage the surroundings. Unfortunately, the number of *"neohelpless"* people is increasing, especially in the industrial world. *"Neohelpless"* people rather depend on the help of others, e.g. superintend, than managing themselves. New domestic appliances for example, are delivered with manuals. All the important information about the domestic appliances and their use can be found in the manual. The *"neohelpless"* people would probably welcome a manual of the building. All the important information about living and maintaining the apartment or the building could be summarised in the manual.

3.5 Condition inspection

When an old single family house is sold in Finland, the condition of the house is normally inspected by a professional, specialised in condition inspection. The aim of the condition inspection is to check the quality of the building, and survey possible faults and damages, for example, possible moisture damage. In addition, recommendations for future maintenance can be given, for example, an estimation of the renovation of the pipes. At some level, the condition inspection could be introduced to the new / newish buildings. For new buildings, the assessment of the installation damages could be useful. (Paper V)

Condition inspection is an excellent way to assess the quality of the building. If it is done regularly, maybe every 10 years, it could act as a plan for maintenance and refurbishment, and later on as a register of the maintenance actions. Even though the service lives of products and components are presented, they are only predictions. The building products and components might be exposed to agents of degradation which are not taken into account in service life prediction, or the maintenance of the building has been neglected. There is also a possibility that the pre-installation factors have damaged the products, but the damage appears only after several years. (Paper V)

4 SERVICE LIFE IN ENVIRONMENTAL ASSESSMENT OF BUILDINGS

Numerous tools have been developed for the building sector to help decision making and improve the environmental performance of buildings and building stocks. The variety of the tools is wide; LCA based tools, rating systems, technical guidelines, assessment frameworks, checklists and certificates. (e.g. IEA Annex 31 2001; Paper I) Many of these building environmental assessment tools require an estimation of the building's lifetime. The service life of a building, however, has not been emphasised within the tools. Rather, the service life is taken as given without further analysis (Paper I, Paper III).And yet, a single building may comprise over 60 basic materials and circa 2000 separate products. Their service lives are different, and they have unique production / repair/ disposal processes (Kohler and Moffatt 2003). (Paper IV)

The environmental performance of different building materials has been studied in several publications. For example, Perez-Garzia et al. (2005) and Puettman and Wilson (2005) analysed the environmental performance of residential building materials. Gustavsson and Sathre (2006) compared concrete and wood buildings materials. Thormark (2006) studied how material choice affects embodied energy in row-houses, and Häkkinen et al. (1999) calculated the environmental impact of coated exterior wooden claddings. Junnila and Saari (1997) estimated material and energy flows for building elements. There are various studies focusing on the environmental performance of a whole building. Peuportier(2001), and Trusty and Meil (1999) compared single-family houses. Adalberth et al. (2001) and Junnila (1998) focused on the environmental performance of apartment buildings. In his dissertation, Junnila (2004) focused on the environmental impact of an office building. Even though the sensitivity analysis is included in some of these studies, e.g. Adalberth et al. (2001), Junnila (2004) and Peuportier (2001), how the length of the service life affects the results of the environmental assessment has not been thoroughly analysed. (Paper III)

4.1 Environmental issues within service life planning

Service life planning can be performed due to several reasons. The economical and the technical aspects, including safety related issues, are quite obvious reasons. The economical viewpoint has been pointed out quite strongly in ISO 15686-1; General parts: *"Service life planning is a design process which seeks to ensure, as far as possible, that the service life of a building will equal or exceed its design life, while taking into account (and preferably optimizing) the life cycle costs of the building."* (ISO 2000)

The environmental viewpoint has been taken into consideration in the standards ISO 15686-6 *Procedures for considering environmental impacts*. The standard defines how to assess relative environmental impacts of design options, and furthermore, it identifies the interface between environmental life cycle analysis and service life planning. (ISO 2004a) However, the standard does not take a position on the balance between environmental and other aspects. It is suggested in ISO 15686-6 that the environmental assessment of design option should be made parallel with technical and economic assessments. According to the standard, the environmental assessment allows the design team to include environmental aspects into the decision making. (ISO 2004a) However, the standard does not make it mandatory to include the environmental aspect into service life planning. (Paper IV)

4.2 Maintenance of a building

During the building's service life, the building needs to be maintained, and some components need to be replaced. The service lives of the components are different. The service life of the inaccessible parts should be the same as the service life of the building (ISO 2000). In other words, the service life of the accessible parts can be shorter than the service life of the building. If the service life of a component is shorter than the building's service life, the component needs replacement. (Paper IV) As an example, if the design life (intended service life) of a building is 150 years, the suggested design lives are (ISO 2000):

- § 150 years for inaccessible or structural components
- § 100 years for components where replacement is expensive or difficult
- § 40 years for major replaceable components
- § 25 years for building services
- § (easy-to-replace components may have design lives of 3 or 6 years).

Maintenance and replacements have environmental impacts. In proactive maintenance, the action is taken in advance – before the damage occurs. In reactive maintenance, the action is taken afterwards – after the damage has occurred. There is a possibility the remaining service life of the components is lost, if the replacement is done proactively. If the replacement of the component is done reactively, the component may have damaged its surroundings. The maintenance of these damaged surroundings has economical and environmental consequences. (Paper IV)

The time between the needed maintenances and replacements differs between different components, and also, the demands for the maintenances are different. In addition, the quality of the maintenance, i.e. the workmanship, influences the forthcoming maintenances and may reduce the remaining service life. Poor maintenance, or disregarded maintenance, may cause damage elsewhere, and thus influence the whole building. For example, as a consequence of missing out the oil change of car, the engine of the car may seize up. The repair of the engine is far more expensive than the oil change would have been. Also, wide repair is always more challenging, and exposed to further damages. (Paper IV)

4.3 Service life of the building components

Haapio and Viitaniemi (Paper III) analysed how different structural solutions and building materials affect the results of the environmental assessment of a building. They calculated the environmental assessments of 78 single-family houses with the building environmental assessment tool ATHENA©. Furthermore, the service life of the buildings varied from 60 years up to 160 years with 20 years interval.

Naturally, the results of the environmental assessment of buildings with different structural solutions and building materials differ. Interestingly, the calculations by Haapio and Viitaniemi (Paper III) showed that only some structural solutions or building materials were renovated or maintained when the service life increased from 60 years to 160 years. The service life of a brick façade is ~50 years. If the life expectancy of the building is 160 years, the building's brick façade should be changed at least three times. It is not logical to maintain and renovate only some structural solutions, but neglect others. The insulations of exterior walls, for example, influence the indoor temperature and the operating energy consumption. Over the years, the insulations will lose some of their effectiveness.

As mentioned earlier, most building environmental assessment tools are used towards the end of the design process by an external user. The assessment tools and the design tools are not used simultaneously. The later the evaluation of the results in the design process is done, the fewer possibilities it has to influence the design itself. Moreover, optimising one solution may not be the best solution for the whole building. The task is facilitated if the assessment tools and design tools are integrated. (Lützkendorf and Lorenz 2006) The service lives of different building components, and their effect on a building and its service life need to be analysed thoroughly.

As the results presented by Haapio and Viitaniemi (Paper III) show, issues relating to service life have not been considered in depth in the environmental assessment of buildings. Service life needs to be included properly into the building's environmental assessment. Only then will the integration of the assessment tools and design tools maximise the benefits. The architect and designers will be able to optimise and compare different solutions during the whole process, starting at the pre-design phase. Furthermore, they will be able to design solutions which consider the components' service lives and accessibility during renovations. (Paper III)

4.4 Obsolescence

Although service life and obsolescence are related issues, they need to be differentiated. Obsolescence should be distinguished from the replacement due to defective performance (ISO 2000). Obsolescence is a condition of being antiquated, old-fashioned, or out-of-date. An obsolete item simply does not meet a condition of the current requirements or expectations. (ISO 2000; Lemer 1996) However, this does not indicate the item is broken or dysfunctional. In other words, the service life of the item is not necessarily over, even if the item is obsolete. (Paper IV)

Currently, the number of renovations caused by obsolescence is increasing, as the requirements and needs of tenants grow. These renovations have environmental impacts; if the component is replaced before its service life is finished, the remaining service life is wasted. It seems a waste, especially if the replaced building materials and components are not recycled. In a case like this, the environmental viewpoint is often forgotten. (Paper IV)

Reliable data for forecasting obsolescence are rarely available. The standard ISO 15686-1 suggests, *"Estimation of the time to obsolescence should be based on the designer's and client's experience and if possible documented feedback from practice"* (ISO 2000). However, during the building's long service life, manufacturing processes and products are developed. What was modern ten years ago is probably old fashioned today. This causes problems in the maintenance; matching old and new techniques and products does not always go smoothly. Often at least some applications or compromises have to be made. For example, in the older buildings in Finland, the pipes are laid in concrete. If the pipes need renovation, the traditional renovation; replacing the pipes with new ones, is possible. Or the service life of the pipes can be extended by lining the inside of the pipes with a newish technique. (Paper IV)

The focus has been on the development of the techniques, processes and products. The importance of the implementation of the techniques has been underestimated. The requirements of the tenants have increased tremendously in recent decades, and there is no end in sight. In addition to these factors, the development of information technology and HPAC set requirements for buildings. It is challenging to adjust these requirements in a sustainable way. (Paper IV)

These mentioned issues need to be taken into consideration in the design process. The focus should be on the development of easily replaceable components since the needs and requirements of the tenants grow and change constantly. The accessibility to the components during the maintenance and the replacement should be considered already in the design phase, in order to minimise the possible damages to the surroundings. (Paper IV)

However, these renovations have environmental impacts; if a product is replaced before its service life is finished, the remaining service life is wasted. These issues need to be taken into consideration in the design processes and in service life planning. (Paper III) In some cases, the discussion may turn into a comparison of the environmental impact of renovating old buildings versus constructing new buildings (e.g. Itard and Klunder 2007).

4.5 Framework of service life planning

The framework of service life planning is presented in Figure 3. The aim of *service life planning* is to ensure that the service life of a building will meet its design life with adequate reliability. In *service life planning*, both the service lives of a building and the components have to be considered. In addition, the service lives of the components as part of the building need to be taken into account.

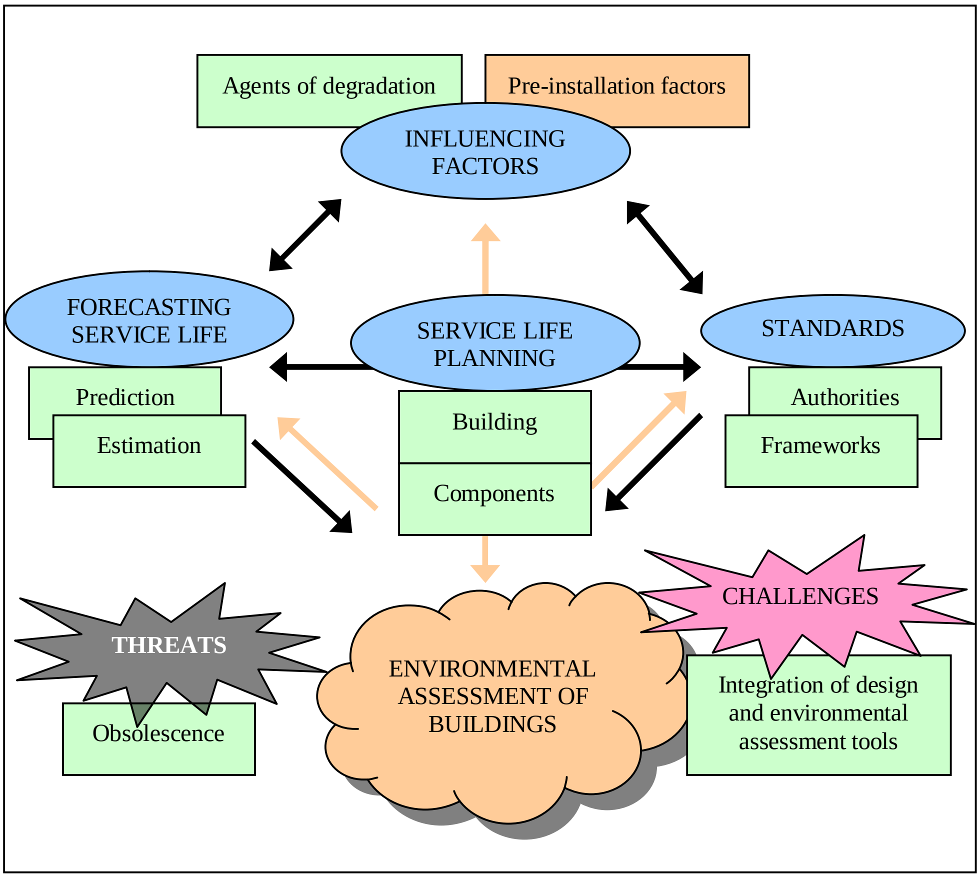

Figure 3 Framework of service life planning

Current *standards* provide guidance and frameworks for *service life planning*, and also for *forecasting service life*, which is based on either prediction or estimation. There are several factors, or agents *(influencing factors)*, which affect the service life of a building during its lifetime. Currently, *the standards* recognise the agents of degradation, but not the pre-installation factors (therefore marked with reddish colour).

The predicted service life *(forecasting service life)* of a building is often used in *the environmental assessment of a building,* but it is taken as a given without further analysis. On the other hand, environmentally related issues are not strongly emphasised within *service life planning*. It is not fully recognised how the service lives of the components and a building affect the results of the environmental assessment.

Obsolescence can be seen as *a threat* both for *service life planning* and *the environmental assessment of buildings*. Currently, the number of renovations caused by obsolescence is increasing as the requirements of tenants grow. These renovations have environmental impacts; if a product is replaced before its service life is finished, the remaining service life is wasted. Obsolescence and renovations need to be taken into consideration already in the design process, and also in service life planning. The integration of design tools and building environmental assessment tools would facilitate the current situation.

5 DISCUSSION AND CONCLUSION

The framework of the development process of the environmental assessment of buildings is presented in Figure 4. With the assistance of information technology, millions of subjects are measured, and values calculated and processed. The amount of acquired knowledge *(information)* is enormous. However, the information flow is not always coherent; subjects may be measured several times since some of the information is lost, or it does not reach the right destination. The problem is the amount of information; there is too much of it. The essential information is swamped with the information available. The challenge is to identify the fundamental information, and moreover, to utilise that information beneficially *(existing tools)*. There is no right answer in the discussion on the environmental assessment of buildings. It is more or less speculation.

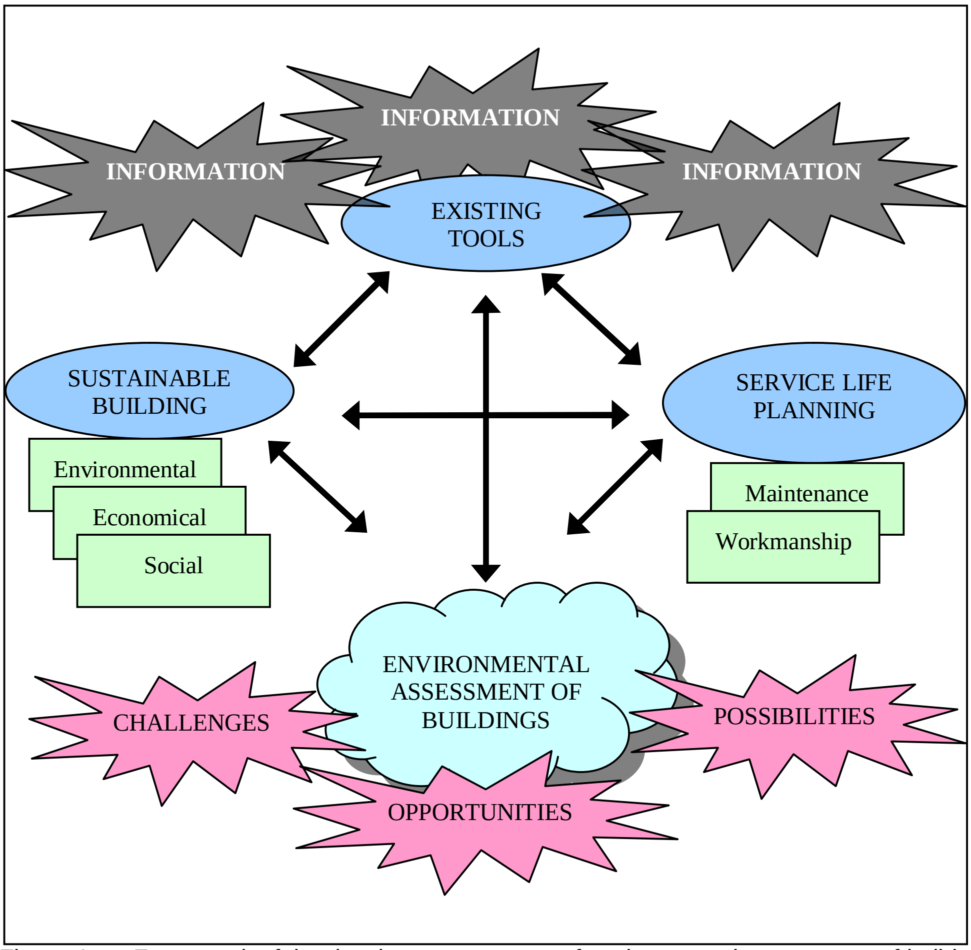

Figure 4 Framework of the development process of environmental assessment of buildings

Furthermore, the aspect for building and living has expanded in recent years. *Sustainable building* considers all three aspects; economical, environmental, and social. The economical aspect has been very dominating, especially in service life planning. If the environmental aspect is to reinforce its current position, it cannot be done at the expense of the economical aspect. In the development of environmental assessment, economical aspects have to be included in the process; otherwise the industry sector and the investors will not be interested. The whole process of the environmental assessment of the buildings needs to be attractive and beneficial for the financiers. Therefore, *the service life planning* needs to be included in *the environmental assessment of buildings.*

Cole (2005) suspects the success of the environmental assessment tools has dwarfed all other mechanisms for instilling environmental awareness. Possibly, the current methods and tools have been seen suitable, and the focus has been on the development and improvement of the existing methods and tools. Inventing, discovering and developing new possibilities and opportunities has been neglected *(challenges, opportunities, possibilities)*. The possibilities of the research in the interdisciplinary fields have not been utilised properly. One could say, the question has been "*What should be done?*" rather than "*What could be done?*".

The existing methods and tools should not be underestimated. However, they should not be considered the sole possibilities. New ideas and interdisciplinary discoveries should also be welcomed in order to keep up-to-date; something worth researching may appear. If the new aspects are neglected, there is a possibility that "*the high quality building*" of today will be "*the low quality building*" of the future.

5.1 Experimental building

To develop construction processes, the buildings and the maintenance of the buildings, new designs, new products and new techniques are used occasionally. New designs and developments can be tested and studied in experimental buildings. These experimental buildings are important, since sometimes the experience from the real construction site is essential for the development process. Karjalainen (2002), for example, studied multi-story timber apartment buildings as pioneers in the development of timber construction. However, from time to time experimental building is regarded as a financing method. In these projects, nothing has necessarily been experimental. These projects detract the reputation of the idea of experimental building. (Paper IV)

The knowledge acquired during and after these on-site experiments is not utilised as well as it could be. Most of the knowledge stays with the people working in that particular project – it is not shared with others. The same mistakes might be made more than once. The knowledge acquired from experimental building should be taken to the next level. In order to be able to analyse building processes, solutions and components more thoroughly, at least some of the experimental buildings should be demolished before the end of their service life. Demolition, however, seldom takes place, even though it would provide more intimate knowledge of environmental performance and service life, and their interaction. How building solutions and components perform as part of a building should be studied by analysing them from demountable or demolished buildings. (Paper IV) Several viewpoints should be considered and analysed thoroughly:

- What is the remaining service life of the building solutions and components, and what is their condition? What is the variation of the service life within the same solutions and components?
- How the building solutions and components affect the surroundings and their service lives, and vice versa?
- How the maintenance and maintenance interval affects the service lives of the building solutions and components? How the skills and levels of workmanship influence the service lives?

Moreover, the environmental impacts of these issues need to be included in the considerations and analysis as well. Naturally, constructing and demolishing a building is time consuming, and very costly. However, the knowledge acquired throughout this process would be beneficial, and could be utilised in forthcoming building projects and development processes.

Occasionally, a comparative study of alternative building structures is conducted (e.g. Häkkinen and Wirtanen 2006; Trusty and Meil 1999). These studies are beneficial when they are accomplished during the design phase, and the results can be utilised in the decision making. For example, Häkkinen and Wirtanen (2006) analysed the environmental impacts of a wooden office building. In addition, they compared wooden structures with corresponding concrete structures. However, the study was done after the erection of the building, and therefore the results did not affect the decision making.

When the comparison of alternative designs is made after the decision has already been made, the significance of the comparison is minor. Unavoidably, the real intensions of the comparison are questionable. There is a possibility that the criteria and indicators are chosen in favour the decision already made.

5.2 Service life in the environmental assessment of buildings

The surroundings and other components affect the component and its service life. The width of the ventilating slot between the wooden cladding and the exterior wall structure, for example, affects the maintenance and the service life of the cladding. When the distance between the wooden cladding and the exterior wall structure is adequate (i.e. the width of the ventilating slot is maximised), the situation can be compared to a fence in the field. On the other hand, when the width of the ventilating slot is miniscule, the wooden cladding acts as part of the exterior wall structure. (Paper IV)

Another example is the remarkable difference in the condition of the old and new wooden buildings in the town of Porvoo, in Finland. The cladding of the new buildings had to be renovated a few years after the completion. The cladding of the old buildings is in much better condition, even though the buildings are decades old. A controlled thermal leakage through the exterior wall structures could be one of the explanations for the better condition of the old wooden houses. In the new buildings, the thermal leakage through the exterior wall structures is much lower, but the cladding needs renovations more often. Which alternative is better from the economical viewpoint, and which is better from the environmental viewpoint? Which alternative is the best considering health related issues? If the observation time changes from 50 to 100 years, how does it affect the choice? (Paper IV)

By optimising the energy efficiency of the external wall structure, the service life of some components may shorten. For example, if the thermal leakage through the external wall is minimised, there is a risk the moisture will condense into the external wall. Consequently, the service lives of the wall's components shorten, and they need replacement sooner. In the long run, the energy consumption of the energy efficient wall may be higher due to the shortened service life and replacements. Furthermore, condensed moisture in the structures may have annoying consequences affecting indoor environment. Since optimising one thing may cause trouble elsewhere, a holistic viewpoint is needed.

In central Europe, the idea of "*passive houses*" is supported. The consumption of heating energy decreases, for example, by lowering the indoor temperature, by utilising the differences of temperatures in ventilation, or by adding insulations. The question is, what will happen in 50, 100, or 150 year's time. How the climate affects the passive houses should also be analysed. The weather and the conditions change radically, for example, when moving from the Mediterranean area to the central European mountain range and to the northern European fell area. Many buildings in the Mediterranean area are without any heating system, whereas in northern Europe the difference between the indoor and outdoor temperatures can be over 50°C. These conditions are challenging for the buildings, especially for the insulations.

Obsolescence causes renovations of the buildings as the requirements and needs of tenants grow. The number of renovations is currently increasing, and there is no end insight. The environmental aspect of these renovations is disregarded. When a component is replaced with a new one before its service life is finished, the remaining service life is wasted. In order to minimise the environmental impacts of the renovations caused by obsolescence, the design of the building needs to be considered in service life planning; the forthcoming renovations should be taken into account already in the design phase of the building. The parts most likely to be changed during the building's service life should be designed to be easy-to-replace with low environmental impact. Furthermore, reuse and recycling of the parts should also be considered. These issues should also be considered in the discussion of the integration of the assessment and design tools.

5.3 Workmanship

The EU has eased the mobility of labour within its member countries. There is a keen competition on building contracts and professional workmen. The lack of professional workers is currently a big concern within the construction sector, at least in Finland. Unfortunately, grey markets are boost in these kinds of circumstances. The number of sub-contractors has been growing over the past decades. Supervising the level of the workmanship becomes challenging as the numbers of the sub-contractors increase. Due to the mobility of labour, there are often several different nationalities at a construction site. In different countries, the building culture, the working methods, and the code of building regulations is different. This complicates the circumstances even more. At worst, it may be a matter of industrial safety. Moreover, professional pride is often not what it used to be. Before a construction worker used to show his work and say, *"This is what I built"*. Today, he shows his wallet, and says, *"This is what I earned"*. (Paper V)

The maintenance and the renovations of the existing buildings are critical issues for sustainable building, especially in Europe. The service life of a building can be decades or even centuries. The service lives of the components vary from a few years up to the service life of a whole building (ISO 2000). But during the building's long service life, manufacturing processes and products are developed. Matching old and new techniques and products could be challenging, especially considering the lack of professional workers. (Paper V)

The distribution of the liability could improve the quality of the building materials and components, and the installation. There could be certificates for every work phase for the practitioners, e.g. producers, manufacturers, assemblers, and installers. By signing the certificate, they would guarantee that they have done their part according to the building code and the certificate. The signature would make the person responsible. However, this would increase bureaucracy. Naturally there are legal responsibilities for faulty materials and components. This could help to trace the responsible person, because in some cases it is very difficult to prove who is responsible. If the names of architects, designers, constructors, and inspectors were engraved on a plate on the front wall of the buildings, would the quality of the building be any better? (Paper V)

5.4 Challenges in the future

In recent years, the interest towards sustainable building and the environmental assessment of buildings has increased in the developing world. The development of the methods and tools for the environmental assessment of buildings has been dominated by the industrial countries. Problems can be expected if the developing countries utilise the assessment methods, which originated in industrial countries without further clarification (Cole 2005). However, environmental issues need the global perspective. Therefore, the gap and the differences between the developing and the industrial world need to be taken into consideration.

Should the focus be on the development of sustainable building in the industrial countries or on the development of manufacturing processes in the developing countries? From the global perspective, the environmental benefits are greater if the focus is on the developing countries.

The increase of population is a growing concern. Currently, the average annual growth rate is 1,4%, but urbanisation is much higher (Statistics Finland 2007, Rees 1999). Furthermore, the population in the industrial world is ageing. The situation is challenging for sustainable building, and also for natural resources. Even if the consumption of natural resources remains constant or decreases in the industrial world, the consumption in the developing world will increase to insure the minimum standard of living (e.g. Kohler 1999).

Furthermore, the differences within the industrial world are challenging. In North America, for example, the urban areas grow rapidly, and therefore attention is divided between the new and the existing buildings. However, in Europe, the building stocks are much older. The maintenance of the existing buildings is a critical issue for sustainable building. Kohler and Moffatt (2003) point out the management of existing buildings, refurbishing of post World War II buildings, and conservation of historic towns.

Different building components can be compared separately or as a part of a building. The buildings can be analysed as a construction, focusing on the structure of the building, or as a residence, focusing on the use of the building. The locations of the buildings vary from rural to urban areas, and from developing to industrial countries. Is the development of the environmental assessment of buildings heading in the right directions? Are all the important aspects considered? No assessment tool or method is able to answer all these questions or to consider all these aspects. However, these different aspects need to be recognised, and their relationships need to be analysed. Furthermore, the limitations of assessment tools and methods need to recognised, and more importantly to be taken into account when interpreting the results.

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