Technologic or technical service life

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Task Group

Conceptualization of service life prediction

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1. Introduction

The mission of the CIB W080 commission is to help to develop the necessary guides, methods, and techniques for the service life prediction of building materials and components. The commission encourages the international cooperation and information exchange in building and construction research and innovation. CIB is engaged in the scientific, technical, economic, and social domains related to the durability of construction, enabling practitioners with relevant information and tools to perform an adequate service life prediction, supporting improvements in the building process and the performance of the built environment.

Considerable work has been developed within the CIB W080 commission, concerning the service life prediction of building and components. This report presents a conceptual discussion about the concept of service life and obsolescence, shows different perspectives, and discusses different criteria to establish the end of service life of buildings and components. These criteria can be either scientific and supported by rational factors or based on subjective ideas and expectations.

Buildings and components suffer various types of depreciation throughout their life cycle, eventually leading to their obsolescence and the end of their service life. The service life is conditioned by several factors, which are discussed in the next chapters: physical deterioration (chapter 3); functional obsolescence (chapter 4); technological obsolescence (chapter 5); changes in the social context, aesthetic obsolescence, or legal obsolescence (chapter 6); and environmental obsolescence (chapter 7).

Each chapter provides an assessment of the current scientific knowledge related with the conceptualization of the service life and the different types of obsolescence of the buildings and components. The seven chapters provide diverse contributions and points of view regarding the concept of service life considering the classifications currently available in literature or in ISO 15686. In chapter 8, a final discussion is provided, analysing the concept of service life and the cause-effect processes underlying ageing and decay. Chapter 8 thus provides a general overview on the various concepts described separately in the previous chapters, allowing intercorrelating them, showing the causal effects among the different types of obsolescence, considering both endogenous and exogenous factors, as well as the human behaviour, on the establishment of the end of service life of buildings and components. This report intends to provide a valuable discussion of the different concepts, aiding the service life prediction of buildings and components.

Chair/Co-coordinator of CIB W080,
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2. Service life: Concepts and definitions

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As soon as constructions are put into use, their "life" begins. As mentioned by Rudbeck (1999), the beginning of the constructions' life cycle is easy to define but the end of their life is much harder to predict, or even define.

As long as a construction is capable of meeting the users' objective needs and fulfil their subjective limits, within acceptable maintenance and management costs and without losses (or indirect costs) to third parties, the construction is said to be within its "service life" period (Haapio and Viitaniemi, 2008).

The concept of service life seems to be reasonably simple, although different definitions and different types of service life can be found in the literature, sharing common ideas (Frohnsdorff and Nireki, 1994; Nireki, 1996; Soronis, 1996; Rudbeck, 1999; Marteinsson, 2003; Silva et al., 2016):

Service life	*"period of time after installation during which a building or its parts meets or exceeds the performance requirements"* (ISO 15686, 2011)
Planned service life (AIJ, 1993) or Design Life (BS 7543, 1992) or Design Service Life (S478, 1995) or Design working life (EC0, 2002)	*"the service life that the designer intends an item (product, component, assembly or construction) to achieve when subject to the expected service conditions and maintained according to a prescribed maintenance management plan"*
Required service life	*"the minimum period during which the structure or a specified part of it should perform its design functions (subject to routine servicing and maintenance) to meet the users' requirements. The actual limits of required service life used at the design stage will depend on the nature of the structure and the client's requirements. The required service life may also depend on the type of structure or its elements, its performance (including safety) requirements, and on the maintenance regime that is adopted"* (BRE, 2007; ISO 15686, 2011)
Economically reasonable working life	*"period of time during which no excessive expenditure is required on operation, maintenance or repair of a component or construction. All relevant aspects are taken into account, such as: costs of design, construction and use; costs arising from hindrance of use; risks and consequences of failure and costs of insurance covering these risks; planned partial renewal; costs of inspections, maintenance, care and repair; costs of operation and administration; disposal; environmental aspects"* (European Union, 1994; ISO 15686, 2011)

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Functional service life	*"period of time after construction in which the building can be used for its intended purpose without changing its properties"* (ISO 15686, 2011)
Social and legal service life	*"period of time after construction until human desire or legal requirements dictate replacement for reasons other than economic factors"* (ISO 15686, 2011)
Technological or technical service life	*"period of time after construction until the building is no longer technologically superior to the existing alternatives"* (ISO 15686, 2011)
Reference service life	*"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 conditions"* (ISO 15686, 2011)
Estimated service life	*"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"* (ISO 15686, 2011)
Predicted service life	*"service life predicted from recorded performance over time"* (ISO 15686, 2011) *"service life predicted from recorded performance, previous experience, tests, or modelling"* (S478, 1995)
Service life planning	*"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 optimising) the life cycle costs of the building"* (ISO 15686, 2011)

Obsolescence is another relevant concept, related with the concept of service life, and which can lead to the inadequacy of a given building or component. Obsolescence is defined in the dictionary, as the process of becoming antiquated, old-fashioned, or out-of-date (Pinder and Wilkinson, 2001). The obsolescence describes a decline in utility, and usually an obsolete component is not broken or dysfunctional, but instead this component does not fulfil the current levels of demand and the users' expectations, functioning at levels below contemporary standards (Lemer, 1996). In this sense, the obsolescence is not usually directly related with the physical deterioration of the component, or the action of time, but instead caused by social, technological or legal changes (Baum, 1991). The sense of utility is a key concept in the definition of obsolescence (Smith et al, 1998); however, as mentioned by Raftery (1991), there is no specific measure of "utility", and a rational, consistent, and defining an objective measure of obsolescence is an extremely difficult task.

The service life and the obsolescence of constructions, buildings and components can be summarised as the inability to meet changing performance requirements. Therefore, the end of service life occurs at the instant in time after which a building or component reaches a conventionally defined "unacceptable level". In other words, when the building becomes obsolete due to various reasons, it can also be said that it has reached the end of its service life.

The end of service life thus will depend on the buildings' nature, the users' needs, the capability to adapt to changing performance requirements over time, and on the maintenance regimes adopted (BRE, 2007). The boundaries to establish the end of service life can be divided in objective and subjective needs. The objective needs are recognized as the requirements for safety, functionality, infrastructural functioning or environmental quality, among others (Bordass et al., 2001a,b,c; Humphreys, 2005; Nicol and Roaf, 2005). The subjective needs correspond to users' desires related with the buildings' performance, e.g. associated with the concepts of comfort, well-being, beauty or quality (Rybczynski, 2001; Leaman and Bordass, 2001).

Haapio (2008) refers that reliable data to predict the obsolescence of buildings are rarely available, since they depend on subjective factors, as the stakeholders' experiences and judgments. A study performed by Aikivuori (1999) reveals that in only 17% of the situations the decision to intervene is taken based on the building's physical deterioration and in 44 % of cases maintenance actions are performed based on subjective criteria. Brand (1997) refers that the change in buildings occurs at two paces: the rate at which the components wear out (physical deterioration); and the frequency with which changes in fashion dictate the replacement of the components. Usually, the building components are replaced before their service life has ended and, usually, "obsolescence-based" maintenance (e.g. due to changes in the social context, or due to aesthetic or legal reasons) occurs earlier than "deterioration-based" refurbishment.

The service life prediction models must take into account the inexorable reasons leading to the obsolescence of buildings and components. In the next chapters, different types of service life are analysed, discussing different criteria that influence the end of the service life of buildings and components. The criteria are analysed individually, starting with a conceptual description of the physical deterioration (chapter 3) as the main motivation for the end of service life of buildings and analysing different criteria that usually lead to the obsolescence of buildings and components (functional in chapter 4, technological in chapter 5, changes in the social context, aesthetic or legal in chapter 6, and environmental in chapter 7). Throughout the various chapters, the causal relationship between the various types of obsolescence is highlighted and discussed, emphasising that the end of service life is generally dictated by a combination of factors. Nevertheless, in chapter 8, a conceptual discussion is provided, to analyse the underlying cause-effect processes that contribute to the end of service life of buildings and components, assessing how the typical effects of obsolescence are interrelated, revealing that the various types or causes of end of service life or types of obsolescence are interconnected, in cause-and-effect chains.

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3. Physical service life

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3.1. Physical service life and physical obsolescence

The obsolescence of buildings seems to be caused by physical factors (e.g. presence of anomalies) and behavioural factors (e.g. users' demands), and the interactions between them (Thomsen and Flier, 2011). Different authors (Allehaux and Tessier, 2002; Dunse and Jones, 2005) intended to establish causal relationships between obsolescence and the buildings' deterioration. The factor time, or the aging process, seems to be a natural cause for the decline of the buildings' performance, but age by itself does not necessarily lead to the end of service life of buildings, nor does it make them obsolete.

Buildings and components are subjected to a cumulative exposure to a critical combination of deterioration agents over their life span, which promote their physical deterioration. Usually, a specific durability-capacity is assigned to a given building or component, and the end of service life due to physical deterioration is established considering the probability and effects of failure of these elements (Rudbeck, 1999). Physical deterioration does not always occur due to environmental degradation agents. Beyond environmental exposure conditions, the service life of buildings and components is strongly influenced by the characteristics of the materials, the design and construction conditions, and by the type of use and maintenance levels (ISO 15686-1, 2011; Petrenko and Manjilevskaja, 2017).

Various authors (Flanagan et al., 1989; Ashworth, 2004) established a difference between "physical deterioration" and "physical obsolescence", referring that "physical deterioration" is related with predictable phenomena and a combination between the design/use/maintenance conditions and the passage of time, while "physical obsolescence" is related with unpredicted and erratic events, rooted in the users' behaviour. On the other hand, various studies (Iselin and Lemer, 1993; API, 2017; RICS, 2017) adopt the two terms interchangeably, assuming that physical deterioration is the fundamental form of physical obsolescence (Pourebrahimi et al., 2020).

3.2. Quantitative indexes to evaluate the physical deterioration or obsolescence of constructions

Various authors (Kyatov, 2001; Straub, 2003) refer the need to define indexes to evaluate the physical deterioration or the degree of obsolescence of buildings and components. Various studies (Shohet et al., 1999; Marteinsson and Jónsson, 1999; Freitas et al., 1999; Brandt and Rasmussen, 2002; Balaras et al., 2005b; Chew, 2005) have established classification systems for defects and degradation ratings to characterise the physical degradation of buildings and components.

These classification systems usually rate the physical deterioration based on a set of reference characteristics (e.g. presence of defects, the percentage of defects in the element under analysis, and the severity of these) (MTQ, 1995; Mourcos et al., 2003; Straub, 2003; Silva et al., 2016).

These systems present a scale of discrete incremental variables, which varies from the most favourable condition (no visible degradation) to the most unfavourable condition (generalized degradation, loss of functionality or risk of failure or collapse of the element analysed). Discrete ratings are used instead of continuous condition indices essentially for reducing the computational complexity of modelling the physical deterioration of constructions (Madanat et al., 1997).

Table 3.1. shows the comparison between the various classification systems proposed, in order to quantify the physical degradation of constructions. These scales are usually used to estimate the end of the physical service life of the elements under analysis, either through the definition of a global degradation index or through modelling the transition between degradation conditions (e.g. using Markov chains). The end of the physical service life is thus reached when the element reaches a condition defined as the conventional limit of degradation, after which the element no longer fulfils the performance requirements. Nevertheless, this theoretical limit is not easy to specify (Moser 2004), and depends on the users' demands and expectations (which can privilege the aesthetic appearance of buildings in detriment of their physical degradation), on economic reasons (e.g. the funds available for maintenance actions) or on the constructions' economic and social context.

3.3. End of physical life and how it occurs in different ways for different constructions and components

Contrarily to a generalised empirical perception, the physical deterioration is often not the prevailing factor in conditioning the durability and service life of buildings and components (Sarja, 2005; Balaras et al., 2005a). In practice, the end of the physical service life can have different meanings depending on the nature of the element under analysis (Brand, 1997; Duffy, 1997):

- Concerning the structural elements, the limit of their physical service time is rarely reached, for safety reasons (Gosav, 1999). Therefore, when buildings reach the end of their service life (for economic, functional or other reasons), the structures are demolished, despite still meeting the requirements for which they were designed;
- Regarding the elements of the buildings' envelope, the end of service life is strongly conditioned by the type of use of the building. There are essential differences between commercial/service buildings and residential buildings, as well as between rented and owned property and between single and joint ownership (Itard and Meijer, 2008). Buildings with profit purposes are generally subjected to regular maintenance and major interventions on the façade (due to the availability of funds and due to a skilled professional management of the assets), even if the respective components have not reached their physical service life limit. On the other hand, in residential buildings, the main maintenance activities are reactive, aiming at the resolution of random anomalies, and several components can reach and exceed the end of their physical service life before being replaced (Thomsen and van der Flier, 2011);

- The infrastructural networks and installations are usually subjected to regular maintenance of the equipment and, except for the cases of malfunctioning or damaged components, it appears that their replacement is mainly due to technical or legal obsolescence, and the limit of their physical service life is rarely achieved (Iselin and Lemer, 1993). In this context, obsolescence must be understood, not as an inability of the equipment to fulfil the performance requirements (since, in fact, maintains the level of performance for which it was designed), but as the mismatch between its performance and the growing demands of the users over time (Gaspar, 2009);
- The interior finishes are rarely replaced due to their physical degradation. On the contrary, in these cases, the criteria that dictate its replacement are mainly related to fashion criteria or aesthetic obsolescence, due to variations on the users' taste and needs.

Table 3.1. - Comparison of the classification systems proposed to quantify the physical degradation of constructions

Reference	Scope	More favourable condition							More unfavourable condition
Camahan et al. (1987)	Pavements / Infrastructures	8 (excellent, no visible degradation)							1 (failed)
BELCAM Lounis et al. (1998)	Building envelope	7 (excellent, no visible degradation)	6 (very good, minor anomalies)	5 (good, presence of some distresses)	4 (fair, moderate deterioration)	3 (poor, major deterioration)	2 (very poor, extensive deterioration)		1 (failed)
Freitas et al. (1999)	Building envelope	D1 (without visible degradation)	D2 (slightly degraded)	D3 (degraded)	D4 (strongly degraded)				
Marteinsson and Jónsson (1999)	Building components	A - no degradation; the defects are present in less than 5% of the surface (Maintenance actions are not required in the next 5 years)	B - slight degradation; the defects are present in 6% to 33% of the surface (Maintenance actions are required in the next 3 to 5 years)	C - considerable degradation; the defects are present in 34 to 66% of the surface (Maintenance actions are required in the next 1 to 3 years)	D - severe degradation; the defects are present in 67% to 100% of the surface (Need for immediate intervention)				
MEDIC Florentzou et al. (2000) Balaras et al. (2005b)	Building components	a - good condition (no action is required)	b - minor deterioration	c - more serious deterioration	d - worst condition, deteriorated or obsolete (requiring replacement)				
EPIQR Brandt and Rasmussen(2002)	Office buildings	a - better condition (no action is required)	b - some deterioration (requires small intervention and maintenance)	c - medium degradation (requires extensive intervention and maintenance)	d - severe degradation (end of service life; requires immediate and extensive intervention or replacement)				
TOBUS Caccavelli and Gugerli (2002)	Office buildings	a - Good condition	b - some deterioration	c - deterioration requires repair as soon as possible	d - service life is over and immediate repair required				
NCES (2003)	Educational	1 (excellent)	2 (good)	3 (adequate)	4 (fair)	5 (poor)	6 (non-operable)	7 (urgent)	8 (emergency)

Table 3.1. - Comparison of the classification systems proposed to quantify the physical degradation of constructions (continued)

Reference	Scope	More favourable condition							More unfavourable condition
Shohet et al. (1999) Shohet and Paciuk (2004)	Building envelope	5 (no signs of degradation; performance index higher than 79%)	4 (slight degradation; performance index between 79 and 60%)	3 (performance index between 59 and 40%)	2 (performance index between 39 and 20%)				1 (severe failure; performance index lower than 20%)
Abbot and Mc Duling (2004)	Hospitals	5 (very good; does not exhibit any signs of deterioration)	4 (good; minor signs of deterioration)	3 (fair; repairs required)	2 (bad; rehabilitation required; the element presents a serious risk of failure)				1 (very bad; the component has failed)
Jernberg et al. (2004)	Building components	0 (Intact, no changes)	1 (Minor damages, some maintenance is suggested)	2 (Malfunction, maintenance needed as soon as possible)					3 (Out of order, replace or repair immediately)
Haagenrud and Krigsvoll (2005)	Historic buildings	0 (no symptoms, without consequences)	1 (minor symptoms, slight consequences)	2 (medium or strong symptoms, medium or strong consequences)					3 (severe symptoms, including poor operation or collapse, serious consequences)
NHS (1993; 2001); Kirkham and Boussabaine (2005)	Hospitals	A (new element, what is expected to last the design service life)	B (element in normal conditions, with minor signs of deterioration)	C (element in normal conditions, but that will be subject to repairs or replacement in the next three years)					D (element in serious risk of imminent breakdown or collapse)
Dutch standard for condition assessment of buildings / NEN (2006) Straub (2009)	Housing	1 (excellent condition)	2 (good condition)	3 (fair condition)	4 (poor condition)	5 (bad condition)			6 (very bad condition)
Abbott et al. (2007)	Hospitals	5 (very good condition)		3 (fair condition, repairs required)					1 (very bad, requires replacement)
Ho et al. (2008)	Housing	1 (satisfactory)	0.75 (above average)	0.5 (acceptable)	0.25 (deficient)				0 (poor)
Pedro et al. (2008)	Housing (urban tenancy regime)	$5.00 \geq Di \geq 4.50$ (minor defects, excellent condition)	$4.50 > Di \geq 3.50$ (slight defects, good condition)	$3.50 > Di \geq 2.50$ (medium defects, medium condition)	$2.50 > Di \geq 1.50$ (severe defects, bad condition)				$1.50 > Di \geq 1.00$ (critical defects, very bad condition)
Foltz and McKay (2008)	Airfield pavements / Infrastructures	85-100 (excellent, no noticeable defects)	70-84 (good, minor deterioration)	55-69 (fair, some deterioration)	40-54 (marginal, moderate deterioration)	25-39 (poor, serious deterioration)	10-24 (very poor, extensive deterioration)		0-9 (failed, no longer function)
Salim and Zahari (2011)	Office buildings	1 (good condition)	2 (minor repairs)	3 (general maintenance)	4 (medium repair and/or replacement)				5 (major repair and/or replacement)
Rodrigues et al. (2011)	Housing	G^+ (exceptional, without any intervention required)	G^0 (good, regular maintenance require)	G^- (good, maintenance cations needed for component with signs of deterioration)	Y^+ (acceptable but needing small rehabilitation actions)	Y^0 (acceptable but needing moderate rehabilitation actions)	Y^- (acceptable but needing large rehabilitation actions)	R^+ (unacceptable, priority intervention)	R^0 (unacceptable, unsuitable for rehabilitation)

Table 3.1. - Comparison of the classification systems proposed to quantify the physical degradation of constructions (continued)

Reference	Scope	More favourable condition									More unfavourable condition
Eweda (2012)	Educational	A (90 - 100%) Excellent		B (75 - 89%) Very good	C (60 - 74%) Good		D (40 - 59%) Fair	E (20 - 39%) Poor		F (0 - 19%) Failure	
FHWA (2012)	Highways and bridges	9 (As-built condition)	8 (No problems noted)	7 (Some minor problems)	6 (Structural elements show some minor deterioration)	5 (All primary structural elements are sound but may have minor section loss, cracking, spalling or scour)	4 (Advance section loss, deterioration, spalling or scour)	3 (Local failures are possible)	2 (Advanced deterioration of primary structural elements)	1 (Major deterioration or section loss present in critical structural components)	0 (Out of service - Beyond corrective action)
MOLIT (2012)	Infrastructures and bridges	A (perfect, no problems)	B (minor problems in secondary elements, small repairs)		C (Minor problems in primary elements or extensive problems in secondary elements, need of repair in primary elements or of rehabilitation of secondary elements)			D (Problems in primary elements, emergency repairs/rehabilitations)		E (Serious problems in primary elements, out of service, need of rehabilitations/replacements)	
Adcock and Wilson (2016)	Housing	J (9 or less in the hazard score) Safest condition								A (5000 or more in the hazard score) Most dangerous condition	
Gaspar and de Brito (2008); Silva et al. (2016); Serralheiro et al. (2017); Ramos et al. (2018)	Building envelope	A (no visible degradation)			B (good condition)	C (slight degradation)		D (moderate degradation)		E (generalized degradation)	

Several studies reveal that, in reality, when considered as a whole, buildings rarely reach the limit of physical service life. Brand (1997) relates the service life of buildings with their uses, from high turnover spaces (with limited service lives) to buildings with slower changes. Awano (2003) made a distinction between physical service life (i.e. the *period of physical existence between construction and demolition*) and real service life (the period during which a building actually meets the users' demands). Thomsen and van der Flier (2009) refer that this distinction can be ambiguous in practice because it is not easy to define when a building has lost its capability of fulfilling the basic performance demands. In fact, the physical service life of a building can be virtually endless by applying appropriate maintenance strategies, while the building can be demolished even though they are still functional in the technical sense (Kohler and Hassler, 2002).

In reality, the end of the physical useful life is often conditioned by the type of use or specific characteristics of the constructions. For example, Aikivuori (1994) referred that, in 26% of the situations, the refurbishment of buildings occurs due to physical deterioration or obsolescence, while Iizuka (1988) revealed that, in 74% of the situations, this reason drives the demolition of bridges.

A study by Horst et al. (2005) revealed that the service life of housing in USA is around 11 to 32 years, while the schools only undergo major renovations after 42 years, but tend to be abandoned by age 60, for functional reasons. This study also reveals that tertiary office buildings in Japan tend to have a service life between 23 and 41 years, and the end of their service life occurs mainly due to economic cycles, rather than physical obsolescence. The same conclusion is obtained by Pinder and Wilkinson (2001), which mentioned that the increasing obsolescence of office buildings has reduced their average service life to less than 25 years. Gann and Barlow (1996) also reveal that the obsolescence of office buildings also tend to be conditioned by variable and increasing levels of demand over time, since the service life of office buildings in the United Kingdom was reduced to 40-50 years in 1950s and 1960s, and to 20-25 years in 1990s.

In the case of health care facilities, it is very common that the buildings become obsolete before having reached the end of their service life. A study performed to the South African university hospitals (Mc Duling et al., 2008; Mc Duling and Abbott, 2008), reveals that, even though the design service life of these buildings is around 50 to 60 years, the hospitals tend to reach the end of their service life after 30 years, mainly due to technological obsolescence, linked to the modernisation in modern medical and health care technology.

3.4. Concluding remarks

Physical deterioration naturally occurs over time, due to the exposure of the buildings and components to a set of deterioration agents. The obsolescence of buildings can be controlled and mitigated by selecting appropriate materials at the design stage, by adopting adequate construction practices and by means of regular maintenance actions.

Although physical obsolescence is the type of obsolescence that is most easily quantified, and scales based on the condition and the presence of anomalies can be used, as analysed in the previous section, the literature reveals that physical deterioration does not seem to be the most conditioning factor to establish the end of the service life of buildings (Aikivuori, 1999).

Therefore, even though the physical service life can be extended for a long period of time, the buildings' end of service life is rooted in the users' behaviours and demands, and eventually the end of service life will occur anyway, due to functional, aesthetic, normative, social, or economic reasons.

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4. Functional service life

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4.1. How to define the functional service life of buildings and building's components?

This section of this report intends to address the following question: How to define the 'functional service life' of buildings and their components? The answer to this question is not easy by using simply a specific definition. Although the concept of functional service life (FSL) is not exactly new, a unique and specific term regarding this concept has not still been unequivocally defined. This occurs mainly because the FSL concerns a relationship between several parameters. To clarify this issue, a brief state-of-the-art has been put together in order to collect different approaches developed by researchers and authors in the Architecture, Engineering and Construction (AEC) area.

At the beginning of the 1970's, Markus et al. (1972) developed a first contribution on buildings' performance, which concerns specifically the significance of understanding the humans' role in the assessment of building's performance. In the next decade (1980's), the Report 64 by CIB (1982) contributes with a wide view on performance properties (acoustics, moisture ingress or fire, among others). This report covers the physical measurement and prediction and introduces the notion of performance test methods (Gibson, 1982). The whole building performance concept was introduced by Rush (1986). In this approach, various predominantly building physics domains were included and examined: (i) spatial performance; (ii) thermal performance; (iii) indoor air quality; (iv) acoustical performance; (v) visual performance, considering building integrity; (vi) physiological, psychological, and sociological topics; and (vii) economic issues. Master and Brandt (1989) initiated the use of the term serviceability in the AEC area. They defined serviceability as the capability of a building, component, assembly, or construction to perform the function for which it is been specially designed and used.

At the end of 90's and according to Andersen and Brandt (1999), the buildings' service life can also be defined as the period during which at least the core performance properties are maintained at a satisfactory level. This kind of definition regards the concept related to serviceability and functionality. Similarly, Davis and Szigeti (1999) defined serviceability of buildings and their components as their capability to support the activities or functions of users and owners, when required. Currently, in contemporary societies, the demands of building occupants become more and more dynamic (Blok et al., 2002), requiring that the building and its components are capable of constantly adapting to fulfil users' criteria and moreover regarding the perspective of performance-based building's legislation (Lacasse et al., 1997; Foliente, 2000).

In the two last decades (2000-2020), several approaches were identified to evaluate the functionality of buildings. Lützkendorf et al. (2005) described and assessed the functional performance of buildings. This analysis includes the suitability of the space program such as use, accessibility and barrier-free design and adaptability to changing users' requirements. Functional performance is closely related to the needs of the building users and others such as visitors, and the public community. Preiser and Vischer (2006) contributed with the analysis of the post occupancy evaluation, which they labelled building performance evaluation (positioning performance at the interface between criteria and design solutions, considering stakeholders in performance) (Szigeti and Davis, 2005; Grussing et al., 2009). The contribution developed by Blok and Teuffel (2014) is also related to the term of flexibility and it is considered as a property of the building that represents the building's ability to change and adapt to new requirements. The authors considered that the analysis of the functional service life of buildings can be much more conclusive in terms of stakeholders' decision-making rather than that of the technical service life. They also stated that FSL is influenced by the ability of the building or its components to manage changes during the whole service life. In 2014, Macías-Bernal et al. (2014) developed a new digital approach focused on the FSL of heritage buildings considering vulnerability variables (geological location, constructive system, roof design, conservation state, among others) and external risks parameters related to static-structural, atmospheric and anthropic affections. In the same way, Ibáñez et al. (2016) and Prieto et al. (2016, 2018) developed a standardisation of a FSL approach, considering the standard ISO31000: 2009 risk management implemented in a set of heritage buildings with homogeneous constructive features. Concerning innovative advances in functional service life, Augenbroe (2019) provided a discussion focussed on the role of building performance simulation in building design, as a virtual experiment to quantify how well a technological solution meets user requirements. In 2020, different approaches are used to analyse the impact of climate change on functional service life of buildings (Lacasse et al., 2020), which have been established under a specific local context of users, environmental, constructive systems of buildings, among others intrinsic and extrinsic input parameters (Prieto et al. 2020).

4.2. Concepts related to functional service life definition

After the analysis of a brief state-of-the-art related to the concept of functional service life from the last 50 years, the standards ISO 15686-1: 2011 and ISO15686-10: 2011 can also assist in a conceptual clarification. In Figure 4.1., a set of concepts related to functional service life definition, discussed in the last five decades, are schematised. According to ISO 15686-1:2011, the service life can be defined as a period of time after installation during which the building and its parts meet or exceed the performance requirements.

Usually, a performance requirement is focused on a specific requirement or condition for a specified use (Figure 4.1.). This concept is related to serviceability, which is defined as a capability of a facility, building or other constructed asset to support the function or functions for which it was previously designed, used or required to be used (Figure 4.1.). In this sense, different levels of serviceability can be stablished. Functional performance requirements concern the level of functionality that is demanded by stakeholders of a building or its components for a specific function. This functionality is defined as the suitability or usefulness for a precise purpose or activity (Figure 4.1.). The level of functionality is understood as a numerical value indicating the relative functionality required for a user group for one topic on a predetermined demand scale (ISO15686-1: 2011).

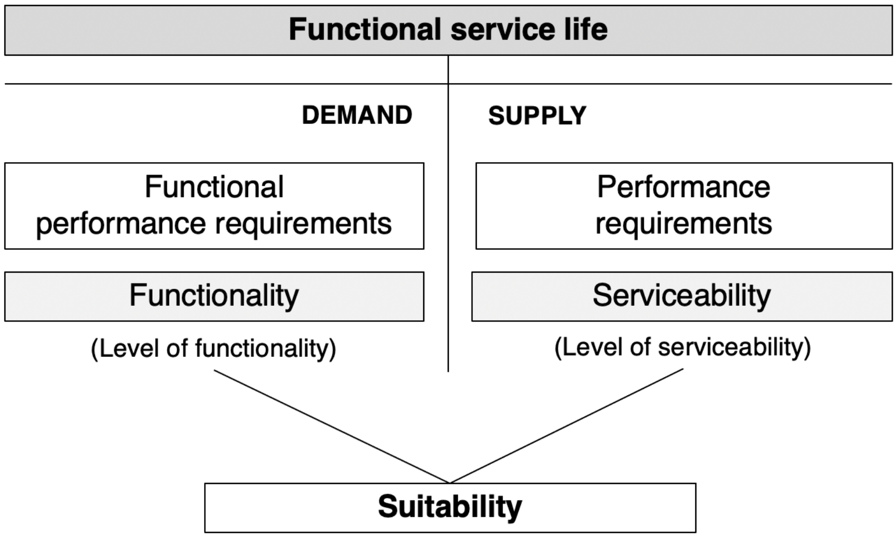

Figure 4.1. - Concepts related to functional service life definition

In a general manner, three main parameters (Figure 4.2.) can be used to describe the concept of functional service life (ISO15686-1: 2011):

- Functionality or users' demand, regarding the description of what stakeholders need in relation to what the building can perform concerning their demand. This concept is defined as level of functionality. Taken together, these levels of functionality form a profile of the requirements of the users and stakeholders;
- Serviceability or building or its component and the ability to fulfil the users' requirements. The extent to which the asset is suitable or useful in relation to the topics labelling the users' requirements is entitled as a level of serviceability, which can be matched to the profile of functionality;
- Suitability, which can be defined as the appropriateness to support the functions or activities of users or stakeholders. Regarding the concepts previously established, the suitability of a facility is assessed when the two profiles (functionality and serviceability) are compared (Szigeti and Davis, 2002).

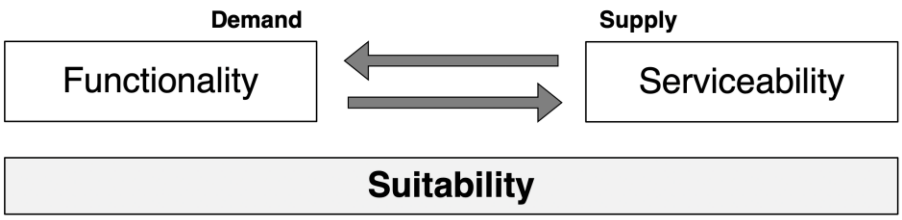

Figure 4.2. - Relationship between functionality, serviceability and suitability

For instance, let us consider the place where an individual does office work in an accounting firm, or the place where a family eats dinner at home, or the place where a physician examines a patient. Each of these places can be more or less suitable or useful for what each set of users and other stakeholders want to do. If the place is not as suitable or useful as it is required, there is a gap between the level of functionality required and the level of serviceability provided for that use by the place (ISO15686-1: 2011).

4.3. End of service life due to functional criteria

The earliest, and most often repeated, example of definition of the end of a building service life was established by the Hammurabi Code (c.1950 to 1910 BC): "a house should not collapse and kill anybody" (Harper, 1904). The end of service life is usually related to technical attributes of a building, whether expressed as a high-level of safety, functional demands, or performance requirements (Bakens, 2005). In this sense, the life cycle of a building or building components should be analysed using a whole set of different performance requirements involving intrinsic variables of the buildings, but also including parameters related to a variety of needs - functional, physical, economic, social, environmental - according to set a series of legal requirements and to potentially accommodate users and owners with different demands level (Kyle, 2001; Geissdoerfer et al., 2017).

In this sense, the service life prediction of buildings or their components cannot be understood as a precise discipline since concerns many different variables related to the prediction of real world phenomena (Silva et al., 2016): (i) the buildings' functional degradation is related to several degradation agents and mechanisms that can act synergistically; (ii) the definition of the end of the functional service life is normally subjective, since it depends on a set of parameters related to acceptance criteria; and (iii) the acceptance criteria usually vary according to time, place, stakeholders and even resources available for implementing maintenance actions or programs (Prieto et al., 2018).

During their service life, buildings and their components suffer from several types of depreciation. The end of the functional service life of a building is mainly influenced by acceptance criteria or expectations of users and owners (Meacham et al., 2005), which evolves over time (usually becoming more demanding), requiring a constant investment to ensure that a construction is capable of technically responding to all new requirements. Aikivuori (1999) stated that the end of the service life can also be analysed based on functional criteria, through the comparison of the existing building performance with either standard performance criteria or personal expectations. According to Flanagan et al. (1989), these criteria may be of various types, such as physical deterioration, functional obsolescence, economic or environmental obsolescence, and aesthetic reasons, among others. The term of obsolescence regards owners and users, for even if the building fulfils the initial requirements, it may fail to respond to new expectations or requirements especially when compared to (often newer) available alternatives (Meacham et al., 2005). Slauther (2001) considered that the usefulness of the buildings is compromised by their inability to accommodate changes over time. In fact, throughout their life cycle, all the buildings experience changes, e.g. changes in its occupants or their needs and expectations, renovations and/or extensions, the ageing and replacement of components and systems (Trinius and Sjöström, 2005).

In Figure 4.3., a graphical description of initial functional service life degradation, including an improvement in the requirement levels, is shown. This graphical description helps in the interpretation of the end of the functional service life. Considering a detailed explanation of Fig. 4.3., the following caption can be provided: (1) shakedown stage; (2) functional service life planned regarding initial requirement level and initial threshold level; (3) initial functional service life failure; (4) suitability condition curves (serviceability showing functionality); (5) functional service life extended after improvements, concerning new requirements and new threshold level; (6) new functional service life failure; and (7) the functional condition is no longer suitable (ISO15686-10:2011).

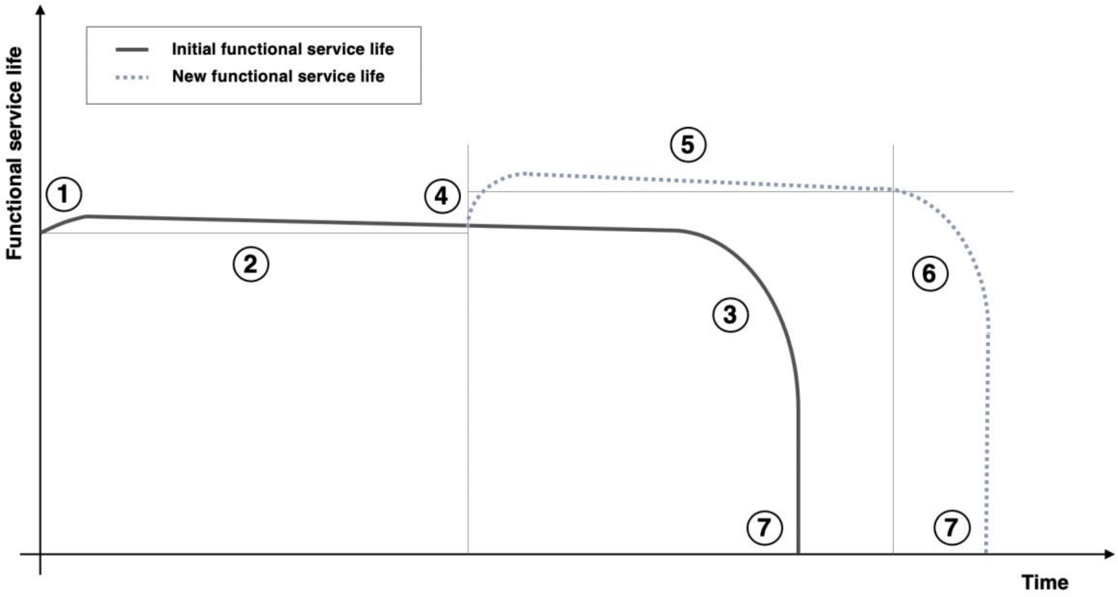

Figure 4.3. - Functional service life degradation, including an improvement in requirement levels, based on ISO15686-1: 2011

Functional life is referred to as the time until an asset must be replaced due to substandard functional (or operational) performance (Fitch et al., 1995). Under certain circumstances, it is possible to derive a relationship between physical or technical life and functional life of the asset: some indicators of the asset's functional or operational performance have a close link to its physical properties (Ford et al., 2011). The functional service life (FSL) of building becomes shorter than the technical service life (TSL), because the building is not functional anymore, while the building could technically function for a much longer time (Landman, 2016). The length of this functional service life depends on the reusability, flexibility, adaptability, among several other variables (Landman, 2016) (Figure 4.4.).

Blok and Teuffel (2014) developed an approach to quantify the end of the service life, considering ranges between 30 to 80 years. This variation was defined by changes in the requirements of new stakeholders of the building and developments in the building technology. These new requirements are normally reasons for a building to no longer meet the minimal requirements and achieve the end of its functional service life (Augenbroe and Park, 2005) (Figure 4.4.). Usually, the issues related to the functional service life of the buildings concerning demand or supply tend to be reciprocal between users' expectations and buildings functions, between functionality and serviceability. In Figure 4.4., some variables (adaptability, flexibility, efficiency, capacity, capability, availability, among others) associated with the functional degradation of buildings and building's components are grouped considering demand and supply.

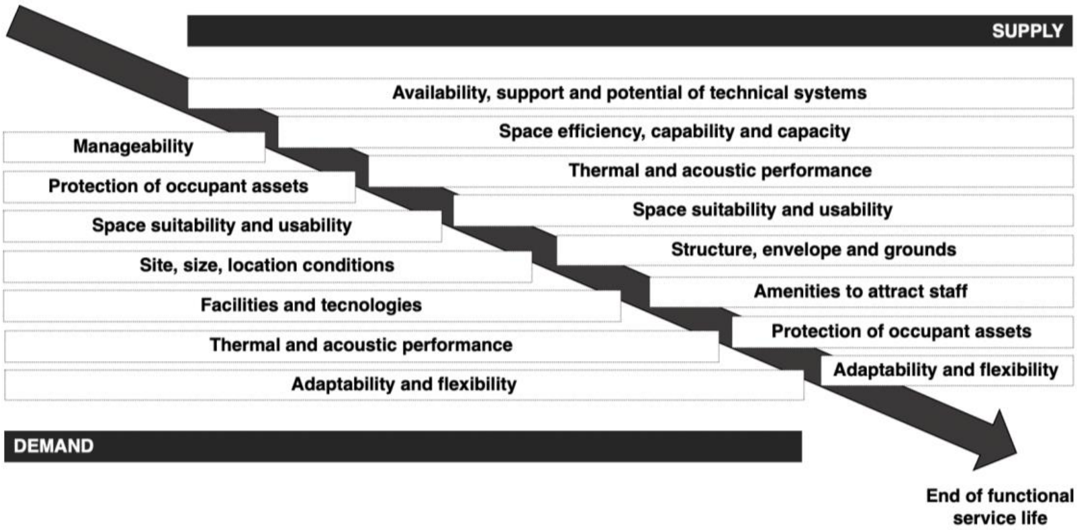

Figure 4.4. - Parameters in the definition of functional service life considering demand and supply of buildings and building' components

4.4. Concluding remarks

Even though there is a set of concepts standardized by the ISO15686-1 standard related to the field of functional service life and defining the end of the functional service life, there are still some ambiguities and uncertainties when defining an exact concept related to the definition of functional service life. Even though the regulations (ISO15686: 2011) are a clarifying framework of concepts, it would still be interesting to continue deepening the definition of the term based on quantitative approximations around the different countries. At present, the field of building performance analysis has only limited performance quantification approaches that are applicable across measurement, simulation, expert judgment, and user evaluation; further work in this area is needed to continue increasing the knowledge related to the definition of the end of functional service life, based on quantitative approximations around the different countries.

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Conceptualization of service life prediction

CIB W080 - Prediction of Service Life of Building Materials & Components

5. Technologic or technical service life

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5.1. Service life vs. Technological service life

The ‘Service Life’ is the “period of time after installation during which a facility or its component parts meet or exceed the performance requirements” (ISO 15686-1: 2011). This definition is based on the assumption that the facility or component is dismantled or taken out of service as soon as it does not meet the performance requirements anymore.

A broader definition of ‘Service life’ might be proposed: “Service life is the period of time from installation to dismantling of a component in the building”. This definition of service life allows the component to be in function for a longer period of time than formally allowed by performance requirements - a situation known of when buildings are overdue but still in service. In addition, this definition allows the service life to be ended when taking the component out of service for other reasons than performance requirements and when it still has some usability left.

The broader definition would also cover what would describe ‘technological service life’: the number of years during which the replacement of the building’s components is still available, and the end of the technological service life occurs by the replacement of more efficient technologies (Pourebrahimi et al., 2020). An example could be single glazing windows that might be fully functional, however replacement of frames is no longer possible as newer solutions with double or triple glazing has been developed due to sharpened requirements for energy performance. Technological service life is often associated with a preventive replacement policy, i.e. the replacement of the components occurs when they become inefficient technically (Dixon et al., 1999).

There might be a contradiction between striving of continuous maintenance of existing technologies and gradually upgrading to newer/newest technology. While this is well known for computers, mobile phones and similar products, this might be less obvious in the building sector, due to the long service life for most building components, often not designed to be replaced in a simple way. They have a long lifespan with minor variations in technology incorporated with time.

5.2. Technological and planned obsolescence

Technological service life is related to technological obsolescence and planned obsolescence. Technological obsolescence is usually associated to the components of the buildings and occurs due to technological advances and the introduction of new (and presumably better) technologies (Pourebrahimi et al., 2020).

The planned obsolescence is defined in economics and industrial design, as the practice of planning or designing a material or component with an artificially limited service life, so that it becomes obsolete (i.e. unfashionable, or no longer functional) after a certain period of time (Wuyts et al., 2019).

This strategy, of deliberately ensuring that the current version of a given product will become out of date, undesirable, or non-functional within a known time-period, guarantees that the users will need to replace their assets in the future, thus promoting the increase of the expected revenue and land value (den Hollander et al., 2017).

According to these definitions, planned obsolescence describes a deliberate policy or process to reach technological obsolescence. Depending on the context, planned obsolescence can be subdivided into a number of types, such as contrived durability (designing a product to deteriorate rapidly), prevention of repairs (the customer must purchase an entire new product after using them a single time), perceived obsolescence (change the styling of products so customers will purchase products more frequently), systemic planned obsolescence (altering the system in which a product is used to make its continued use difficult), software lock-out (making older versions of software unserviceable deliberately), legal obsolescence (e.g. governments wanting to increase electric vehicle ownership through purchase subsidies mechanisms), and smart obsolescence (deliberate attempt to make old devices more prone to malfunction or to decrease their performance based on an smart trigger).

Similarly, Zallio and Berry (2017) distinguished between different types of obsolescence, not using the exact same terms, but covering the same types. Based on a literature survey, the study concluded that the number of references has increased significant in the last 20 years, as planned obsolescence has become gradually a more normal part in manufacturer and industrial production. The study focused on electronic products and similar, not buildings nor building components.

Technological and planned obsolescence is normally connected to industrial design. Examples of planned obsolescence could be: unreliable parts in a product; software that makes a product fail after a period of time or a number of actions (e.g. a printer); software update incompatible with older devices; or clever marketing and an insignificant upgrade. The effects of technological obsolescence can sometimes be managed and mitigated through measures like cannibalized asset, spare parts inventory, knowledge of failure effects, and loss prevention strategies.

In terms of buildings, planned obsolescence often relates to the economic life of a building, i.e. whether it still makes a benefit for the user, fulfilling his need. That is why we see buildings deliberately being replaced by newer, higher, and beneficial buildings, although from a physical point of view they have not at all reached their service life (Akyurek and Ciravoğlu, 2017). However, the owner finds it attractive to replace the building, or is forced to do it, because nobody wants to rent (part of) the building. That might be due to the standard of the building compared to other buildings in the neighbourhood but might also be due to the neighbourhood becoming less attractive in general for living or running a business. Finally, buildings may also be torn down due to reorganising the infrastructure in a city. The lifetime of a building in this context is a function of the land value, the floor area ratio, the proximity to the centre of the city, the physical condition of the building, whether the building is registered as a historic/listed, and whether the owner or tenants use the building.

5.3. Obsolescence

Obsolescence in itself might be described as “the process of becoming obsolete”. Obsolescence occurs when a building is judged to be becoming less fit for purpose. (Garnett, 2006) or the loss in the utility of component not due to physical deterioration, but other factors such as the development of improved or superior technology (Pourebrahimi et al., 2020). Obsolescence arises as a result of a variety of factors, such as physical aging, new codes and standards, new products, or planned obsolescence.

“It is the desire to avoid obsolescence that acts as a motivating force to maintain, repair, improve, modernise, and renew buildings. Some of this work is reactive, but much needs to be planned for. It is decisions about how to plan for future works that pose particular problems of appraisal. Although the future is full of uncertainties, a ‘sustainable’ maintenance and renewal strategy necessarily needs to be based on judgements about future demands and costs. It is the capacity of a building to function in the interests of its owners or users that determines its ‘suitability’ and thus its value. This means that obsolescence is a relative and not an absolute concept. The degree of obsolescence is always relative to the distinctive interests and proprietary plans of identifiable people or organisations” (Garnett, 2006).

Based on literature studies and conversations with practitioners and consultants in various sectors of the built environment industry, it is observed that the term 'obsolescence' is scarcely used or comprehended with its diverse implications (Butt et al., 2015). In the context of climate change impacts, this term is even more uncommon. Butt et al. (2015) describe the implications of the term in the form of definitions and types of obsolescence from various perspectives, including the built environment and climate change. The study also briefly explains that obsolescence is a multi-faceted entity and the comprehension of its concept and implications can help to effectively manage the built environment in a sustainable manner, particularly to the face of climate change.

5.4. How to define the end of technological service life

In principle, the end of technological service life emerges when the technology becomes outdated. Depending on the type of product, this might take place long before the physical service life has ended, as shown by the example with computers and mobile phones. Mobile phones become outdated when a new generation of network is introduced. As a result, in most homes several mobile phones are stored away, no longer used, as they have less features than newer mobile phones. Their physical service life has not ended, but the technological in most cases has.

For computers, mobile phones, cars, or fashion it is normal to present new models quite often, containing new technology, features or similar, making them “better”. Or to build/fabricate the product not to last that long, expecting that they might have become old fashioned in the meantime, or simply to sell more products of this type - but this is probably not related to ‘technological service life’, rather ‘functional service life’. This is based on an assumption by the producers that they can sell enough new products to pay for their development.

Normally, buildings are built to last (for long), which seen from a purely sustainable point of view might be good, as production of most building materials is energy consuming. However, how long they should last can be discussed, as our needs and expectations change over time, i.e. it could be relevant to include planned obsolescence (Section 2.5.2) or reconsider the design of buildings. Using concrete, brick and similar materials that last for a long time and not easy to take apart (e.g. brick masonry) makes it costly to break down buildings if we consider that “better” methods or design exist that contains more features.

If the development in the building sector were similar to the one for computers, cars, etc., then we should replace buildings from time to time when “better” ways to design or build, or “better” products are developed, e.g. containing new/more features. Features could be built-in sensors making it possible to monitor the hygrothermal conditions inside the constructions, to reveal if hidden installations leak, etc. Or we should use biodegradable products for construction of houses or in other ways design houses to have a short physical service life, expecting that they are not feasible anymore after that time. The last example might be the case for some specific types of building, built with a specific purpose, e.g. containing apartments for students placed in an area of a town not yet fully developed to host permanent buildings, covering an urgent need for small, simple buildings.

From time to time, it is discussed whether buildings should be designed to last no more than e.g. 20 or 30 years, instead of 100+ years, as our needs change, e.g. today many people live alone. Seen from a sustainable point of view, buildings that last for long without being sufficiently flexible might not be the optimal solution. Another example is hospitals where reconstruction seems to be an ongoing process as needs for other types of rooms change when new kinds of treatment emerge. In addition, tiny houses are becoming more popular, as exemplified in Figure 5.1.

Figure 5.1. - Tiny houses, seen from outside (businessinsider.com at left) and from inside (treehugger.com at right); copyright might restrict the use

There might be a mix of functional service life and technological service life when considering a building no longer being used, due to not being fully updated e.g. with elevators, installations for heating/cooling and ventilation, and/or not fitted for modern use due to the size and location of rooms. Of course, another reason for not using the building might be the location. Many buildings are kept (not torn down) although they have not been occupied for a long time, simply because no one wants to put up another building instead. Increasing awareness of sustainability further complicates this. Does it mean that we are reluctant to tear down buildings that in principle are OK, but are not used anymore?

Moreover, how do we consider a building without e.g. an elevator, not being possible to include, unless parts of the building must be taken apart? Has the technological service life ended? The building as such has survived for many years without an elevator but might not live up to expectations of present (potential) users.

5.4.1. Examples of the end of technological service life

Some examples to show the end of technological service life; they might not all fully relate to technological service life, but also functional or aesthetic aspects. Further, they are written in a Danish context and may not fit in other countries.

Example 1 - Windows

Many houses still have old windows with only one layer of glass, but in many cases secondary glazing or an inner sash is added as a way to improve the energy efficiency and reducing draught without replacing the original windows. This of course assumes that the original windows are in technically acceptable conditions, but even if they are ready to be replaced, such an improvement might be relevant to keep the external appearance of the windows, instead of replacing the original design with modern double-glazing windows. During the 1970s, 80s and 90s (until around 1995), wooden frame windows (at least in Denmark) were produced with low quality wood and painted with very diffusion-tight paint. As the design and way of production was not changed, this should be regarded as a reduction of the expected physical service life, rather than a change of technological service life, however showing that the different types of service life might not be so easy to distinguish.

In those cases where windows with original single glazing were supplemented with either secondary glazing or an inner sash, is that an expression of the original windows having reached their end-of-life (draught, high U-value)? Later this solution was replaced by energy glazing, although people typically did not replace the windows until they found that the existing windows were no longer acceptable; they were not replaced simply because new types of windows were available.

Example 2 - Roof tiles

Roof tiles were previously torched, later it became normal to install/use roofing underlay (plates or membranes), as this made it easier to maintain the roof, although many products with a short service life were developed and used until a classification system was introduced (in Denmark, www.duko.dk).

Example 3 - Toilets

Toilets were previously placed outside the apartments in multi-storey buildings (due to how human excrement was disposed of), and although they might work today as well (and does in many less developed countries), they have been replaced by toilets within the apartment. This took place when suitable installations were developed/designed, although it often was difficult to find a place for the toilet in existing apartments. The same story goes for introduction of bathrooms instead of washing taking place at the kitchen sink or in a public bath.

Example 4 - Stoves

Stoves heating e.g. with coal (the stove placed in the living room, and space in the basement for storing coal) was quite normal in Denmark from about 1850 (Figure 5.2.). Later they were replaced by oil-fired boilers, later replaced by natural gas or district heating. All the technologies might have worked for additional years after being replaced, however they were less efficient, less environmental-friendly, and eventually worse for the working environment than the new ones.

Figure 5.2. - Stove from late 19th century, no longer in use (bukowskis.com; copyright might restrict the use)

Example 5 - Fire alarm control panel

Building owners decided to replace the fire alarm control panel because replacement parts could no longer be procured. It was deemed too high a risk to wait until functional failure, which would have necessitated a fire watch.

Example 6 - Enforcement by law

In a few cases, retroactively laws were introduced, i.e. not only to be followed in new buildings or at renovation but also to be met for all existing buildings within a certain time. This typically has to do with safety, e.g. lowering the risk of spread of fire or failed electrical installations, but other reasons are seen as well. Three examples from Denmark:

1) In 1935, a law enforced all apartments to have flush toilets, or access to one (two or more apartments might share a toilet, e.g. accessed from the backstairs);
2) Around 1980 all existing buildings (esp. multi-storey buildings) had to upgrade the fire resistance (limit spread of fire and ease the evacuation of persons), e.g. by adding plates to doors separating the apartment and a staircase, especially the backstairs in buildings with wooden constructions, and by adding plates underneath staircases;

3) From July 1, 2008, all sockets should be connected to a RCCB (residual current circuit breaker) or similar.

The society might also impose requirements to hospitals or care homes that could result in changes that might require replacement of components not necessary met the end of their physical service life.

5.5. Concluding remarks

Many of the technologies of modern facilities, as well as the activities they shelter and support, have changed substantially in recent decades and are continuing to change. These changes lead to rising expectations about the services and amenities a facility should provide. Rising expectations can effectively shorten the lifetime of a facility and are the essential characteristics of obsolescence. Obsolescence reflects changed expectations regarding the shelter, function, comfort, profitability, or other dimension of performance a facility is expected to provide (Iselin and Lemer, 1993). Facilities can be programmed, designed, and operated to be robust, to be able to accommodate change without substantial loss of performance capability. Experience shows that facility designers and owners can improve their ability to forestall or avoid obsolescence by taking a number of actions in the building process, especially during design/programming and procurement.

Seen in the context of the continuous development of new types of units outperforming the old versions, different strategies for maintenance and replacement were studied by Clavareau and Labeau (2009): 1) to maintain all components at constant time intervals, 2) to repair individual components when they fail, 3) to replace a component when it fails (corrective replacement), or 4) to replace all components preventively, i.e. in a station when most of the components still function. Preventive replacement might be relevant in some cases, as new equipment often performs better in terms of lower failure rate, lower energy consumption, a lower purchase cost, etc. The question is in which cases. For instance, strategy 3) includes the risk that it becomes difficult and costly to find spare parts, compared to strategy 4). The effective age model was used to model the effects of these interventions. The effective age is different from the calendar working time of the unit; it represents an equivalent working time of the unit, given the different interventions it has undergone. The model is further detailed and validated in the paper, involving Monte Carlo simulations.

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6. Social, aesthetic, and legal obsolescence

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6.1. The obsolescence of buildings and components

The deterioration of buildings and components begins from the moment they are built, leading to a progressive loss of performance. Therefore, buildings are increasingly unable to fulfil the users' needs, requirements, and expectations, until they become obsolete (Gaspar and de Brito, 2005). Thomsen and Flier (2011b) refer that obsolescence is a serious threat for the built park, but questioned the meaning of obsolescence, since the term 'obsolete' is used in a generalised manner to describe all types of buildings' depreciation.

Various authors (Mansfield and Pinder, 2008; Thomsen and Flier, 2011a; Grover and Grover, 2015) define the obsolescence of buildings as the loss of performance, utility, values or suitability, either due to physical deterioration, technological developments, political changes, economic or/and social reasons and alterations in users' and stakeholders' demands (Mansfield, 2000; Pourebrahimi et al., 2020). According to Burton (1933), the usefulness of buildings and their components may be compromised by several factors beside their physical deterioration, referring that the action of these other factors in reducing the usefulness of buildings can be defined as obsolescence.

The concept of obsolescence can be difficult to define, since buildings and components can become obsolete due to a large variety of reasons, which usually overlap each other (Reed and Warren-Myers, 2010), making it possible to find common causes between different types of obsolescence.

After being considered 'obsolete', buildings and components are usually subjected to maintenance, rehabilitation, or replacement/demolishing. The decision to intervene is frequently grouped into predictable and unpredictable factors; while the physical deterioration can be seen as a foreseeable or quantifiable reason, social and legal factors are more difficult or even impossible to predict in the long-term (Marteinsson, 1999).

According to ISO 15686-3 (2011), the social and legal service life of a building or component corresponds to the period of time after installation until human wishes or legal requirements determine their replacement, for reasons other than economic criteria. Marteinsson (2005) refers that the requirements to establish the end of service life can, and probably will, change during the service time of the building, which implies that the building can become obsolete due to changes in performance requirements before its technical service life expires. Therefore, the concept of social and legal service life can be subjective and variable between different authors. In this sense, the next sections present a conceptual discussion, and several examples are provided on how social, aesthetic, and legal reasons can influence the buildings' end of service life.

6.2. Social obsolescence

The concept of social obsolescence is described by different authors (Forster-Kraus et al., 2009; Rodi et al., 2015) as the decrease of the usefulness or serviceability of a building or component due to societal changes based on an individual or collective sense of taste.

Burton (1933) defined obsolescence as “social deterioration”. A building or component can be “as good as new”, but either way be discarded, typically long before it reaches unacceptable degradation levels, merely because more advanced, and presumably better solutions are available (BRB, 1993; Pinder and Wilkinson, 2000).

The buildings’ performance and their capability to fulfil the users’ demands varies over time, as social and political changes take place (Ohemeng and Mole, 1996). Each building faces an increasing process of obsolescence, showing a declining capability to meet the varying and rising expectations of users through time (Bryson, 1997). In this sense, Douglas (2006) refer that the social obsolescence can occur due to changes in the expectancy levels, which are influenced by personal experience and needs.

Other dimension of social obsolescence is cultural obsolescence, which is related with local traditions, cultural values, the users’ lifestyle and working conditions (Sarja, 2006). The social obsolescence is thus related with the social variability of the cultural context of the building, which is variable at global, regional, and local levels. Specifically, what is acceptable, or the acceptance criteria, vary from country to country, within the same country and even from neighbourhood to neighbourhood. For instance, large-scale social housing frequently shows low standards in construction levels, to avoid pushing up costs, thus reducing the quality, comfort, and durability of the buildings (Power, 2008). However, in this situation, most tenants show lower levels of demand, which can lead to higher service lives than high quality buildings with more demanding owners.

Williams (1986) refers to the social obsolescence in a broader sense, using the definition of ‘community obsolescence’ to describe the loss of capability of a building to fulfil the users’ requirements due to local conflicts of interest arising from the use of a building. Nevertheless, the author mentioned that obsolescence is a relative concept, since a building may be obsolete according to a give user’s requirements or for a specific use, but still present a high level of utility for other users or for alternative uses.

Generically, social, cultural, and community obsolescence is established by social trends, which usually occur due to shifting in (Sarja, 2010; Pourebrahimi et al., 2020): social tastes and demands; constructive traditions; users’ life style; business culture; social perceptions; collective preferences; individual/private preferences (willingness-to-pay or to accept a given performance condition); social role of housing and the causal relations with family, facilities, schools, transport and jobs; proximity to familiar landmarks; neighbourhood identity and local culture; among others.

6.2.1. End of service life due to social and cultural reasons

According to Preiser and Vischer (2005), the reasons beyond users carrying on rehabilitation and maintenance actions are, in decreasing order of relevance: health; safety in use; functionality; psychological issues; social issues; and aesthetics. Even though, the users acknowledge the relevance of avoiding the progression of physical deterioration, they present a low sensitivity to this problem, and it is very difficult to define what reasonable acceptance criteria are. Usually, users’ claims are only made at advanced degradation levels, when the buildings safety may be already compromised (Flores-Colen et al., 2010). Users thus tend to define the need for intervention based on subjective criteria and individual perceptions.

Even though practitioners believe that buildings can last a long time, in practice several studies show that the buildings' service life can be significantly shorter than their theoretical or design service life (O'Connor, 2004). In some situations, social motivations may dictate the demolition and reconstruction of a whole neighbourhood. An example is the Quattrograna West District at Avellino (in Italy), where the municipal government decided to demolish the original buildings (after an earthquake), ignoring the buildings' physical condition or deterioration. The reasons beyond rebuilding the district are the response to users' needs, in order to promote social cohesion and the living comfort of the inhabitants (Marino, 2006, 2008).

But the demolition and reconstruction of buildings has numerous disadvantages, namely from an environmental point of view, due to the production and deposition of waste, but also from a political and social point of view, since rehousing the inhabitants also entails inevitable social problems, e.g. the payment of demolition subsidies and guaranteeing alternative housing for those displaced (Power, 2008).

In this sense, in several occasions, a building may have reached the end of its service life, due to social and comfort issues (e.g. living standards and/or energy performance of buildings), but owners continue to use it, without carrying out any rehabilitation actions, due to economic issues (e.g. the return of the initial investment) (Farahani et al., 2019). In reality, the decisional power of the different stakeholders varies significantly. Usually, investors are mainly concerned with economic goals, which may be far from the users' social benefit or other cultural values. A survey performed to housing associations regarding their demolition plans and motives raised a suspicion that a secret agenda may be behind the decision to intervene. Above criteria related to the building's technical/physical and functional performance, owners may be interested in demolishing and/or rehabilitating their assets due to the disposal of unwanted tenants and redevelopment of attractive locations (van der Flier and Thomsen, 2006).

6.3. Aesthetic obsolescence

Aesthetic obsolescence is perhaps the most difficult concept to define and practically impossible to model. Different terms can be used to define aesthetic obsolescence. Various authors (Dunse and Jones, 2005; Remøy, 2010; Wilkinson et al., 2014) refer that visual obsolescence and aesthetic obsolescence are similar concepts, related with an outdated or old-fashioned appearance of a building or its components. Other authors (Flanagan et al., 1989; Ashworth, 2004; Grover and Grover, 2015; Johnston, 2016) correlate the concept of aesthetic obsolescence with changes is style, fashion, image, or stylistic attributes of a building. The concept of aesthetic obsolescence is also usually related with changes in architectural styles (Douglas, 2006).

According to Pourebrahimi et al. (2020), changes in fashion, style and aesthetic values are inevitable since a building that once was considered attractive may now be considered unpleasant. These changes tend to stipulate new requirements regarding the buildings' appearance or material choices (Marteinsson, 2005).

The recognition and definition of 'aesthetic obsolescence' by different stakeholders is subjected to considerable subjectivity and personal prejudice. In a broader sense, aesthetic obsolescence occurs when, even maintaining an adequate functionality and serviceability, the building becomes obsolete because the users consider that it no longer fits popular fashion or its style is antiquated (Wilkinson et al., 2014).

6.3.1. End of service life due to aesthetic obsolescence

More than would be desirable, the replacement of a given element occurs due to aesthetics reasons, regardless of the technical performance of the element under analysis. Even if the end of the service life occurs due to the physical degradation of the buildings, the moment in which it occurs is often conditioned by architectonic and aesthetic points of view. Alaimo and Accurso (2008) refer that there is a close relationship between carrying out maintenance actions, especially those carried out based on the aesthetic appearance of buildings, and the social and urban environment in which the buildings are included.

One extreme example in which the end of service life occurred abruptly, due to aesthetic, architectural and social criteria is the Gillender Building, which was built in 1897 and demolished in 1910, to make way for a larger skyscraper. Abramson (2016) mentioned several examples of "speedy obsolescence" all over the United States and especially in New York (e.g., the Grand Central Terminal, the Plaza Hotel, the Western Union Building, among others); the author refers that this type of obsolescence became endemic in American downtowns in the 1910s due to architectural obsolescence, associated with cultural and economic factors. Nonetheless, other examples can be found worldwide. A study performed on residential buildings in the U.K. found that 46% of the buildings are demolished after 11 to 32 years (DTZ Pieda Consulting, 2000). In Japan, the office buildings usually present an estimated service life between 23 and 41 years (Yashiro et al., 1990).

The end of the service life of non-structural buildings components, such as interior walls and floors, is frequently conditioned by changes in the demographics, i.e., the users' demands vary along their life, and style and fashion are a matter of time. Therefore, a building component may comply with senior owners' expectations, while the change of owners to younger generations can lead to the end of the service life of some building elements (e.g., the use of carpets as coating system).

An example where, generally, the renovation and replacement of building elements occurs due to aesthetic and fashion criteria, is hotels. According to the International Society of Hospitality Consultants (ISHC, 2015), hotel renewals usually occurs every 5 to 7 years, long before they have reached their physical or functional service life.

6.4. Legal obsolescence

The legal obsolescence occurs due to changes in standards and legislation (Reed and Warren-Myers, 2010). The building and their components are designed in order to fulfil existing standards. However, over time, when new building regulations are proposed and made mandatory, the buildings might become legally obsolete, requiring intervention, maintenance or replacement of their components, in order to comply with new standards (Reed and Warren-Myers, 2010; Teo and Lin, 2010).

Various authors (Nutt et al., 1976; Raftery, 1991) refer to legal obsolescence as 'control obsolescence', mentioning that this type of obsolescence occurs due to changes in the regulating instruments that control the buildings' design and rehabilitation.

Other dimension of legal obsolescence is 'political obsolescence', which occurs due to changes in public interests and the local community (Wilkinson et al., 2014). Pourebrahimi et al. (2020) refer that 'political obsolescence' overlaps the concept of 'social obsolescence', but instead of dealing with subjective concepts, political obsolescence is translated into regulatory principles, and therefore it is usually considered as legal obsolescence. Williams (1986) described legal obsolescence as 'statutory obsolescence', but the definition is similar, i.e. the building becomes obsolete due to its inability to fulfil statutory requirements.

6.4.1. End of service life due to legal obsolescence

The service life of a building and component can be influenced by legal reasons, every so often related with economic and cultural factors. The performance requirements that should be met or exceed during the building's service life can be defined by national building codes and/or owners' demands. The requirements prescribed in standards or codes are usually related with safety issues, while the owners' demands are rather subjective, and usually related with economic or aesthetic motivations (Hed, 1998).

New regulations and new urban development plans and policies can also motivate the end of the service life of buildings (Dias, 2003; Fu et al., 2013). For example, the end of the legal service life can be reached due to new regulations regarding the fire safety or when the building presents materials that are not allowed anymore (e.g., asbestos).

The changing users' demands would be expected to lead to the end of service life of buildings and components. Nevertheless, several reasons can lead to postponing the end of service life of buildings, involving significant maintenance and repair costs (Rauf and Crawford, 2015). The service life can be extended due to political changes or enforced regulatory changes, for example, when a heritage classification is awarded to a building (Kincaid, 2000). In other occasions, the demolition and reconstruction of buildings may force the owners to comply with new and stricter regulations for new construction, which usually imply exceeding the building's service life beyond what would be considered as "acceptable" in current conditions (Dias, 2013).

6.5. Concluding remarks

The buildings' obsolescence can be dictated by different factors as the nature of the buildings and their users, organisational and social changes, fashion responses, individual and community perceptions, legal and political interests, among other parameters. In this section of the report, the concepts of social, aesthetic, and legal obsolescence are described, referring to the different approaches present in the literature. Although different authors present different concepts and terminology, it seems to be almost consensual that the criteria that dictate the obsolescence of buildings are not easy to establish unequivocally, mainly due to the dynamic nature of change in society and the difficulty in constantly meeting performance requirements that are continually changing.

The service life of buildings is not limited by its physical deterioration or functional loss of performance. In fact, the service life can be interminably prolonged, as long as the building continues to be useful, considering social and cultural criteria, or even emotional ties. However, in the opposite way, the end of service life can also occur abruptly, also due to the same reasons or due to legal constraints, when a supposedly better alternative is found. This section of the report describes some examples of how social, aesthetic, and legal factors condition the end of the buildings' service life, describing some real examples, where these factors overlapped the physical and functional service life of buildings.

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7. Environmental service life

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7.1. Service life of building materials and components

The service life of a building can be considered as "the period of time in which a building is in use" (Rauf and Crawford, 2015). In relation to buildings and components, ISO 15686-1: 2011 states that the service life is the "period of time after installation during which a facility or its component parts meet or exceed the performance requirements". Building materials, just like buildings themselves, have an estimated service life, but there are factors internal and external to the building that can result in different service life lengths.

This chapter is concerned with environmental service life. As will be discussed, the term environmental does not lend itself to a clear definition of service life. This is because buildings and components exist within both the built environment, and the natural environment. In turn, this leads to multiple causes of end of service life, which could all be considered environmental: ranging from a building being in an economically unviable geographic location, to components of buildings becoming legally unusable from an ecological perspective.

7.2. Defining environmental service life

The environmental service life of buildings has been defined in Wilkinson et al. (2014) as "the time span after which demolition and reconstruction becomes environmentally more favourable than adaptation and reuse". This can be adapted to building components by stating that their environmental service life continues as long as replacement is less 'environmentally favourable' compared to retaining them in the structure of a building. However, this leads to ambiguity because the word 'environment' can have several meanings. The biggest scope for ambiguity comes when referring to either the built environment or the natural environment and these interpretations are discussed further below.

As a possible definition, environmental service life could be defined as "the period of time after which a building component is replaced as a result of either: the state of the surrounding built environment; or the component itself having a prohibitively adverse effect on the natural environment".

7.2.1. Environmental obsolescence vs environmental service life

The two main processes leading to decreased utility of a building or its components, causing the end of service life in general, are physical deterioration and obsolescence. Physical deterioration is "an absolute decline in utility resulting from usage, wear and tear and the action of the elements" (Mansfield and Pinder, 2008). Obsolescence, being the "decline or loss of utility of an object, building or product" (Pourebrahimi et al., 2020), is not directly related to use, the action of elements, or the passage of time and is a phenomenon causing service life to end prematurely, often regardless of a building's

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performance (Grover and Grover, 2015). This indicates that the object becoming obsolete may still be in working condition, but is no longer in demand, causing it to be replaced or removed (Butt et al., 2014). Physical degradation is able to be predicted with reasonable accuracy using calculations and models, based on historic records, because it is a continuous process. Obsolescence, on the other hand, is unpredictable because it is age-independent and occurs at irregular intervals (Sarja, 2005) (Mansfield and Pinder, 2008). While physical degradation is dependent on weather and climate conditions, obsolescence (and in this case environmental obsolescence) can be caused by a wider range of factors.

Studies have often discussed and defined environmental obsolescence rather than environmental service life. Table 7.1. shows various definitions of environmental obsolescence.

Table 7.1. Various definitions of environmental obsolescence from the literature

Definition	Source
The physical deterioration of a "building's surroundings, such as other buildings, the infrastructure or the location's amenities"	Buitelaar *et al.* (2020)
It "relates to conditions in the surrounding area and that these may cause the property to be unfit for its current use"	Hughes and Jackson (2014)
Occurs when "the location or the building becomes obsolete due to an external factor"	Grover and Grover (2015)
Occurs when "the conditions of the neighbourhood are inappropriate for current usage patterns"	Pourebrahimi *et al.* (2020)
"An external correlated factor which operates to render a location or the buildings obsolete. This can arise from changes such as in the present and future characteristics of a locality, national and local planning policies"	Bowie (1984)
"The time span after which demolition and reconstruction becomes environmentally more favourable than adaptation and reuse". "Environmental obsolescence is on the one side defined by changing building rules. On the other hand, changing trends and office user preferences for sustainable buildings"	Wilkinson *et al.* (2014)
"when the conditions in a neighbourhood render it [the building] increasingly unfit for its present usage patterns"	Blakstad (2001)

The definitions in Table 8.1. show that environmental obsolescence is principally caused by external changes - either to a building's surroundings or to policies - which affect the utility of buildings. Therefore, environmental service life also depends on these changes. One aspect to note is that changes to the surroundings affect entire buildings, while policy changes can affect the service life of individual materials and components as well.

Pourebrahimi et al. (2020) classifies 33 types of building obsolescence into 10 distinct categories. In that work, environmental obsolescence appears as a type under the category of locational obsolescence and as its own category, containing ecological obsolescence as a type. In the latter case, ecological obsolescence is associated with having an unacceptable effect on the natural environment. If Table 8.1. and Pourebrahimi et al. (2020) are taken as representative of the literature, the most common use of the term environmental when discussing obsolescence is when referring to locational factors rather than ecological factors.

In line with Pourebrahimi et al. (2020), the main factors that are associated with environmental service life are locational and ecological. With respect to locational factors, environment refers to the location of the building within the built environment. The built environment has been defined by Kaklauskas and Gudauskas (2016) as that which "encompasses places and spaces created or modified by people including buildings, parks, and transportation systems". Locational/Environmental obsolescence therefore depends on the state of the surrounding built environment, such as infrastructure, amenities, and deterioration of the neighbourhood. This leads to building devaluation, further linking to economic obsolescence (Mansfield and Pinder, 2008; Hughes and Jackson, 2014; Pourebrahimi et al., 2020).

With reference to the natural environment as opposed to the built environment, whilst Pourebrahimi et al. (2020) classify environmental or ecological obsolescence as a distinct 'category', Butt et al. (2015) names climate change obsolescence as a category. In ecological obsolescence, building components may become obsolete and be replaced if their waste, emissions and/or pollution production cannot be reduced (Sarja, 2006). Climate change has a slightly different influence on buildings and their components by accelerating their physical degradation, rather than causing obsolescence (Butt et al., 2015). Both processes, however, bring about the end of service life more rapidly than is expected. The increasing awareness of environmental issues has also created new policies and technologies for their mitigation, linking the ecological component of environmental service life to legal and technological obsolescence. Ecological/Environmental service life is therefore dependent on the impact of a building component on the natural environment, or vice versa, the impact of changes in the natural environment on the state of the building component.

7.3. Causes of the end of environmental service life

A study by Sarja (2005) states that Ecological/Environmental obsolescence (of a building) occurs due to "the inability of a facility to fulfil the increasing ecological and environmental requirements of the society, regarding to energy consumption, pollution, raw materials consumption, waste production or loss of biodiversity or geodiversity". This includes the inability to comply with emissions limits, or hazardous materials in its structure, such as asbestos, and a lack of passive heating and cooling systems (Pourebrahimi et al., 2020) (Grover & Grover, 2015).

(Buitelaar et al., 2020) discuss causes of Locational/Environmental obsolescence when the location of a building can become less desirable because of changes in planning policies, deterioration of the quality of surroundings, decreased accessibility, unattractive neighbouring buildings, and unsuitable amenities and infrastructure.

There is also an intersection between locational and ecological aspects when a drop in demand for a location is caused by ecological concerns. According to Mansfield & Pinder (2008), additional causes for end of environmental service life in the context of sustainability are:

- Construction work associated with new developments:
  - loss of visual amenity;
  - closure of access;

    - use of the works:
        - nuisances such as noise, dust, vibration, smell, fumes and smoke;
- Substances or radiation that are hazardous to health;
- Erection of high voltage overhead transmission lines) or other telecommunication masts;
- Contamination of land;
- Proximity of nuclear power plants or other unattractive uses;
- Failure to receive planning permission for development;
- Properties being "by-passed" by improvements which shift values to other locations.

7.4. Concluding remarks

When discussing end of service life, it can be seen that we are again faced with the fact that the word environmental has multiple meanings. In addition, Locational/Environmental service life and Ecological/Environmental service life invariably overlap with different types of service life, such as economic, legal, technological, and functional. For example, the proposed phasing out of gas boilers in the UK (Prime Minister's Office, 2020) is aimed at reducing the environmental impact of buildings. As a result of the policy changes involved, this could be considered as a legal service life, because the changes will come into law; a technological service life, because the boilers are intended to be replaced with more environmentally-friendly systems; or an environmental service life, because the underlying reason for change was an ecological concern.

Service life, in a general sense, is an important concept when performing an environmental impact assessment of a building, but the bringing about of end of service life due to a pure Environmental/Ecological reason would be quite uncommon. Instead the direct cause of end of service life is more likely to be another dominant factor e.g., for economic, technological, or functional reasons.

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8. Service life and the cause-effect processes underlying ageing and decay: a discussion

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8.1. Definitions and approach

After a century of unprecedented growth of populations, new mass construction and built-up areas, the last decades came with the stern wave of ageing and decay and a subsequent growing interest in maintenance and rehabilitation. This concern is followed by a wave of associated publications and new terms arise. Similar terms not always have the same meaning and, often, different terms present the same meaning. Also, regarding life cycle and life span, two different research practices have emerged, stock management and life cycle analysis (LCA), with also different interests, terms, meanings, and connotations.

To circumvent possible confusion, the following definitions are at first - but not without criticism - derived from available ISO standards, in particular ISO 15686-1 (ISO, 2000), more particular the underlying vocabulary in ISO 6707-1 (ISO, 1997). Where not stated otherwise, the definitions regard-built artefacts, buildings, building parts and materials.

8.2. What is service life?

The life span of buildings can be divided in the real life - or its physical existence -, and the service life - the period of ability to fulfil the function for which it is built (Awano, 2006).

ISO 15686-1 (2011) defines the term service life as “the period of time after installation during which a facility or its component parts meet or exceed the performance requirements”.

8.3. What is the end of service life?

Although not separately defined in ISO 15686-1 (2000), the end of service life is - in line with the definition above - the moment after which a facility or its component parts does not meet the performance requirements, e.g. the ability to fulfil its functions. It should be noted that this moment is a normative abstraction, as without consequent human intervention the building or component may physically survive till it collapses.

8.4. What is obsolescence?

ISO 15686-1 (2000) defines obsolescence as “loss of ability of an item to perform satisfactorily due to changes in performance requirements”. These changes are further defined in three types of obsolescence: Functional, Technological and Economic obsolescence, typically described as respectively “Function no longer required”; “Better performance available from modern alternatives” and/or “Changing pattern of building use”; and “Fully functional but less efficient” and/or “more expensive than alternatives”. Apart of the inconsistent distinction between the as functional labelled no longer required functions and as technologic labelled changing building use - the underlying sources and/or considerations are not presented, and the term is missing from ISO 67071-1 - this trichotomy is somewhat outdated.

8.5. What is economic obsolescence?

Before redefining economic obsolescence, it should be questioned why and on what basis further specification of obsolescence is required.

To understand obsolescence as major cause of ageing and decay of built artefacts, more recent studies indicate that the importance of the various underlying interrelated sequences of cause-effect processes (Thomsen and van der Flier, 2011; Nieboer et al., 2014, Grover and Grover, 2015; Pourebrahimi et al., 2020). Physical effects - as inadequate maintenance - usually have behavioural causes - neglection - that result in behavioural effects as declining appreciation and declining economic market value, which at their turn will result in physical decay, run down functionality as well as economic instability and, if not cured in time, eventually, to the end of service life and physical existence. Consequently, limited cause or effect-oriented classifications do not contribute to problem-oriented insight in the underlying processes and solution-oriented research of ageing and decay of buildings and the built environment. If nevertheless a definition of economic obsolescence is desired, it should be the “loss of ability of an item to perform satisfactorily due to changes in performance requirements caused by and/or resulting in loss of economic performance/qualities”.

8.6. What defines the economic obsolescence driven end of service life?

In line with the above, economic obsolescence driven end of service life be defined as “the moment that a building or its component parts does not meet the performance requirements, i.e. the ability to fulfil its function due to loss of economic performance/ qualities”.

The target issue of this chapter is how to define, determine and predict this moment.

The loss of economic performance can have a wide range of causal processes. Buildings are men made and men ended artefacts. The end of service life of buildings and building parts is not a matter of more or less autonomous physical decay - as some techies like to think - but of human behaviour, in particular of the property owner/ manager. The most frequent motive for the demolition of residential property has not primarily to do with the quality of the building but with the value of the land; demolition arises when the land price for new construction is higher than the value of the property (Thomsen and van der Flier, 2009). On the second place, follows the investment costs of renovation being higher than replacement by new construction, though the underlying comparison - if done at all - is most often biased by hidden prejudices and/or interests. Our research findings also show the decisive importance of factors as building type, ownership/tenure and location/market conditions - not included in the lay out! -, and systematically neglected in most LCA studies. For example, though the design quality and maintenance of two single family row-houses may be exactly the same, the average service life prediction of the social rented one may be less than 50 years whereas the owner-occupied one may last almost endlessly till the moment that all the owners commonly decide.

The conceptualization of service life prediction of separate buildings and incorporated building parts seems all together a mission impossible. Service life prediction will in practice only be feasible on the level of large-scale aggregated data. To what extent prediction of separate potential end of life causes as economic driven obsolescence will be useful - if feasible at all - is questionable.

The question is then: what kind of aggregation, for which purpose? LCA analyses, more often directed at the level of (accumulated) building parts, require different data and approaches than stock management and policy analyses. As the first is generally directed at the level of (accumulated) building parts and materials, the role of building type and tenure are of less importance, but location and climate do matter.

And last but not least: What is then the meaning of distinguishing physical, functional, design based, technologic, social, legal and environmental service life, and economic and aesthetic obsolescence?

8.7. Cause-effect chains in the definition of economic obsolescence

Figure 8.1. shows a more cause-effect oriented approach for the definition of economic obsolescence, based on the two main cause-effect dimensions of obsolescence: endogen vs. exogen on the one axis and physical vs. behavioural on the other, further elaborated in Figure 8.2. Obsolescence stands in this context for general decay processes, in contrast to incidents like fire, collapse, flooding, earthquake, among others.

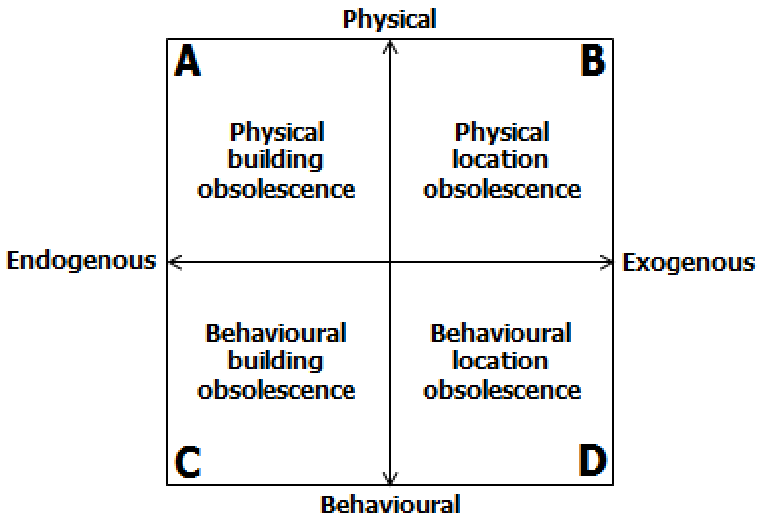

Figure 8.1. - Obsolescence, extended analytical model

The model is based on the hypothesis that the core dynamics of obsolescence consists of a series of complex recurrent and intertwined cause-effect processes at different levels of scale within and in between the four quadrants of the model, resulting in the eventual performance decline of buildings.

Though these cause-effect chains are fundamental for all kind of disease, ageing and decay processes, systematic interdisciplinary research has been limited up to now to specialized fields as in particular state of the art medical research, in particular cancer studies, varying from risk factors to cell-based studies (NN, 2020) and to some extent aircraft and automotive manufacture and maintenance, but hardly or not at all in the built environment.

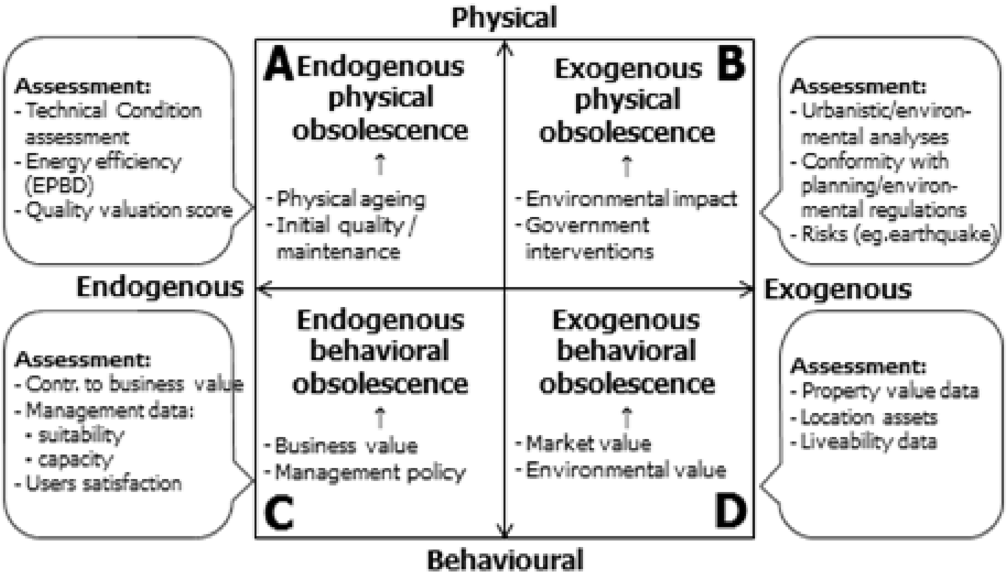

Figure 8.2. - Basic analytical model (Thomsen and Van der Flier, 2011)

The health of built artefacts can in principle be likewise approached. But unlike human beings, buildings show a wide variety of different types and functions, from residential single family row houses to non-residential offices, windmills, bridges and harbour keys, an almost unsearchable multiplicity, usually simplified by just targeting at the physical structure, building parts and materials and/or the more coherent and data rich residential stock. Our research in this field carries as such a tentative and preliminary character.

An exploration on standard single-family dwellings (Thomsen, 2017) (Table 8.1.) and a try out on a non-residential building (a former chocolate factory partly converted into a shopping centre) (Thomsen and Carels, 2016) (Table 8.2.) show that sifting through cause-effect series based on the quadrant of Figure 8.1. results in 12 prototypes with 36 typical effects of obsolescence of which 7 respectively to 21 might be counted as some kind of economic obsolescence.

8.8. Concluding remarks

Ageing and decay of built artefacts consist of recurrent series of complicated cause-effect processes that should not be captured in single labels on penalty of not understanding the underlying dynamics of cause-effect processes.

If nevertheless a definition of economic obsolescence related to service life is desired it should thus read “loss of ability of a built item to perform satisfactorily due to changes in performance requirements caused by and/or resulting in loss of economic performance/qualities”.

These research findings also show the decisive importance of factors as building type and ownership/ tenure not included in the lay out and systematically neglected in most life cycle analyses. For example, though the design quality and maintenance of two single family terraced houses may be exactly the same, the average service life prediction of the social rented one may be less than 50 years whereas the owner-occupied one may last for several centuries.

Table 8.1. - Cause-effect process types

Type	Cause		Effect	
A→A	A	physical defects; design errors; poor hydrothermal quality	A	consequential damage; condensation, rot; functional defects;
A→B			B	environmental damage; shadow, wind, reflections; environmental effects;
A→C			C	loss of demand, nuisance; discomfort, energy waste; owner/ user disinvestment;
A→D			D	liveability effects; insecurity; loss of demand; depreciation
B→A	B	environmental defects; planning errors; climate/ earthquake impact	A	physical damage; material damage; functional defects;
B→B			B	consequential damage; spatial obsolescence; environmantal insecurity;
B→C			C	nuisance; discomfort; owner/ user disinvestment;
B→D			D	liveability losses; insecurity; loss of demand, nuisance; depreciation;
C→A	C	loss of demand; discomfort; misuse, neglecting; disinvestment	A	maintenance backlogs consequential damage; loss of condition
C→B			B	maintenance backlogs environmental damage; environmental effects;
C→C			C	(increased) discomfort; misuse, neglecting; disinvestment
C→D			D	liveability losses; insecurity; loss of demand, depreciation;
D→A	D	liveability defects, insecurity loss of demand depreciation	A	maintenance backlogs consequential damage; loss of condition
D→B			B	maintenance backlogs environmental damage; environmental effects;
D→C			C	(increased) discomfort; misuse, neglection; disinvestment
D→D			D	(increased) liveability losses; insecurity; loss of demand, depreciation;

Table 8.2. - Obsolescence analysis

Life cycle phase			Cause-effect type *)							
Phase	Stage	Description	A	Impact	B	Impact	C	Impact	D	Impact
I.	1-10	Initial phase	1. New, well built and maintained construction.	++	1. Open industrial area with accordingly infrastructure: road, waterway, nearby rail and station.	++	1. No data. Well suited, specific. designed.	+	1. No data. Attractive and valuable property; able to accommodate various functions.	+
			2. Good energy efficiency (to that time standard) with partly double glazed windows.	+	2. Full conformity with (that time) regulations, based on long term masterplan.	+	2. No data.	?	2. No data.	?
			3. No data. Fine architecture. Well dimensioned multipurpose spatial structure.	++	3. Absense of environmental threats or conflicting neighbor interests.	+	3. No data.	+	3. Well situated for commercial use: waterfront situation, direct road and waterway connection, nearby rail, station and city center. Ample extension space.	++
II.	11-18	Heyday phase	1. As above. Well maintained.	+	1. As above. Development mixed industrial and commercial area.	++	1. As above.	+	1. As above.	+
			2. As above.	+	2. As above.	+	2. No data.	?	2. No data.	?
			3. As above.	++	3. As above.	+	3. Former workers still testify love	+	3. As above.	++
III.	18-19	First decline	1. As above; emphasis on adaptability spatial structure.	+	1. As above. Further development of adjacent shopping area.	++	1. No data. Closure = insufficient business value.	--	1. No data. Acquisition indicates acceptable market value.	+
			2. Energy efficiency stays behind.	o	2. As above, incl. change of use.	+	2. No data. Closure = failure.	-	2. No data.	?
			3. As above.	++	3. As above. Some increase of conflicting neighbor interests.	o	3. No data.	?	3. As above, with emphasis on opposite close by city centre.	++
IV.	19-26	Extended use phase	1. Still as above but alterations of lower quality, partly harming architecture (cladding façade).	+	1. Development of Overstad with changed urban plan: shopping centre, leisure, housing.	+	1. No data. Acquisition and investments indicate cost effective operation.	+	1. As above.	+
			2. Energy efficiency insufficient.	-	2. As above.	+	2. No data.	?	2. No data.	?
			3. As above. Architecture hurt by brutal fast ageing cladding.	+/o	3. As above.	o	3. No data.	?	3. As above, close by opposite city centre and station.	++
V.	27-32	Second decline	1. Fast increasing maintenance backlogs.	+/o	1. Redevelopment of Overstad with again changed urban plan.	+	1. No data. Closure = insufficient business value.	--	1. No data. Acquisition after bank-rupty likely negative for value.	o
			2. Energy efficiency insufficient.	-	2. imperilling existing Ringers bld.	-	2. No data. Closure = failure.	-	2. Liveability score: fair.	+
			3. As above.	+/o	3. Increase conflicting interests.	o/-	3. No data.	?	3. As above.	++
VI.	33-34	Redevelopment	1. As above	+/o	1. As above	+	1. No data yet, in development.	o	1. No data yet. Depends from negociation/ retreat MAB.	?
			2. As above	-	2. Acceptance of redevelopment existing Ringers building.	+	2. MAB: no data; Dobla positive.	o/+	2. Liveability score: fair.	+
			3. As above	+/o	3. As above, but in control.	o	3. No data.	?	3. As above. Ringers acknowledged as essential for Overstad.	++

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