Service life and durability in the context of circular economy assessments – initial aspects for review

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<td>Article</td>
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<td>Date Submitted by the Author:</td>
<td>03-Jul-2019</td>
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<tr>
<td>Complete List of Authors:</td>
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</tr>
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(i) Title:

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v) Word count : 4412 (excluding references)
Abstract

This paper introduces some challenges involved in assessment of service life and durability in the context of circular economy principles. It proposes a possible agenda for service life planning in a resource-constrained economy. Aspects considered include the re-use of materials and components over multiple life cycles within built assets. The interface between life cycle assessment and costing techniques, service life planning and resilience against changing climate and performance requirements is considered. The current codes and standards, in particular within ISO 15686 series on service life, CEN 15643 on integrated sustainability assessment and ISO 20887 on design for disassembly are briefly described together with some implicit challenges. The contributions of CIB Task Groups are also considered, in particular CIB TGs 16, 39, 115 and CIB W80 on Prediction of service life of building materials methodologies. Several current EU research and development projects are briefly mentioned, in particular BAMB (Buildings as Material Banks).

Keywords

Circular economy, service life, durability, discount rate, ISO 15686, re-use, dis-assembly, life cycle, sustainability, climate change, EN 15643

Introduction

The standard linear model of procurement of constructed assets has been the “take, make, dispose” model, or some would say the “take, make, waste” model. It has increasingly come under pressure as the realities of limited resources become apparent, and the process of change has been accelerated by consideration of climate change and the need to decouple growth from resource constraints. This move from a linear to a circular model of procurement affects the construction industry and the built environment very strongly, due to the disproportionate contribution of the industry to materials consumption which is estimated for example at 60% for the UK, and also to waste arisings - estimated at one-third for UK (see Lowres and Hobbs 2017).

The primary driver and motivation for moving towards a circular economy model in the early part of the 21st century has been that of environmental and ecological imperative in the face of increasingly scarce resources. There is some suggestion that this may be a recognizable ecological pattern of a pulsing general system of growth and recession,
followed by succession again, related to how ecosystems respond to abundant or scarceresources (see Gellini, P et al. 2015).

It now appears demonstrable that the supply of non-renewables will not permit “business as usual” growth in consumption to continue, and numerous negative effects have been found by organizations as diverse and the World Business Council for Sustainable Development, the Intergovernmental Panel on Climate Change and the World Economic Forum. Accenture have produced a paper (2014) indicating that the process of accelerating risks starts around the turn of the 21st century, where the previous relationship of Gross Domestic Product (GDP) being tied to growth in consumption of resources starts to break down. Whereas previously commodity prices have been inversely tied to growth, around the year 2000 this relationship starts to invert. Accenture estimate that in the period 2000 to 2013, for every 1% growth in GDP the commodity price index rate rose by 1.9% rather than the historic 1% growth with only 0.4% increase in prices (Accenture 2014). Along with this threat there is however a huge potential opportunity. The Ellen MacArthur Foundation estimate that the economic value offered by adoption of a circular economy could be over $1 trillion US Dollars annually by 2025, and represent over 100,000 new jobs over the next five years (see Ellen MacArthur Foundation 2014). Perhaps inevitably therefore, attention is drawn to the economic assessments underpinning these projections, and that brings us to consideration of the expected service life of built assets within the circular economy (henceforth referred to as CE).

The movement towards CE is international, not limited to any one industry, country or discipline; indeed most writers emphasize the absolute necessity of collaboration to achieve this change. Within Europe the European Commission has adopted an ambitious Circular Economy Package (see EU Circular Economy), which includes measures that will help stimulate Europe’s transition towards CE, boost global competitiveness and foster sustainable economic growth. As an example of city level action, London has adopted a series of policy initiatives aimed at supporting CE, with specific targeted support to small and medium sized enterprises, a circular economy route map and potential savings of £11 million per annum over 5 years for London’s local authorities (see LWARB Circular Economy). Still in the UK British Standards Institute published BS 8001 which is a framework for adoption of circular economy principles (BSI 2017). In Canada the Smart Prosperity Institute has produced a primer that links existing policies on climate change and clean growth to CE principles (see Smart Prosperity Circular Economy). All these developments have taken place in the last couple of years and are testimony to the urgency that is seen in
tackling the changes needed. Policy initiatives internationally support the transition (Henrotay, C., et al., 2017) but approaches and priorities differ depending on the context for each state (see Ghisellini et al. 2015).

The RESOLVE Framework – a brief overview of action areas leading towards CE

The Ellen MacArthur Foundation introduced the RESOLVE framework as a summary of the policy actions needed to foster CE thinking in business and the economy (see Ellen MacArthur Foundation 2015). It bears similarities to the older waste minimization concept of the 3 R’s - “Reduce, re-use, recycle” but emphasizes business models.

The framework contains the following 6 principles:

*Regenerate* – comprising the shift to renewable energy and materials, reclaiming health of ecosystems and returning biological resources to the biosphere.

*Share* – comprising the shift to sharing assets, re-use, and prolonging life through maintenance, design for durability and upgradability.

*Optimise* – through increasing performance and efficiency of products, removing waste from the supply chain, leveraging big data and automation.

*Loop* – through remanufacture of products or components, recycling of materials and extraction of biochemicals from organic waste.

*Virtualise* – directly through digitalization (e.g. books to CDs) or indirectly (e.g. online shopping).

*Exchange* – through replacing old with advanced materials, or new technologies or products.

While each of these are important to adoption of CE principles, the primary focus for this paper will be on the Optimise, Share and Loop principles - which are closer to the older waste hierarchy of Reduce, Reuse, Recycle – with their implications for the practice of service life planning in the built environment. These will be examined through two aspects; firstly, in respect of evolving approaches to re-use and recycling. Here the focus in the paper will be particularly on work in Canada and internationally on design for disassembly, which cuts across the RESOURCE principles as one approach which minimizes resource consumption. The second focus will be in respect of predicting
or estimating service lives across multiple building life cycles or multiple uses. This latter aspect will be particularly
considered in respect of how it links with associated techniques of life cycle costing, life cycle assessment and social
sustainability assessment. Some links with current EU research projects will be made, to include Horizon 2020
funded BAMB project (Buildings as Material Banks) and current UK research into re-usable components and
buildings funded by LWARB (London Waste and Recycling Board).

**Deconstruction, design for disassembly and re-use – evolving service life planning approaches**

**Initial approaches to economic assessment of recycling**

Where landfill or materials have historically been scarce, the economic advantages of recycling were considerably
heightened and by the late 1990's various technologies had evolved to reduce construction waste and minimize
resource consumption (Tomosawa et al. 1998; Pietersen et al. 1998). In countries not encountering those spatial and
resource constraints there were increasing fees for waste disposal; haulage, tipping as well as direct taxes and an
increasing desire to manage construction waste (Miller 1998; Wilson et al. 1998).

Boyle et al. (1999) examined existing deconstruction infrastructure in six Canadian cities and assessed the potential
economic outcome of applying a standardised set of dismantling/deconstruction procedures to a case-study
building renovation project. The authors noted that building owners, design consultants and construction
contractors had begun to realise the potential economic advantages afforded by incorporating dismantling and
deconstruction within renovation projects. They observed that design team(s) should take advantage of the
opportunities to enhance material recover and reuse. They further stated that if reused materials met performance
requirements they should be incorporated into the newly designed or refitted facilities and suggested that the
design of new facilities should acknowledge the potential future life cycles or renovation of the space as well as the
potential requirement to be dismantled with the highest proportion possible of the materials available for reuse
with minimal damage.

Most significantly, Boyle et al. (1999), concluded that the deconstruction approach that they proposed would be of
economic advantage in all examined locales.

**Initial approaches to sustainability assessment of re-use**

An early identification of the potential contribution of deconstruction to sustainability objectives was made by the

International Council for Research and Innovation in Building Construction (CIB). The initial work of CIB Task Group (TG) 16: Sustainable Construction and then the collective works of CIB TG 39: Deconstruction, and subsequently CIB Commission W115 are very significant: Construction Materials Stewardship CIB [2000,2001,2002,2003,2005,2008,2009,2011], have provided immeasurable and invaluable guidance relative to deconstruction and material harvesting practices. They had developed various models for the Design for Deconstruction and coined the term Design for Disassembly (DfD). As these procedures evolved, the consideration of adaptability within the life cycle design and sustainable performance of buildings has become very strong, with many of the CIB W115 initiatives explicitly considering adaptability, CIB [2009].

**Standardised procedures to design for re-use**

With the desire to harvest materials for reuse, recycling or redirection (repurposing) comes the need to standardise procedures for the disassembly or deconstruction processes, required material quality of, and the conditions governing the application of harvested materials. If the economic advantage of disassembly and deconstruction is to be improved there has to be guidance and standardisation of design for disassembly and adaptability concepts and principles.

In 2004, in support of sustainable development initiatives of various levels of governments and the building industry in Canada, the CSA Group (CSA) established a Technical Committee (TC) on Sustainable Construction Practices (formerly the TC on Sustainable Buildings); tasked to develop Canadian national standards to develop technical standards for the design, construction and maintenance of buildings respecting sustainability. The TC decided to produce a guidance document on the conceptual framework, concepts and principles for the design of buildings following disassembly and adaptability principles with the objective of providing an overview of DfD/A principles and a method of defining the scope of integrating these principles into the design process to reduce the overall environmental burden associated with material assemblies.

The first edition of ‘Guideline for Design for Disassembly and Adaptability in Buildings, CSA-Z782-06’ [CSA2006] was published under the auspices of CSA in November 2006. The document details a framework for reducing building construction waste via consideration at the design phase, by applying DfD/A principles. The Guideline also reviews quantifiable metrics for each DfD/A principle that, subject to further development, can be assembled into a matrix or checklist to guide users in the direction of disassembly criteria design. The Guideline is not to be used as a
design tool; rather, it can be used to aid the comparison of environmental performance of various design options within the context of DfD/A principles.

**Current work on design for disassembly and adaptability**

In September of 2015, the ISO Technical Advisory Group (TAG) 8 Buildings, accepted a proposed new work item for the development of an ISO standard on DfD/A and recommended using the CSA Z782-06 as a seed document along with the body of works from CIB. ISO placed the standards development project under the purview of ISO TC59 - Buildings and civil engineering works. The work was assigned to Subcommittee (SC) 17 - Sustainability in buildings and civil engineering works. The international standard is in the final stage of committee review and publication of the first version of the ISO 20887 *Design for disassembly and adaptability of buildings* is planned for 2019 (ISO CD 20887).

**Current work on materials passports and reversible building design – EU BAMB project**

In parallel with the developing international standard an EU Horizon 2020 funded project, BAMB (Buildings as Material Banks 2015) is working with a consortium of 15 partners from 7 states to develop two key breakthrough supporting tools, namely materials passports and reversible building design. This project includes themes of resilience (Apelman et al. 2016), as well as identification of barriers and opportunities to reuse of building materials and components (Hobbs, G., and Adams, K.A., 2017). This latter paper points out some of the key barriers to re-use, including the reluctance to use products without certification of tested performance as well as issues of value of reused materials. Another key theme is the materials passports concept (see Luscuere L., M. 2017), where value tracking is enabled through monitoring and recording actions throughout the life cycle from production through maintenance, to enable assurance of performance to be assessed. Tools are being created which explicitly recognise the fundamental links with service life planning methodologies and design lives (see for example Andrade, J.B., and Bragança, L. 2017).

**Prediction of service lives across multiple uses or building life cycles – alignment with life cycle costing and life cycle assessment methodologies.**

The focus on re-use of building materials, products and components inevitably draws attention to the life cycle – the predicted service life, the design life, the applicability of the reference service life and how to estimate a “revised” or “residual” service life. The methodologies for these assessments have been developed through the series of ISO
15686 standards on Buildings and Constructed Assets – Service Life Planning (ISO 15686 – various dates), and in particular Part 1 (2011 General Principles), Part 2 (2012 Service Life Prediction Procedures), and Part 8 (2008 Reference Service Life and Service-life estimation). More recently Part 7 (2017 Performance evaluation for feedback of service life data from practice) has been added to reflect the importance of “real life” feedback loops. These all rest on the basic terminology and definitions, which have generally been aligned with the work of other codes and standards in ISO/TR 15686-11 (2014 – Terminology), in particular with those on sustainability originating from ISO TC 59 SC17, but also on general terminology in TC59 SC3. The terms and definitions can be found by searching the ISO online browsing platform (see https://www.iso.org/obp/ui/#home). However, the nature of interlocking standards developed over a long period of time, as these have been, is that interpretation of terms may require close study of various standards.

The key terms and their associated definitions for this paper are defined in ISO/TR 15686-11:2014 as follows:

- **Design life** is “service life intended by the designer”
- **Life cycle** is “consecutive and interlinked stages of the object under consideration” with Note 1 indicating the “life cycle comprises all stages from construction, operation and maintenance to end of life, including decommissioning, deconstruction and disposal”.

Curiously, end of life is not specifically defined, but end of life cost is defined as follows:

- **End of life cost** is “net cost or fee for disposing of an asset at the end of its service life, or interest period, including costs resulting from decommissioning, deconstruction and demolition of a building, recycling, making environmentally safe and recovery and disposal of components and materials, and transport and regulatory costs”.
- **Disposal** is “[end of life] transformation of the state of a building or facility that is no longer of use”. It includes a note indicating that “transformation can include, either individually or in some combination, the decommissioning, deconstruction, recycling and demolition of the object of consideration”.

The implication of these definitions in the context of CE principles, and re-use in particular, is that the “object of consideration” or “asset” needs to be closely considered, as does the life cycle in question. The unspoken assumption behind the definitions is made clear in ISO 15686-1 in the scope which states “This part of ISO 15686 identifies and establishes general principles for service life planning and a systematic framework for undertaking service life...
planning of a planned building or construction work throughout its life cycle (or remaining life cycle for existing buildings or construction works).” The focal point therefore was the life of the building, and this is confirmed by the introduction which states “Service life planning is a design process that seeks to ensure that the service life of a building or other constructed asset will equal or exceed its design life.” And also in the Scope that “This Part of ISO 15686 is applicable to the service life planning of individual buildings.”

It should be noted that there is no suggestion that service life planning approaches cannot be applied to constructed assets at a level of granularity of less than the building, and indeed the principles are explicitly applied to components and materials, as demonstrated by methodologies to assess the design life of a component (abbreviated to DLC) and the estimated life of a component (abbreviated to ESLC) in Part 8. It is simply that the drafting has assumed the key objective of service life planning is to ensure that assets included within the building last at least as long as the building itself unless these can be replaced periodically.

As part of work on the BAMB project and another EU project (GELCLAD – see https://www.gelclad.eu) the applicability of ISO 15686 to components, materials and assemblies was considered in the context of alignment with standards on life cycle assessment (LCA) and life cycle costing (LCC). The specific other standards relevant are the ISO 14000 series, in particular ISO 14040 and also on CEN standards developed by CEN TC 350 on integrated assessment of sustainability, specifically on the EN 15643 series on integrated assessment of sustainability of construction works, and the linked standards on calculation methodologies, in particular EN 15978 series on life cycle assessment, and EN 16627 on economic assessment of sustainability.

The specific issue was the need to align component-level assessments of service life and LCA and LCC, and in particular to quantify environmental and economic impacts of use of the same components across multiple buildings or building service lives. Periods of up to 3 building service lives (assumed to be a maximum of 180 years) were considered. It became apparent that though there are numerous standards currently determining the principles and calculation of impacts for environmental and economic impacts across the life cycle, at both ISO and CEN level, there is little guidance on how to consider the life cycle of the asset where it does not coincide with the life cycle of the building or other constructed facility.

**Challenge 1 – the design life and period of analysis**
In particular, the “design life” intended by the original designer should not be expected to cover uses subsequent to the original use / building service life, and the default assumption for both LCA and LCC that the “entire” life cycle of the building should be used as the period of analysis also breaks down. Once there has been a separation of the performance intentions as originally considered in the design life, the (evolving) level of acceptable performance becomes important, as it is relevant to determination of the “end of life”.

Challenge 2 – the asset or object of assessment and associated system boundary

Within the CEN 15643 series of standards the reporting structure defines the object of assessment as “the building, its foundations and external works within the area of the building’s site (curtilage) and temporary works associated with the building’s construction.” There are detailed rules for reporting of impacts beyond the system boundary, but the life cycle is assumed to be that of the “original” building. The rules on functional equivalency for comparisons equally require that major functional requirements and intended use shall be defined so that the assessment of each of the pillars (environmental, social or economic) will be on an equivalent basis. Again, no real guidance is given on how to take account of functional requirements which have changed over the lifespan, or from one building life cycle to the next. Scenarios are set on the basis of the building life cycle, and there is a separate reporting module (module D) for impacts beyond the system boundary or building life cycle.

Challenge 3 – discounting future costs for LCC

One area of challenge in applying ISO 15686 guidance on LCC (and indeed EN 16627 guidance also) includes the selection of the appropriate discount rate for bringing future cash flows to a common basis. The Stern Review, prepared in 2007 in the UK for the UK government aimed to assess the economics of climate change (Stern, N., 2007, and 2014). This concluded that the damage from “business as usual” in a world where the climate was changing would be expected to reduce Gross Domestic Product by 5% based on market impacts alone, or by 11% if social and environmental impacts which do not have prices (externalities) are included. Under more aggressive climate change scenarios these losses increase to 7% or 14% respectively and could lead to 20% losses globally. As part of the recommendations to address avoidance of these losses, which were primarily policy changes, one which attracted considerable commentary was the issue of the appropriate discount rates for inter-generational wealth exchanges. The recommendation for reducing the long term rates conflicts with default requirements in the EN 15643-4 standard on economic assessment, and one part of the research in BAMB has entailed a sensitivity analysis on the
effect of the amended rates on the value or cost of durability or service life extension.

**Challenge 4 – assumptions underlying assessment of predicted service life**

The soon to be published standard ISO 20887 *Design for disassembly and adaptability of buildings* will recommend that the procedures of the ISO 15686 series be used to conduct those reassessments.

There are several issues associated with material and system reuse that affect the service life expectations and some of these also directly impact upon recyclability and reusability, as well as assessment of maintenance requirements and associated environmental and economic impacts. Generally the items considered are associated with 1) more rapid material and system degradation either due to contamination (i.e., bacteria, moulds, insect infestation, material incompatibilities etc.) or unforeseen increases to in-service loadings, and 2) heightened resistance requirements due to redefined functional/performance needs.

Both of these general categories imply that the underperforming material/component or system will need to be taken out of service (from initial use) and replaced, put to other use and/or recycled. Regardless, the remaining performance capacity and service life expectations of the materials and systems will need to be reassessed and this reassessment will be directly dependent upon detailed knowledge and projections of the material and system capabilities and deterioration as well as the current and predicted loadings.

**Challenge 5 – changing performance requirements and climate change**

For the processes and procedures of ISO 15686 to be of fully applied throughout the asset life (or lives), practitioners must acknowledge that, dependent upon the level of application, the functional requirements must be continuously redefined, and that that redefinition implies re-evaluation of expectations of design life. While that redefinition was historically driven by changed user needs, market demands and condition deterioration, the primary concern is increasingly in response to the potential impacts of climate change.

Climate change presents the possibility of a significant alteration to historical design considerations, by potentially shifting both the load applied and the ability to resist. With heightened increases to the frequency and amplitude of many climatic loads that had previously been considered as stable, the load side of the design requirement shifts and the reliability of the projected service lives is weakened. Longer term exposure to slightly more intense climatic
conditions may cause more rapid material and system deterioration leading to reduced resistance to loading and shortened service lives.

Conclusions

The objective of a circular economy is to ensure that the best “whole life” outcome is achieved, and analysis on the BAMB project suggests this may entail some counter-instinctive results, as the increase in durability may entail additional (unwanted) economic and/or environmental impacts. Depending on the methodology of assessment, and in particular the period of assessment, these impacts may indicate that the apparent “benefit” of re-use is outweighed by these burdens. Work done to date suggests that there are gaps in current guidance which require reassessment of some of the fundamental underlying definitions and perhaps concepts of service life planning.

Some of the almost unquestioned underlying assumptions about service life planning in the standard methodologies may conflict with the need to evaluate the benefits and burdens of increased durability.

Five challenges are identified in the paper and some tentative conclusions on priorities for response have been identified as follows. These will require additional work to resolve. Though identified individually, the authors believe that the challenges are interconnected and perhaps even interlocked.

Challenge 1 – the design life / period of analysis – this will require definition and focus on the “residual” life. This will bring with it a need to identify the future purpose(s), intensity of use, environment etc in a scenario / set of assumptions.

Challenge 2 – the system boundary – service life planning could learn from approaches to life cycle assessment in the environmental and social spheres, and the adoption of a fixed system boundary and identification of the scenario under consideration in assessments of service life. This would permit the identification of changes, potential or realized, in either underlying conditions or aspects outside of the original scope, thereby enhancing the service life planning process.

Challenge 3 – the discount rate – potentially adoption of a lower rate to take account of very long service lives may be considered, but certainly sensitivity analysis of results of changing the discount rate to should be possible.
Challenge 4 - in conjunction with Challenge 1 the issue of the technical residual life will be a key feature for the future development of service life planning. Consideration will need to be given to the material and system degradation under changing conditions of use as well as how to capture and assess the historic response to use.

Challenge 5 – adaptation of service life assumptions to changing climate – there will be a need for both overarching and specific amendments to assumptions about the climate to be anticipated, and it may be that the approach to scenarios and sensitivity analysis will help to address this aspect. It is expected also that this will encourage the use of a range of potential predicted service lives, depending on the climate scenario assumptions.

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ISO CD 20887 under development. Design for Disassembly and Adaptability of Buildings. Available to committee members of ISO TC59/SC17 only at this stage.


