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Sustainability in buildings and civil engineering works — Design for disassembly and adaptability — Principles, requirements and guidance

Développement durable dans les bâtiments et ouvrages de génie civil — Conception pour la démontabilité et l'adaptabilité — Principes, exigences et recommandations

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 59, *Buildings and civil engineering works*, Subcommittee SC 17, *Sustainability in buildings and civil engineering works*.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Applying the principles of design for disassembly and adaptability (DfD/A) to the service life planning of buildings and civil engineering works can make a positive contribution to sustainable development. While service life planning is a design process that seeks to ensure that the service life of a constructed asset will equal or exceed its design life, design for disassembly and adaptability is a strategy to optimize both the service life and the design life. The strategy does not suggest overbuilding to meet a vast number of unknowns that a constructed asset might encounter.

Introducing aspects of design for disassembly can be used to reduce and/or prevent waste and increase resource efficiency by encouraging alternative considerations at the project definition phase. The application of adaptability concepts and principles can minimize the need for unnecessary removal and new construction, by repurposing or modifying constructed assets to renew their service life, and result in constructed assets that are able to accommodate a larger variety of uses. From a broader perspective, the recovery and subsequent reuse or recycling of disassembled construction materials and components will support the evolving concept of a circular economy.

The design and construction industry has often trusted/depended upon traditional assembly methods, products, and processes that typically do not consider deconstruction. As such, during a renovation or demolition project, products and materials are often not easily salvaged for reuse, recycling or energy recovery, and therefore, become waste that is landfilled.

Incorporating DfD/A concepts early in the planning and design phase will increase the likelihood that activities during the stages of use, maintenance (including repair, replacement, refurbishment), and end-of-life (e.g., disassembly, reuse, recycling, disposal) will be conducted more efficiently from a total resource perspective (i.e., time and associated costs, labour costs, materials, and energy).

Design for disassembly devises explicit methods, prior to construction, for optimal recovery of specific products and materials without damaging either that which is being removed or surrounding components. The adaptability aspects of DfD/A support the continued use of constructed assets by allowing for and accommodating substantial change (e.g., demographics, social, economic, and technological conditions and physical surroundings and needs) within an existing or expanded physical asset. Designing for adaptability means designing for both present and future uses, encouraging the use of phased developments and matching supply with demand in a timely fashion. The decision to use these methods is usually considered in conjunction with the investment rate of return over time and risk.

Successful application of DfD/A principles will require their integration into the early phases of a project, when it is still cost-effective to do so. Implementation of DfD/A will require compromises and trade-offs to make choices that can be constrained by factors such as technical complexity, lack of resources and time, risk of obsolescence and limited information on costs or relative environmental burdens over the total life cycle. Therefore, it is important that all parties involved in the design, product supply, construction, commissioning, operation and decommissioning aspects have sufficient knowledge and understanding to implement the intended results. Designers have the major role in considering DfD/A to facilitate the best technical, economic and environmental opportunities. Clients often drive the design team to consider and implement DfD/A elements within a project. The supporting supply chain, including product suppliers, constructors, facility managers and those decommissioning constructed assets also need to adapt their approaches to optimize the design intentions which relate to DfD/A.

This document is intended to provide a framework of the DfD/A principles and the key issues that should be considered by the different actors, particularly designers involved in the project. It is equally important that this knowledge base is continually added to by those implementing these principles, and associated activities, for example, by knowledge sharing through the creation of case studies and associated journal articles.

This document is one in a suite of documents dealing with sustainability in construction works that includes the following, in addition to this document:

a) ISO 15392, *Sustainability in buildings and civil engineering works — General principles*;

b) ISO/TS 12720, *Sustainability in buildings and civil engineering works — Guidelines on the application of the general principles in ISO 15392*;

c) ISO/TR 21932, *Sustainability in buildings and civil engineering works — A review of terminology*;

d) ISO 21929-1, *Sustainability in building construction — Sustainability indicators — Part 1: Framework for the development of indicators and a core set of indicators for buildings*;

e) ISO/TS 21929-2, *Sustainability in building construction — Sustainability indicators — Part 2: Framework for the development of indicators for civil engineering works*;

f) ISO 21931-1[1)], *Sustainability in building construction — Framework for methods of assessment of the environmental performance of construction works — Part 1: Buildings*;

g) ISO 21931-2, *Sustainability in buildings and civil engineering works — Framework for methods of assessment of the environmental, social and economic performance of construction works as a basis for sustainability assessment — Part 2: Civil engineering works*;

h) ISO 16745-1, *Sustainability in buildings and civil engineering works — Carbon metric of an existing building during use stage — Part 1: Calculation, reporting and communication*;

i) ISO 16745-2, *Sustainability in buildings and civil engineering works — Carbon metric of an existing building during use stage — Part 2: Verification*;

j) ISO 21930, *Sustainability in buildings and civil engineering works — Core rules for environmental product declarations of construction products and services*;

k) ISO 21678[2)], *Sustainability in buildings and civil engineering works — Indicators and benchmarks — Principles, requirements and guidelines*.

This document deals with environmental, social and economic aspects of sustainability. The relationship among the suite of documents is elaborated in Figure 1.

1) Revision under preparation.

2) Under preparation. Stage at the time of publication: ISO/FDIS 21678:2020.

ISO/TC59/SC17	environmental aspects	social aspects	economic aspects	technical aspects	functional aspects
Principles	**ISO 15392** General principles				
	ISO TS 12720 Guideline on the application of ISO 15392				
	ISO TR 21932 Terminology				
Buildings (Parts 1) + Civil Engineering Works, CEW (Parts 2)	**ISO 21929-1** Framework for the development of Indicators – Part 1: Buildings				
	ISO 21929-2 Framework for the development of Indicators – Part 2: CEW				
	ISO 21931-1 Framework for methods of assessment of the environmental, social and economic performance of construction works as a basis for sustainability assessment – Part 1: Buildings				
	ISO 21931-2 Framework for methods of assessment of the environmental, social and economic performance of construction works as a basis for sustainability assessment – Part 2: Civil Engineering Works				
	ISO 20887 Design for Disassembly and adaptability - Principles, requirements and guidance				
	ISO 16745-1+ 2 Carbon metric of an existing building during use stage. Part 1: Calculation, reporting, communication. Part 2: Verification				
	ISO 21678 Methodological principles for the development of benchmarks for sustainable buildings				
Products	**ISO 22057** Enabling use of Environmental Product Declarations (EPD) at construction works level using building information modelling (BIM)				
	ISO 21930 Core rules for environmental product declarations of construction products and services				

Figure 1 — Suite of related documents for sustainability in buildings and civil engineering works

Sustainability in buildings and civil engineering works — Design for disassembly and adaptability — Principles, requirements and guidance

1 Scope

This document provides an overview of design for disassembly and adaptability (DfD/A) principles and potential strategies for integrating these principles into the design process. This document provides information for owners, architects, engineers, and product designers and manufacturers to assist in their understanding of potential DfD/A options and considerations, and for other parties who are responsible for financing, regulating, constructing, transforming, deconstructing, or demolishing construction works.

This document is applicable to all types of buildings (e.g. commercial, industrial, institutional, and residential), civil engineering works (e.g., dams, bridges, roads, railways, runways, utilities, pipelines) and their constituent parts. It can be used for new construction, refurbishment and renovation, and in the design of incremental improvements in, or complete redesign of, buildings, building systems, civil engineering works, and their constituent parts.

This document also provides guidance on measuring performance regarding each DfD/A principle and related objectives.

This document is intended to be used in conjunction with and following the principles set out in ISO 15392 and the ISO 15686 series.

This document does not set specific levels of performance for the disassembly or adaptability of constructed works, however, it does include requirements that are mandatory for the implementation of specific DfD/A principles that are applicable when these principles are adopted.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 6707-1, *Buildings and civil engineering works — Vocabulary — Part 1: General terms*

ISO 15392, *Sustainability in buildings and civil engineering works — General principles*

ISO 15686-1, *Buildings and constructed assets — Service life planning — Part 1: General principles and framework*

ISO/TR 21932, *Sustainability in buildings and civil engineering works — A review of terminology*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 6707-1, ISO/TR 21932 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
accessibility
ability for ease of access to *components* (3.7) for *disassembly* (3.12), *refurbishment* (3.29), *replacement* (3.32), or upgrade

Note 1 to entry: Within the context of this document, this definition does not directly apply to accessibility for people with additional, specialized needs.

3.2
adaptability
ability to be changed or modified to make suitable for a particular purpose

[SOURCE: ISO 6707-1:2017, 3.7.3.79]

3.3
assembly
set of related *components* (3.7) attached to each other

Note 1 to entry: Examples of assemblies include the total building envelope or the individual walls, roofs, or parapets and bearing or cable assemblies for bridges.

[SOURCE: ISO 6707-1:2017, 3.3.5.5, modified — Note 1 to entry has been added.]

3.4
building
construction works (3.9) that has the provision of shelter for its occupants or contents as one of its main purposes, usually partially or totally enclosed and designed to stand permanently in one place

[SOURCE: ISO 6707-1:2017, 3.1.1.3, modified — Note 1 to entry has been removed.]

3.5
circular economy
economy that is restorative and regenerative by design, and which aims to keep products, *components* (3.7) and materials at their highest utility and value at all times, distinguishing between technical and biological cycles

[SOURCE: ISO 20400:2017, 3.1]

3.6
civil engineering works
infrastructure
civil engineering project, US
construction works (3.9) comprising a structure, such as a dam, bridge, road, railway, runway, utilities, pipeline, or sewerage system, or the result of operations such as dredging, earthwork, geotechnical processes, but excluding a *building* (3.4) and its associated site works

Note 1 to entry: Associated site works related to buildings are sometimes considered as civil engineering projects, for example particularly in the US.

[SOURCE: ISO 6707-1: 2017, 3.1.1.2, modified — "infrastructure" has been added as an admitted term; Note 1 to entry has been modified.]

3.7
component
product manufactured as a distinct unit to serve a specific function or functions

EXAMPLE Nails, cladding anchors, reinforcing bars and membranes (basic units) or reinforced concrete slabs, windows and doors (complex units).

Note 1 to entry: Components can be manufactured, prefabricated, or built or formed on site, and can be basic or complex units.

Note 2 to entry: A complex unit can also be considered an *assembly* (3.3), depending on the context.

3.8
constructed asset
anything of value that is constructed or results from construction operations

[SOURCE: ISO 15686-1:2011, 3.2]

3.9
construction works
everything that is constructed or results from construction operations

Note 1 to entry: This includes *buildings* (3.4), *civil engineering works* (3.6), structures, landscaping, external works, and other types of construction works within a built environment.

Note 2 to entry: From an economic perspective, completed construction works are typically referred to as a *constructed asset* (3.8).

[SOURCE: ISO 6707-1:2017, 3.1.1.1, modified — The original Note 1 to entry has been removed; two notes to entry have been added; the US synonym ‘construction’ has been deleted as an admitted term.]

3.10
convertibility
ability to accommodate a substantial change(s) in user needs by making modifications

3.11
demolition
removal by destructive methods

EXAMPLE Demolition by pushing or pulling, fragmenting by crushing or shearing, implosion or rapid progressive failure of *construction works* (3.9) or their component parts.

3.12
disassembly
non-destructive taking-apart of a *construction works* (3.9) or *constructed asset* (3.8) into constituent materials or *components* (3.7)

Note 1 to entry: This process can be applied to a product, *module* (3.23), system, component, or *assembly* (3.3).

[SOURCE: ISO 15392:—, 3.11, modified — Note 1 to entry has been added.]

3.13
design for disassembly
approach to the design of a product or *constructed asset* (3.8) that facilitates *disassembly* (3.12) at the end of its useful life, in such a way that enables *components* (3.7) and parts to be reused, recycled, recovered for energy or, in some other way, diverted from the waste stream

Note 1 to entry: The definition is derived from ISO 14021:2016, 7.4.1.

3.14
design life
service life (3.36) intended by the designer

Note 1 to entry: As stated by the designer to the client to support specification decisions.

[SOURCE: ISO 15686-1:2011, 3.3, modified — The abbreviated term "DL" and two deprecated terms have been removed.]

3.15
durability
ability of a *constructed asset* (3.8) or any of its *components* (3.7) to perform its required functions in its service environment over a specified period of time without unforeseen maintenance or *repair* (3.31)

Note 1 to entry: Preventive or routine maintenance are foreseen measures intended to increase functional *service life* (3.36).

[SOURCE: ISO 17738-1:2017, 3.6, modified — The word "building" has been replaced with "constructed asset"; the word "specified" has been added; the reference to "cost" has been deleted; Note 1 to entry has been added.]

3.16
expandability
ability of a design or the characteristic of a system to accommodate a substantial change that supports or facilitates the addition of new space, features, capabilities and capacities

Note 1 to entry: Expandability is a form of scalability. Similarly, contraction can also be a beneficial capability that is a form of scalability.

3.17
exposed connection
connection that is left accessible for *disassembly* (3.12) or modification

3.18
independence
quality that allows parts, *components* (3.7), *modules* (3.23) and systems to be removed or upgraded without affecting the performance of connected or adjacent systems

Note 1 to entry: This can relate to functional, physical and structural independence, as well as the degree of independence.

3.19
inherent finish
condition of material left in its most basic state without contamination by an applied finish

Note 1 to entry: An applied finish can reduce or prevent reuse or recycling.

3.20
life cycle assessment
compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle

Note 1 to entry: Core rules for the development of Type III environmental product declarations, based on life cycle assessment, for construction products are addressed in ISO 21930.

[SOURCE: ISO 14040:2006, 3.2, modified — The abbreviated term "LCA" has been removed; Note 1 to entry has been added.]

3.21
life cycle costing
methodology for systematic economic evaluation of life-cycle costs over a period of analysis, as defined in the agreed scope

Note 1 to entry: Life cycle costing can address a period of analysis that covers the entire life cycle or (a) selected stage(s) or periods of interest thereof.

[SOURCE: ISO 15686-5:2017, 3.1.8]

3.22
modular
composed of *modules* (3.23) for easy construction or arrangement and adaptation or *disassembly* (3.12)

[SOURCE: ISO 7176-26:2007, 4.8.11, modified — References to “modules”, “adaptation” and “disassembly” have been added.]

3.23
module
set of standardized parts or independent units

Note 1 to entry: Modularization can be key to *disassembly* (3.12) in many types of *civil engineering works* (3.6).

Note 2 to entry: A module could be a type of complex *assembly* (3.3).

3.24
obsolescence
loss of ability of an item to perform satisfactorily due to changes in *performance requirements* (3.25)

[SOURCE: ISO 15686-1:2011, 3.14]

3.25
performance requirement
performance criterion
minimum acceptable level of a critical property

[SOURCE: ISO 15686-1:2011, 3.19]

3.26
recyclability
ability of component parts, materials or both to be separated and reprocessed from products and systems and subsequently used as material input for the same or different use or function

3.27
recyclable
characteristic of a product or associated *component* (3.7) that can be diverted from the waste stream through available processes and programmes and can be collected, processed and returned to use in the form of raw materials or products

Note 1 to entry: Whilst many products, components and materials are technically recyclable, in practice, recycling facilities might not be readily available or economically feasible to use.

Note 2 to entry: Recycling infrastructure for the material should exist in at least 60 % of locations where the product is sold. See Reference [21].

Note 3 to entry: The definition is derived from ISO 14021:2016, 7.7.1.

3.28
refurbishability
ability to restore the aesthetic and functional characteristics of a product, *building* (3.4) or other *constructed asset* (3.8) to a condition suitable for continued use

3.29
refurbishment
modification and improvements to an existing *building* (3.4) or *civil engineering works* (3.6) in order to bring it up to an acceptable condition

[SOURCE: ISO 6707-1:2017, 3.5.1.45, modified — The GB synonym "renovation" has been deleted as an admitted term; reference to "plant" has been deleted.]

3.30
remanufacturability
ability of a product to be disassembled and refabricated at the end of its useful life in a manner that provides restoration to a condition suitable for resale

3.31
repair
returning a product, *component* (3.7), *assembly* (3.3), or system to an acceptable condition by renewal or *replacement* (3.32) of worn, damaged, or degraded parts

[SOURCE: ISO 6707-1:2017, 3.5.1.47, modified — The word "item" has been replaced with "product, component, assembly, or system"; "through the" has been replaced with "by"; reference to "mending" has been deleted.]

3.32
replacement
change of parts of an existing item to regain its functionality

3.33
reusability
ability of a material, product, *component* (3.7) or system to be used in its original form more than once and maintain its value and functional qualities during recovery to accommodate reapplication for the same or any purpose

3.34
re-use
use of products or *components* (3.7) more than once for the same or other purposes without reprocessing

Note 1 to entry: Reprocessing does not include preparation for re-use, such as removal of connectors, cleaning, trimming, stripping of coatings, packaging, etc.

3.35
reversible connection
connection that can be disconnected and/or disassembled for easy alterations and additions to structures

Note 1 to entry: This is applicable to *components* (3.7), *assemblies* (3.3), *modules* (3.23) or systems within a *constructed asset* (3.8).

3.36
service life
period of time after installation during which a facility or its component parts meet or exceed the *performance requirements* (3.25)

[SOURCE: ISO 15686-1:2011, 3.25]

3.37
service life planning
service life design (deprecated)
design process of preparing the brief and the design for the *building* (3.4) and its parts to achieve the *design life* (3.14)

Note 1 to entry: Service life planning can, for example, reduce the costs of building ownership and facilitate maintenance and *refurbishment* (3.29).

[SOURCE: ISO 15686-1:2011, 3.24]

3.38
simplicity
quality of an *assembly* (3.3) or system that is designed to be straightforward, easy to understand and meet *performance requirements* (3.25) with the least amount of customization

EXAMPLE Using as few *components* (3.7) as possible, simple assembly steps and maintenance requirements.

3.39
usable space
area of rooms on all floors of a *building* (3.4), either assigned to or available for assignment to an occupant or specific use or necessary for the general operation

3.40
versatility
ability to accommodate different functions with minor system changes

4 Decision-making framework

4.1 General

Not all DfD/A principles are equally applicable or suitable in all situations. Therefore, the careful consideration of which principles should be adopted for each construction project, is part of the DfD/A design and implementation process.

The ease of execution and cost benefit analysis as well as the potential for change or obsolescence shall be considered. Guidance on the impact of, and methods to consider, obsolescence within the service life planning process is provided in ISO 15686-1:2011, Clause 7.

4.2 Developing the client brief

The client brief is very important, since this sets out the vision, technical and functional requirements for the construction works, which will have an impact on the most applicable design approaches. To be most effective, the realization of the client brief should be a collaborative process between the client and the designer.

NOTE 1 For a civil engineering works project, the client brief can also be referred to as the "project definition" or "functional specification".

It is important to challenge the functional specification for a construction works and how it stands the test of time and change. At the conceptual design phase, it is possible to provide more details of the timing of the delivery of the functions, which might lead to phased/staged development or alternative independent delivery mechanism.

The following needs to be established to help direct the subsequent design and service life planning process:

— required service life of the construction works — this can be highly variable from a temporary structure to infrastructure with several-hundred-year service life requirements;

— expected use(s) of the construction works over its required service life — is it going to be a single use type, such as a dwelling; or is there likely to be multiple use types, such as commercial, retail and leisure;

— consideration of staged development to meet the changing demand or alternative uses;

— ownership of the asset — for example, a public sector long-term infrastructure asset versus a speculative commercial building with multiple tenants; this could also be relevant if leasing of products or systems form part of the business model;

— operation of the asset — who will maintain the asset and be responsible for documentation storage and transfer of information;

— any specific options, targets, benchmarks and objectives relating to adaptability, disassembly or outcomes depending on these, such as re-use potential or reduction of life cycle impacts;

— review of the regulatory and policy environment, including compliance requirements and incentive programs;

— review of foreseeable economic and market risks;

— likelihood of obsolescence;

— length of supply contracts (e.g. power or energy contract) for civil engineering works.

NOTE 2 Forms of obsolescence include functional, technological, and economic and can vary from highly likely or planned obsolescence to less likely or lesser degrees of predictability as determined through research and consultation.

4.3 Design strategies

4.3.1 General considerations

The application of DfD/A principles and their relevance and priority shall take into account the client brief and its requirements. The principles are not mutually exclusive, both between and within aspects of disassembly and adaptability.

The first priority is to determine current and potential functional, service life, regulatory, policy and other requirements. When assessing DfD/A design, system, element, component and material options, there should be an assessment of the potential trade-offs between impacts using scenario building and approaches like life cycle costing and life cycle assessment.

The following project characteristics, which could influence the scope and applicability of DfD/A, should be considered on a project specific basis:

1) location physical context — potential and allowance for change due to economic conditions, land-use zoning, demographics, topography and ecology and remoteness of location;

2) location cultural context — labour vs. material costs, formal patterns of style and prescribed methods of construction, conservation requirements;

3) owner-type — owner occupant, developer, investor, corporate, government;

4) use type(s) — buildings: institutional, healthcare, residential, retail, commercial, educational, industrial, warehouse/storage; civil engineering works: e.g. flood defense, water supply, energy supply, transportation;

5) typologies — buildings: e.g. high-rise, low-rise, detached; civil engineering works: industrial process infrastructures, linear infrastructures (including above and below ground), dams and other fluvial works, maritime works and public spaces;

6) construction technologies — e.g. air-supported structure, balloon frame construction, cable stayed bridge, composite construction, curtain wall building, folded-plate structure, framed building, platform frame construction, post and beam construction, precast concrete, steel-framed building;

7) construction materials — e.g. concrete, masonry, steel, heavy timber, light-wood framing or a combination thereof;

8) size — footprint and height, plot space, right of way width; space programme — space types and allocations, spatial organization, etc.;

9) design life — proposed life of "first-use" and any anticipated "further use" identified by the client;

10) performance goals related to environmental, social and economic sustainability targets;

11) performance goals related to construction, function and operation;

12) climate change potential effects or other hazard zone requirements (e.g. wind, flooding, earthquake), which can add requirements for strengthening or alternatively enhanced adaptability or disassembly for major repair;

13) schedule — time to construct and/or disassemble the construction works, time to in-service date can drive alternatives;

14) Service environment — factors that could influence deterioration or additional inspection and maintenance.

Table 1 provides examples of scenarios that illustrate how the context, which stems from the client brief and understanding of the present and future use of the construction works, could influence the applicability of DfD/A principles. These are example scenarios; they are context specific and will not necessarily be applicable to the context of other projects.

Table 1 — Examples of interactions between design context and DfD/A principles

	Scenario description/Context	
	Short term (required service life <20 years) with multiple ownership	*Long term (required service life >60 years) with minimal change in ownership*
Application of disassembly principles	High relevance for reversible connections and independence, repurposing, easily reusable materials	High relevance for durability, standardisation of components, repair and upgrade or easily reusable and recyclable materials
Application of adaptability principles	Low relevance for longer term strategies but improving versatility and convertibility could reduce impacts if repurposing is likely	High relevance, such as expandability of highway capacity, and versatility of public transport hubs in line with future technology shifts

4.3.2 Durability considerations

Durability and adaptability are closely related; and both aspects need to be considered and balanced. If a material is durable but is likely to go out of fashion or become obsolete quickly, it is possible that it will be discarded long before the end of its useful life. By minimizing the maintenance or replacement of a product, there is a potential for reduced environmental impacts over the life cycle. This provides an efficient use of resources and helps to divert materials from landfill. However, if a building is destroyed long before the end of its required service life, and DfD/A has not been properly integrated into the design, the material and energy components that have gone into the structure will not have been used to their fullest extent. If not properly considered, durable materials could obstruct replacement and adaptability, depending on their degree of integration with other products or systems that hinder disassembly (i.e., independence based on component life expectancy).

Requirements for durability can vary across constructed assets and from one component to another within a construction works. These components are selected according to the intended use, cost, and the frequency, difficulty, and extent of maintenance, replacement, and repair. Requirements for durability are expressed in terms of service life. The service life of the construction works provides one basis for determining the service life of the systems and components. The general principles and framework for service life planning are found in ISO 15686-1. Other documents within the ISO 15686 series describe the procedures to be used to assess, predict and apply service life information throughout the life cycle.

Maintenance requirements shall be assessed to ensure that a product will maintain its aesthetic and functional value. Creation and adherence to routine maintenance or preventative maintenance programs is paramount.

Materials with a high durability rating that require less frequent maintenance, repair, or replacement should be selected. In some cases, however, it might be possible to reduce overall environmental burdens by designing for a shorter life, and for easier disassembly and re-use of components and materials (e.g., with temporary structures).

The durability of materials or subsystems within the context of the design life of the constructed asset shall be considered. If the expected design life is short, the importance of durability can be offset by other principles (e.g., accessibility, independence, simplicity, ease of re-use, and recyclability).

Assess the service environment to determine the factors that could influence the rate of material or assembly deterioration and determine resilience requirements. Manufacturers' warranties can be used to provide a marginal measure of a product's durability.

4.4 Levels and scope of analysis

4.4.1 General

The primary goal of DfD/A is to design constructed assets that can adapt to changing requirements or can be disassembled for re-use or recycling considering the various layers and constituent materials (e.g., elements and components). It might not be practical to consider that an entire building or civil engineering works should be disassembled and re-used, as some components (e.g., a ventilation system), might be obsolete by the time it is disassembled, and undesirable for re-use.

The three design for adaptability principles and seven design for disassembly principles specified in 5.2 and 5.3 shall be considered for major elements, major components and the construction works as a whole, so as to determine the overall efficacy of the design to accommodate future uses and material recovery or re-use.

Each of the principles elaborated in Clause 5 should be examined to each of the five levels of analysis set out in 4.4.2 to 4.4.6.

The five levels of analysis should be an integral part of the design, construction and information management processes throughout the life cycle of the constructed asset.

4.4.2 Systems

Analysis at this level is generally applied to adaptable construction works that can change to suit changing requirements. In some cases, entire modular buildings can undergo wholesale disassembly, movement, and re-use.

Also at the highest level, it is possible to find alternative concepts that phase the development, such as twinning lines, or adding temporary features or functional constraints to meet short term capacity requirements, e.g., snow loads, or lowered spring breakup road allowances for gross vehicle weight.

4.4.3 Elements

Analysis at this level focuses on a major structural part of a construction works, e.g., a roof, foundation, wall, or raised flooring system, bridge girders, as well as designs for modular and panelised elements that are readily fit into common dimensional standards.

4.4.4 Component or assembly

At this level, analysis is focused on combinations of several subcomponents that are often non-structural, e.g., valves, solar panels; “layers” or different systems are designed to allow upgrading, repair, and replacement. The replaced products can then enter the recycling loop or be used again in some form.

NOTE Annex A provides an example of how components or assemblies can be assessed for each DfD/A principle.

EXAMPLE 1 A carpet system consisting of carpet, backing, and adhesive.

EXAMPLE 2 Non-load bearing internal partitions.

4.4.5 Subcomponent

Analysis of subcomponents breaks down a component into its smaller pieces, e.g., the duct system of a heating or cooling system; the glazing used for curtain walls; gaskets in piping systems, or controllers and software in a fire protection system.

4.4.6 Material

When a product has been stripped back to its most basic materials, these can be re-used or, at a minimum, serve as a feedstock in the recycling process to produce other materials.

5 Principles of design for disassembly and adaptability

5.1 General

This document and the principles of design for disassembly and adaptability shall be used in conjunction with the principles set out in ISO 15392 and ISO 15686-1.

The DfD/A principles fall into two categories: those related to adaptability and those related to disassembly. Generally, adaptability principles deal with changes in functional use of space for buildings and changes in functional requirements for other constructed assets, while disassembly principles deal with the material resources.

NOTE 1 In this clause the definition of each principle is repeated for emphasis and clarity.

Not all of the principles are necessarily relevant in all situations or contexts. Wherever a principle is applied, the requirements provided within this document shall be followed and the related guidance should be considered.

NOTE 2 See Annex C for guidance on measuring performance related to DfD/A objectives.

5.2 Adaptability principles

5.2.1 General

Adaptability is necessary to accommodate changes in use type, demographics, user needs or due to the need for adaptation to external factors, such as climate change, for resilience or future proofing. The initial cost may be balanced against the future cost of adaptation.

The needs of users might also change with respect to limitation of physical abilities during the course of time. In case of residences, an adaptable building can enable users to live an independent life in their familiar surroundings for as long as possible. Adaptability falls into two categories;

— specific — for known/expected adaptation, and

— general — for unknown potential future adaptations.

Also, adaptations can be sequential, occurring over time (often non reversible), or parallel, able to perform various functions, typically repeatable over a period of time. Specific adaptations in both parallel and sequential modes are less abstract and more clearly defined in functional requirements and typically take precedence over general adaptations.

If the principles of universal design are taken into account at the outset (e.g. by respecting the space needed for manoeuvring a walking frame or wheelchair, the door width, the absence of thresholds or the installation of ramps and lifts), it can avoid the need for costly conversion at a later date.

Design principles for adaptability that shall be considered are

a) versatility; (5.2.2),

b) convertibility; (5.2.3), and

c) expandability (5.2.4).

5.2.2 Versatility

Versatility is the ability to accommodate different functions with minor system changes.

Versatile structures and spaces facilitate alternative uses over the course of a day or week with minor system changes. In designing for versatility for specific adaptation, it is important to consider the needs of the targeted users. For example, having one space that accommodates many uses can reduce the overall building footprint, required floor area, costs, and resources. For general adaptations, leading to potential future adaptations, it is possible to look beyond the boundaries of the current user/owner immediately occupying the space to seek potential partnerships with outside interests that could use it at times when it would otherwise go unused, potentially cutting costs and reducing the need to construct more single-use structures and assets. This type of versatility can result in measurable benefits by increasing building utilization. One of the aims of versatility is to reduce strip-out and fit-out over the life cycle.

A construction system in which parts of the constructed asset are interchangeable to some extent and not necessarily unique to a single application, should be considered. This will allow alterations in the layout through the relocation of components, without significant modification.

EXAMPLE 1 A gymnasium can double as a community theatre or arts centre if it is provided with portable seating and has acoustic panels integrated into the ceilings and walls.

EXAMPLE 2 Day-to-day or intraday changes in use can be made by dividing a room with folding partitions or by placing a removable floor over a pool.

EXAMPLE 3 Parking lots can be used as temporary farmers markets or public plazas for events.

Versatility can also apply to products and components.

EXAMPLE 4 A common connection device can be highly versatile and used in multiple assemblies throughout a building.

EXAMPLE 5 A dividing partition can also function as a conduit for utilities.

EXAMPLE 6 A pipeline that can batch various products or processes can create important variations in products.

5.2.3 Convertibility

Convertibility is the ability to accommodate substantial changes in user needs by making modifications.

In regard to buildings, convertibility is related to versatility, in that both principles involve using single spaces for multiple uses. However, convertibility is achieved by designing the space or fit-up to facilitate minor, non-structural modifications to interior spaces (e.g., partitions, ceiling, and finishes) or furnishings to suit changing needs, either on an infrequent or irregular basis or at a future point in time. Convertibility for multiple uses can improve the profitability of a space, as well as reducing the need for other facilities, thereby reducing resource and energy use.

Convertibility can be related to versatility in civil engineering works, however, conversions are more often sequential, and rarely revert back to the original use (e.g., coal fired power plant being converted to natural gas).

In some exceptional cases, structural components can be rapidly converted to suit changing needs. Such long-term designs involve building in redundancy in the short term, but forgoing the need to demolish the existing construction works or construct a new one for a purpose that can be met, with some creativity, with the existing structure.

NOTE Convertibility can also accommodate increased loading.

Designing for convertibility should include the following considerations:

a) Long spans and post-and-beam construction reduce interior structural elements and allow for structural stability when removing partitions and envelope elements, while allowing for flexibility of interior fit-ups.

b) The design of the structure accommodates the widest variety of interior design, fit-up, and building adaptation possible.

c) Base/support elements (the rudimentary shell of a building) are constructed in a generic way to facilitate a wide range of infill possibilities.

EXAMPLE 1 An articulated, sound-dampening divider within a room can be extended to create two smaller rooms.

EXAMPLE 2 Sports facilities can be converted to accommodate non-sports events such as concerts or fairs.

EXAMPLE 3 An office building can be designed and constructed to enable conversion to residential occupancy.

EXAMPLE 4 Lightweight wall components that can easily be removed or added can be used to modify facility spaces.

EXAMPLE 5 A natural gas pipeline is converted to an oil pipeline to accommodate shifts in energy needs.

EXAMPLE 6 A boiler or prime mover fuel system converts from natural gas to propane depending on energy pricing.

5.2.4 Expandability

Expandability is the ability of a design or the characteristic of a system to accommodate a substantial change that supports or facilitates the addition of new space, features, capabilities and capacities.

In regard to buildings, expandability involves designing to allow for either vertical or horizontal additions in floor space. Expanding vertically can require consideration of structural allowances in the foundation and superstructure to bear larger loads or allow for the ability to easily increase the load bearing capacity of the structure without major disruptions to the occupants. For expanding horizontally, the design shall facilitate the disassembly of existing walls, envelope, or partitions so that space can be expanded without significant damage and materials can be re-used, either on the existing project or another. Designing in this way will also facilitate the reduction of space, as necessary, as well as evaluating the potential for increased space requirements in the future. Designing for expansion can require redundancy, e.g., foundation allowances for vertical and horizontal expansions (additional loads and footprint size, respectively).

In regard to civil engineering works, expandability includes changes (both increase and decrease) to capacity, including various operating modes, throughput, and bearing load by minor revamps or major development phasing.

EXAMPLE 1 Vertical columns can be designed to accommodate an additional floor level on the top of the existing structure.

EXAMPLE 2 Bridges can be designed to accommodate additional lanes of traffic below or alongside the original bridge deck.

EXAMPLE 3 Twinning railways or temporary modules can be used during peak demand.

5.3 Disassembly principles

5.3.1 General

These principles apply to assemblies and systems within a constructed asset that can be disassembled at the end-of-life, or renovated, with the potential for components to be used for other purposes. The disassembly principles that shall be considered are:

a) ease of access to components and services;

b) independence;

c) avoidance of unnecessary treatments and finishes;

d) supporting re-use (circular economy) business models;

e) simplicity;

f) standardization; and

g) safety of disassembly.

Practices that can support the principles are:

a) When possible, materials and components, which can be easily, safely, and more cost-effectively replaced or removed and transported, should be used.

b) A means of handling components during disassembly should be provided. Handling during disassembly can require points of connection for lifting equipment or temporary supporting devices.

c) Components that are sized to suit the intended means of handling should be used. Various possible handling options at all phases of assembly, disassembly, transport, reprocessing, and reassembly should be considered.

d) Spare parts, and on-site storage for them, should be provided, particularly for custom-designed parts, to allow broken or damaged components to be easily disassembled and replaced, and to facilitate minor alterations to the design.

5.3.2 Ease of access to components and services

Ease of access in design allows for a material, component, or connector of an assembly, especially those with the shortest anticipated life cycle, to be easily approached, with minimal damage to and impact on it and adjacent assemblies. Ease of access reduces replacement time and the generation of unnecessary waste during the replacement or maintenance of materials or components. Ease of access is closely related to independence and is often related to uncoupling "layers" of a building or components of construction works that have significantly different lifespans.

Ease of access to parts and components of the building or civil engineering works should be provided for ease of disassembly and adaptability. If possible, recovery of components without the use of specialized equipment should be allowed for.

NOTE Accessibility in terms of ease of entry and use of a building or construction works and its services and facilities by all potential users with the widest range of capabilities is implicitly taken into account by the principles set out in this document.

Exposed connections are left accessible for disassembly or modification of components, assemblies, or systems within a constructed asset.

By making the connections more visible, it will be more apparent where steps have been taken to promote ease of disassembly. Where such connections are not visible, there is an increased risk that disassembly techniques which optimise material and product re-use will not be planned or subsequently adopted in deconstruction or strip out of the construction works.

Connections should

a) be exposed wherever possible;

b) leave necessary room on all sides to accommodate disassembly options including associated disassembly equipment (e.g. pulling heat exchanger bundle, space for extracted heat exchanger bundle and lifting equipment).

5.3.3 Independence

5.3.3.1 General

Independence is the quality that allows parts, components, modules and systems to be removed or upgraded without affecting the performance of connected or adjacent systems.

Maximizing independence of the functional requirements of parts, components, modules and systems is key for optimizing disassembly for both re-use and upgrade. Modularization overlaps between adaptability and disassembly when modules achieve functional independence.

Independence has to do with designing building systems or “layers” to stand independently, to facilitate the removal, adjustment, replacement, or upgrade of components. It is particularly important to think in terms of “layers” when planning from a temporal perspective for functionality and upgrades. Components of constructed assets have different design lives, and these variations need to be factored into the design. For example, the shell might require a service life that varies from 50 to 100 years, while the services might be expected to last 15 years and the interior fit-out elements perhaps 5 years.

For buildings and some civil engineering works, the three principal “layers” related to the constructed asset can be identified as follows:

a) shell and core — structure of constructed asset, including foundation, superstructure, and envelope;

b) mechanical and electrical services — pipes, ducts, cables, machinery, elevators, etc.;

c) fit-out — partitioning, ceiling, floor coverings, fixtures and finishes.

The challenge is to achieve independence of layers without compromising the integration and functional performance of systems and materials, e.g., controlling heat and moisture.

Independence aims to decouple the main systems within a building or civil engineering works. The advantages are the re-use of systems, spatial adaptability, and functional adaptability. A separation of structure from enclosure will greatly facilitate adaptation and disassembly. Disassembly of a system depends upon the separation between components that are arranged within a system. The advantages are re-use of components and adaptability of the system’s functionality. Disassembly at the component level deals with separation between elements and materials, and its main advantage is in the adaptability of the component’s functionality, re-use of the elements, and recycling of the materials.

Materials or components should be removable without disrupting other components or materials. Where this is not possible, the most reusable parts of the assembly should be made the most accessible, to allow for maximum recovery of those components and materials.

The “layers” of the building shall be separated from each other to facilitate adaptation and disassembly. Separating long-lived components from short-lived components will facilitate adaptation and reduce the complexity of disassembly, allowing specific types of materials to be removed one at a time, thus facilitating the collection process for recycling or upgrading.

5.3.3.2 Reversible connections

Reversible connections can be disconnected and/or disassembled for easy alterations and additions to structures.

The use of reversible connections instead of fixed fasteners to connect products or components can allow for easier disassembly. Not only can the material be used again but the connectors (e.g., screws, bolts) can also be re-used. Other methods of disassembly include selecting materials that are fastened by a tongue-and-groove connection rather than by an adhesive compound, which can produce a permanent connection that contaminates the material and affects its re-use and ultimate recyclability.

By making products easier to take apart, so that constituent components are not harmed, elements can be re-used directly, so long as they meet performance requirements. Materials can also be readily separated by material type and then serve as inputs for other products through recycling processes. Poured and welded (wet, chemical, or fixed) connections of otherwise demountable elements decrease the potential for disassembly.

Elimination of the need for caulking and sealants, e.g., by using mechanical- instead of chemical-based water protection in the connections, will ease removal of components for repair and replacement.

Connections should

a) leave necessary room on all sides to accommodate disassembly options;

b) require the same standard tools for assembly as well as disassembly;

c) use universally recognized connection methods that do not damage the materials being connected or the surrounding areas;

d) minimize interdependency of different materials, products, components or systems.

Fewer types of connections should be used. A mix of bolts, screws, and nails requires constant shifting from one tool to another. Fewer connectors and consolidation of the types and sizes of connectors will reduce the need for multiple tools and constant change from tool to tool.

Joints and connectors should be designed to withstand repeated use, so as to minimize damage and deformation of components and materials during repeated assembly and disassembly procedures.

Assembly technologies that are compatible with standard building practice should be used. Specialist technologies will make disassembly difficult and can require specialist labour and equipment that make the option of re-use more difficult.

5.3.4 Avoidance of unnecessary treatments and finishes

Choice of finishes can limit the options for reusing or recycling the substrate, particularly if potentially hazardous substances are included. To support disassembly, finishes that can prevent the substrate from being re-used or recycled should be avoided. Finishes should serve a specific purpose, e.g. for fire and/or corrosion protection.

There might be recyclable or reusable materials that can be used either on the exterior or in the interior of a constructed asset that will have suitable inherent finishes in their “natural state”, so that there is no need to use paint, veneer, or other finishes.

EXAMPLE Cedar wood, stone, and copper roofing.

5.3.5 Supporting re-use (circular economy) business models

5.3.5.1 General

This principle is concerned with supporting the market for re-used, refurbished, remanufactured and recycled materials and products now and in the future, in support of circular economy business models. Design approaches to provide resources for future construction works should facilitate the use of secondary materials and resources in buildings and infrastructure. Wherever possible, the following approaches should be adopted, as appropriate for a specific context.

NOTE ISO 21930 addresses end-of-life approaches for construction products that relate to possible end-of-life scenarios as outlined in Annex B.

5.3.5.2 Reusability

Reusability is the ability of a material, product, component or system to be used in its original form more than once and maintain its value and functional qualities during recovery to accommodate reapplication for the same or any purpose.

Consideration shall be given to the re-use potential of materials, products, components and systems. A consideration of the service life in the re-used application compared to the residual service life of the product or material in the original application shall be factored into this approach.

Materials should be selected for which it can be anticipated that a market will exist for their re-use in the future, and for which facilities exist for any required handling or processing. To facilitate future re-use, materials should be selected that can be re-used in the same application and in the original form, without repair beyond expected maintenance. This approach is intended to achieve the economic and environmental benefits associated with disassembly. The ultimate reusability depends on the value of the material and extent to which it can retain that value and function after being removed or disassembled.

5.3.5.3 Refurbishability

Refurbishability is the ability to restore the aesthetic and functional characteristics of a product, building or other constructed asset to a condition suitable for continued use.

The refurbishing of products can reduce the consumption of natural resources.

Depending on the intended design life of the construction works, refurbishability can also help reduce operating and maintenance costs. The supplier shall make information available on how a product is refurbishable.

The use of construction components that can be refurbished, allowing for an increase in their service life, shall be considered.

EXAMPLE Wood flooring, carpet tiles.

NOTE In this context, components or modules rebuilt and returned to service as part of a routine maintenance program, is considered refurbishment.

5.3.5.4 Remanufacturability

Remanufacturability is the ability of a product to be disassembled and refabricated at the end of its useful life in a manner that provides restoration to a condition suitable for resale.

Remanufacturing differs from refurbishing in that ownership of the product is transferred to the original manufacturers or to another party that provides the restoration services. Remanufacturable products are designed in a manner that allows for complete upgrading: products can be inspected and assembled to their individual elements, and damaged pieces can be repaired or replaced. The product is therefore restored to an “as new” condition for resale by the fabricator.

The use of construction components that revert to the ownership of the original manufacturer (e.g. via take back programs) can reduce waste and lower costs.

EXAMPLE Carpet assemblies.

5.3.5.5 Increased recycling

The use of recycled materials, either directly or as feedstock within a manufactured product, supports the market for recycling of waste materials from the built environment and other sectors. This can reduce reliance on primary non-renewable materials, costs and environmental burdens. Recycling produces both economic and environmental benefits (e.g., reduced energy, water, and natural resource consumption and reduced emissions) by replacing virgin materials with recycled materials within the life cycle. The costs and impacts of transportation of recycling shall be considered.

Consideration shall be given to the use of materials, products, components and systems that have recycled content. Recycled materials might be available as the result of full or partial demolition, deconstruction, disassembly, strip out and other removal of assets. The application of pre-demolition or pre-refurbishment audits can help to identify possible materials and products to be incorporated into subsequent recycling initiatives. Recycling efficiency is optimized with homogeneous material. Recycled products, or products that contain a proportion of recycled content, might also be available from third-party suppliers.

5.3.5.6 Future recycling (recyclability)

Recyclability is the ability of component parts, materials or both to be separated and reprocessed from products and systems and subsequently used as material input for the same or different use or function.

A material is recyclable if it can be diverted from the waste stream and, through existing processes, facilities, and markets, returned to the economy. If a material is readily recyclable, a portion of its initial cost can be recovered at the end of its useful life through separation and resale as a recyclable commodity.

Consideration shall be given to the practical recyclability of materials, products, components and systems. This should include consideration of the current economic value, recovery infrastructure, and markets for the recycled materials.

NOTE Composite materials can pose a challenge, as it is often difficult to separate their individual constituents for recycling at the end of their life.

5.3.6 Simplicity

Simplicity is the quality of an assembly or system that is designed to be straightforward, easy to understand and meet performance requirements with the least amount of customization.

As a design principle, simplicity reduces the number of elements, components (subcomponents), or materials to the minimum required to execute the intended function. Experience shows that simplicity will generally reduce the likelihood of failure or breakdown and facilitate repair. Design options include limiting the use of decorative details, minimize the quantity and diversity of materials used, while working within a client's aesthetic parameters (e.g., using a standard and limited colour palette). One of the aims of simplicity is to remove barriers to disassembly.

While taking into account functional and technical requirements, the number of types of materials components should be minimized. The more homogeneous the materials of a structure, the simpler it is to sort materials on site for re-use and recycling. For components, this can help reduce the tools and techniques required for disassembly simplifying the process of sorting on site and making the potential for reprocessing more attractive, due to the larger quantities of the same or similar items.

EXAMPLE Consolidation of plumbing and electrical service points within a building has the benefit of reducing the length of lines and also reduces the potential points of entanglement and conflict with other elements (walls, ceilings, and roofs).

5.3.7 Standardization

Standardization is concerned with the use of common components, products, or processes to satisfy a multitude of requirements.

Standardized parts, which make it easier for contractors to disassemble structures while using efficient and repetitive techniques, should be considered. Standardization can support aspects of simplicity, adaptability and further re-use. Standardized parts can also allow for easier transportation, storage, and re-use.

Due to the interchangeability of standardized parts and components, standardization facilitates simplicity, adaptability and further re-use in both design and the various phases of constructed assets.

Selecting standard-size material can accommodate re-use and upgrading, since materials can be purchased with greater ease (and more cost effectively) when they are of standard dimension. Standard sizes also cut down on the creation of on-site off-cut waste for everything from timber, plywood, masonry, and insulation panels to floor tiles. Using standard dimensions needs to be reconciled with the client's requirements and the sizing requirements imposed by logistics, ergonomics, and functional needs.

Design should consider optimization of materials such as modular construction or prefabrication to reduce materials use. Prefabricated elements or components and a system of mass production should be used to reduce site work and allow greater control over component quality and conformity.

There are a number of aspects relating to standardisation, including:

i) dimensions — such as standard height and sizes that allow for multiple types of use;

ii) components — such as standard lengths/spans to facilitate further re-use and ease of replacement;

iii) connections — such as connecting parts which can be separated using readily available and standard tools;

iv) modularity — such as volumetric pods which can be slotted together, added to or taken away to promote adaptable living or working environments.

Modular design, and components and preassembled subassemblies that are compatible with other systems both dimensionally and functionally, should be used.

5.3.8 Safety of disassembly

Safety of disassembly is of paramount importance. Any component, module or system to be disassembled requires a disassembly plan that is considered at the onset of design to ensure its effectiveness.

NOTE 1 A good practice is to revisit the original disassembly plan at the time of execution to ensure all new conditions are considered including, but not limited to, inaccurate as-builts, wear or damage to structural components, presence of hazardous wastes, changing regulations, weather, error and omissions.

In the design context, safety of disassembly is concerned with easy access to accurate information on the original materials and assembly methods used for an asset, together with details of any subsequent major renovation. This information can support the correct disassembly sequencing that has been designed into the built asset to support further re-use and recycling.

Documentation that supports safe disassembly shall be maintained and available throughout the life of the constructed works (see Clause 6 for further information).

NOTE 2 The principles and approaches outlined above can support safer disassembly in the following ways:

- accessibility — can facilitate disassembly thereby reducing risk of injury and handling difficulties;
- exposed connection — can help make decisions in the absence of full documentation, such as detailed drawings;
- reversible connections — can enable controlled and non-destructive disassembly;
- interdependence — can enable easier removal of separate parts, potentially reducing loads and improving the working environment;
- avoidance of unnecessary finishes — can reduce the risk of exposure to chemicals and removes the element of doubt where there are similar finishes that could be hazardous to health or not;
- simplicity — can reduce the number of elements, components and materials that could require different approaches, thus reducing time and equipment requirements;
- standardisation — can enable experience of similar systems to be used in the disassembly process, rather than having to potentially deal with elements not previously encountered;
- durability — can provide fewer instances of breakage upon removal.

6 Documentation and information

6.1 General

Documentation that supports adaptability and disassembly of the construction works shall be available and maintained throughout its life. This requires that DfD/A details and instructions are recorded and transferred across the built asset life cycle.

Disassembly manuals shall be prepared, submitted, and incorporated in shop drawings and documentation on the materials used during construction and refurbishment and material marking is needed. Furthermore, a copy of this material shall be made available to parties that need it for reference. If changes are made or additional information is developed at any stages of the life cycle, documentation and models shall be updated accordingly.

6.2 Design details

Sufficient information (see Table 2) shall be generated in the design phase documenting specific disassembly methods, material composition, recovery methods, and adaptable design features. Design details shall include specific disassembly drawings, sequences and methods of construction, and the size, strength, and material of every component involved in the assemblies.

A disassembly/adaptability manual shall be completed at the construction documentation phase and included in the commissioning process. A DfD/A section may be added to the operating manual. Details of specific adaptations should be clearly outlined. General adaptations should be noted along with the rationale for the impact on functionality, noting interconnections, interactions, and interdependencies.

6.3 Material constituents and manufacturers

Products and materials should be traceable to a specific manufacturer or supplier, with contact details, such as product manufacturer websites, included in the construction documentation. This information shall be maintained so that manufacturers can be contacted to assist in a situation where clarification is required (e.g., the separation of materials for future use or recycling).

Material constituents should be recorded to aid in the evaluation of the material or components for reusability or recyclability at the time of disassembly, environmental impacts associated with materials, as well as identifying potentially hazardous materials (specific handling requirements related to hazardous materials should be identified throughout their life cycle).

NOTE Environmental product declarations can be a source of end-of-life information and scenarios for recycling and re-use.

Materials and components should be labelled with their engineering properties so that items can be properly identified and managed at the end of their service life.

6.4 Connection detailing

Connection detailing, especially for reversible connections, should be well documented for the aspect of assembly and disassembly. Connection details are typically documented in detail design documents such as shop drawings and shall include standard descriptions such as the type of connection and connectors, size and material. In case of non-standard connections, step-by-step assembly and disassembly instructions should be provided.

Information on any required tools and necessary handling spaces shall be provided in appropriate documentation. Required tools should be retained onsite where needed for a bespoke connection type.

Durable labels or short instructions with assembly and disassembly information should be considered for the elements close to the respective connections.

6.5 Data digitisation

Data digitisation, such as that required for building information modelling (BIM), can provide a means for capturing and transferring information in standardised formats and processes. BIM can also be used for evaluating alternative designs.

Where this data and information is transferred and forms part of the documentation available at points of adaptation and disassembly, use of BIM or an asset information model (AIM) can provide those involved in these processes a better view and understanding of the best approach to disassembly or adaptability.

EXAMPLE Bar coding, quick response (QR) codes, radio frequency identification device (RFID) tags, or references to more detailed documentation, will be appropriate in some cases. “Intelligent” electronic products that contain a computer chip such as a “green port”, can provide information to facilitate disassembly and re-use.

6.6 Information transfer and management

Transferring and updating relevant information and documentation over the asset life cycle is fundamental to achieving the original design objectives in relation to DfA/D. This includes updating documentation/information in the event of modification, which affect adaptability and/or disassembly.

Information about the disassembly process shall be retained. This shall be done, whenever possible, on the actual components themselves, as well as on permanent as-built drawings, in maintenance and operations manuals, and in other documents.

The information shall be periodically updated to record changes made over the course of time and take into consideration changing re-use and recycling options, market values, etc.

Documentation and information management are very important in realizing the DfD/A objectives. The following checklist items shall be used to demonstrate that the suggested activities have been adopted.

Table 2 — Information transfer checklist

Documentation and information description	***Metric***
DfD/A design details in drawings, specifications, disassembly plan	Yes/no
Disassembly/deconstruction plan, including disassembly sequencing information	Yes/no
Traceable inventory of materials, suppliers, warranties	Yes/no
Approach developed and embedded into handover and operation to ensure transfer and updating throughout the constructed asset’s life	Yes/no
Components, products and constructed asset has directly accessible information pertaining to identification, warranties, services life, disassembly (e.g. bar code, RFID tagging)	Yes/no

7 Continuing implementation of DfD/A

7.1 General

It is important that all involved in the design, product supply, construction, commissioning, operation, refurbishment and decommissioning aspects have sufficient knowledge and understanding to implement the intended DfD/A results. Designers have the major role in considering design for disassembly and adaptability to facilitate the best economic and environmental opportunities. Clients often provide the drivers and the context for designers to adopt this role. The supporting supply chain, from product suppliers, to constructors, facility managers and those decommissioning constructed assets also have a role in supporting DfD/A.

7.2 Product and component suppliers

Those providing materials, products and systems to the construction sector can greatly influence the DfD/A principles laid out in this document. Evaluation of product characteristics and composition, methods of assembly and supporting information against these principles shall be undertaken to identify potential for improvement. Providing access to this information through a digital platform, such as BIM, should be considered.

Sector-based improvement strategies can also be developed, where input from the related supply chain should be considered. At minimum, this shall include representation from design, assembly (construction), disassembly, deconstruction, demolition, and resource management.

This document describes the development of different end-of-life approaches on the construction works or construction product level in Annex B.

7.3 Construction

Most of the decisions pertaining to DfD/A will have been made already so there is an assumption that these would be carried through into the construction phase. Knowledge transfer between the design and construction teams to discuss the DfD/A intent and implementation measures, as well as any perceived challenges which might be encountered during the construction phase, should be undertaken. More detailed planning and atypical procurement could be necessary to deliver these decisions, so collaborative work as early as possible should be undertaken.

Where this is not achievable (e.g. for cost constraints or lack of availability of specified components), the constructors shall work with the design team to identify alternatives that are the next best solution and will minimise impact on other decisions taken to promote DfD/A. Documentation and models shall be updated accordingly.

7.4 Handover/commissioning

A critical aspect of handover is to ensure all appropriate documentation and modelling relevant to DfD/A is transferred to those owning and operating the asset, including training of building owners, their agents and facility managers. See Clause 6 for further information on documentation that should be prepared and transferred.

7.5 Use stage

Routine or scheduled maintenance during the use stage of the asset life shall be established to ensure that the disassembly properties of components and elements are not compromised, including the following:

— documentation and information models are updated or transferred;

— maintenance requirements to optimise durability are complied with;

— unnecessary finishes and treatments are not applied.

NOTE Management and ownership changes can challenge document transfer protocol. Systems or checklists can be put in place to make sure documentation is not lost or out of date.

7.6 Refurbishment

Refurbishment offers the opportunity to embed DfD/A where they might not be incorporated into the asset already. In this instance, the previous steps from the client brief onwards should be considered, alongside the specific DfD/A principles.

In the case of refurbishment of an asset that includes aspects of DfD/A, it is recommended that these are fully exploited during the refurbishment process and retained and enhanced where possible. In particular, alongside the risks outlined in 7.5 are further risks arising from significant refurbishment works, these include:

— reduced capacity for mixed or alternative use, such as creating fixed partitioning where there was previously a more flexible arrangement;

— partial demolition which reduces the capacity for expanding or converting;

— connections are covered or replaced with irreversible connections;

— reusable and recyclable materials and components are removed and there is no further use or a low-grade recovery or disposal route is taken;

— standardised elements are replaced with non-standardised ones.

7.7 End-of-life/decommissioning

Any design for disassembly approaches developed, maintained and retained during the asset life shall be fully transferred and communicated to and acknowledged by those commissioning or undertaking the dismantling of the asset. This shall be made available in the documentation, which had been updated and transferred during the operational phase, including any refurbishment.

For shorter-lived assets, it might be possible to gain and transfer information on how successful design for disassembly approaches were at this stage. This could then inform further projects in their design and products in their development.

Annex B describes the development of different end-of-life approaches for materials, products, components and systems on the construction works or construction product level.

7.8 Education and capacity building

As DfD/A benefits often take many years to observe over a full cycle, conscious promotion of such efforts is required. Therefore, an objective should be set to transfer knowledge from any project adopting the DFD/A principles set out in the standard to third parties. To facilitate this, an operation and maintenance plan and public relations plan shall be developed, implemented and disseminated.

Consideration should be given to the level (and development) of experience of clients, designers, product suppliers, constructors, asset managers, deconstructors and other supply chain actors involved in the constructed asset in the context of DfD/A and wider resource efficiency or supporting circular economy objectives. Relevant DfD/A information from previous projects should be clearly acknowledged, with the principles provided here acting as a checklist to ensure information gaps do not skew the focus of the project.

Where knowledge gaps (based on the specific DfD/A principles) exist an action plan for filling each gap should be developed and implemented. This could be through training, reading guidance or bringing additional resource into the project, such as an advisor with specific experience. For example, training on the maintenance of either the asset or the documentation should be provided.

Annex A
(informative)

Feasibility assessment of design for disassembly options for elements or components/assemblies

Table A.1 provides an example of how specific elements or components/assemblies can be assessed for each DfD/A principle. The example deals with building mechanical systems, which include ducting, diffusers, pipes, flexible tubing, and connectors. A similar DfD/A evaluation process can be applied to other elements and constructed assets. The tabular format can be used to assess and communicate early outline specifications to ensure DfD/A principles are being addressed and to identify opportunities for improvement. Different configuration or design options can be assessed or ranked using decision-making tools.

Table A.1 — Assessment of components/assemblies for specific DfD/A principles

Design for disassembly summary Mechanical/electrical — Mechanical	Versatility	Convertibility	Expandability	Standardization	Ease of access to components and services	Safety of disassembly	Simplicity	Supporting re-use (circular economy) business models	Independence/ reversible connections	Avoidance of unnecessary treatments and finishes
Consider plastic fasteners where corrosion is an issue					X			X		
Use removable/adjustable fasteners: clips, ties, snap locks, clamp and hanger systems, worm clamps, tie wires, twist locks									X	
Use standardized screws with same-sized head				X			X	X	X	
Use corrosion-resistant and dielectric fasteners where appropriate										
Ensure access to one side					X				X	
Common driver; can use magnetized bit							X			
Use Robertson, Torx or Hex fasteners (avoid Phillips and slot screws) for reversibility							X		X	
Use standardized nut and bolt sizes	X			X			X			
Ensure access to two sides (to the nut and bolt)					X					
Common driver; can use magnetized bit				X			X			
Nuts and bolts provide reversible connections; use self-locking nuts to reduce parts required							X		X	
Use embedded nuts for one-sided bolt insertion and removal							X		X	
Two part — Hook and hanger										
Two-part system allows quick disconnect of the hanger from the permanently installed hook. Hanger requires only one tool.							X		X	
Ducts										
Flex duct										
Flexible ducts can be re-used and rerouted and are simple and easy to install	X		X				X		X	
Pre-insulated option is available							X			
Specify quick clamp connections									X	
Fibre ducting contains one component (consider the possibility of fibre emissions)							X			
Rectangular ducts (metal) have common format/size. Use common rectangular ducts where ducting systems are not expected to change frequently.	X		X							
Use reversible fasteners and seals for duct installation									X	
Only one component is required. Provides minimal size and weight and is reversible.							X		X	
Standardized; provides simple, reversible installation. Separate fasteners are not required.							X		X	

Table A.1 *(continued)*

Design for disassembly summary **Mechanical/electrical — Mechanical**	**Versatility**	**Convertibility**	**Expandability**	**Standardization**	**Ease of access to components and services**	**Safety of disassembly**	**Simplicity**	**Supporting re-use (circular economy) business models**	**Independence/ reversible connections**	**Avoidance of unnecessary treatments and finishes**
Specify modular, self-contained, plug-and-play, internally matched components	X		X				X		X	
For easy access, use open ladder raceways instead of conduit where possible. Install below suspended ceiling and/or HVAC where appropriate.					X					
Standardized labelling facilitates recognition										
Facilitate speed of recovery and recycling by using labels, tags, imprinted or engraved information										
Use colour-coded or alphanumeric (end-point) identification label or tags for all runs										
Label all circuits on distribution boxes for ease of identification. Match to electronic map/control panel.										
Use standardized flexible tubing that can be recovered and re-used	X									
Specify flexible tubing instead of rigid conduit to simplify installation and facilitate disassembly	X									
Use colour-coded flexible tubing to aid in quick identification										

Annex B
(informative)

Developing end-of-life scenarios

Design for disassembly should enable the selection, collection, recycling/reprocessing and re-use of construction materials, products, components and systems, thereby contributing to the evolving concept of a circular economy. This concept depends on the efficient use of resources and the closing of the life cycle loop by avoiding waste, both in terms of amount and hazardous potential. The implementation of this concept depends on the provision of documented information according to Clause 6 in order to support the application of the DfD/A principles in 5.3.

The assessment of the full life cycle of a construction product requires the development of scenarios at the level of buildings or civil engineering works, in alignment with the requirements of modules C1-C4 as described in ISO 21930. Although most removal methods involve more than one type of end-of-life scenario, the following methods can be defined:

1) demolish the construction works by destructive methods;

   EXAMPLE Implosion, high reach arm, wrecking ball.

2) disassemble and separate components of the construction works by removing parts (deconstruction, dismantlement);

3) selectively disassemble specific components of the construction works (partial deconstruction) and demolish the remainder of the construction works by destructive methods (partial demolition).

The development of end-of-life scenarios for construction works should take into account the decisions made during the design and construction stages of the life cycle. The development of end-of-life scenarios could also depend upon considerations such as:

— service life planning;

— proximity to other structures;

— environmental issues;

— hazardous waste content and other occupational health hazards;

— use of recyclable products;

— ease of deconstruction;

— recyclability of building products;

— adherence to the design guidance provided in this document;

— manufacturer take back programs;

— degree to which building materials can be separated, collected and prepared for re-use or recycling.

Modelling the life cycle of buildings requires a clear scenario at end-of-life (deconstruction/demolition respectively).

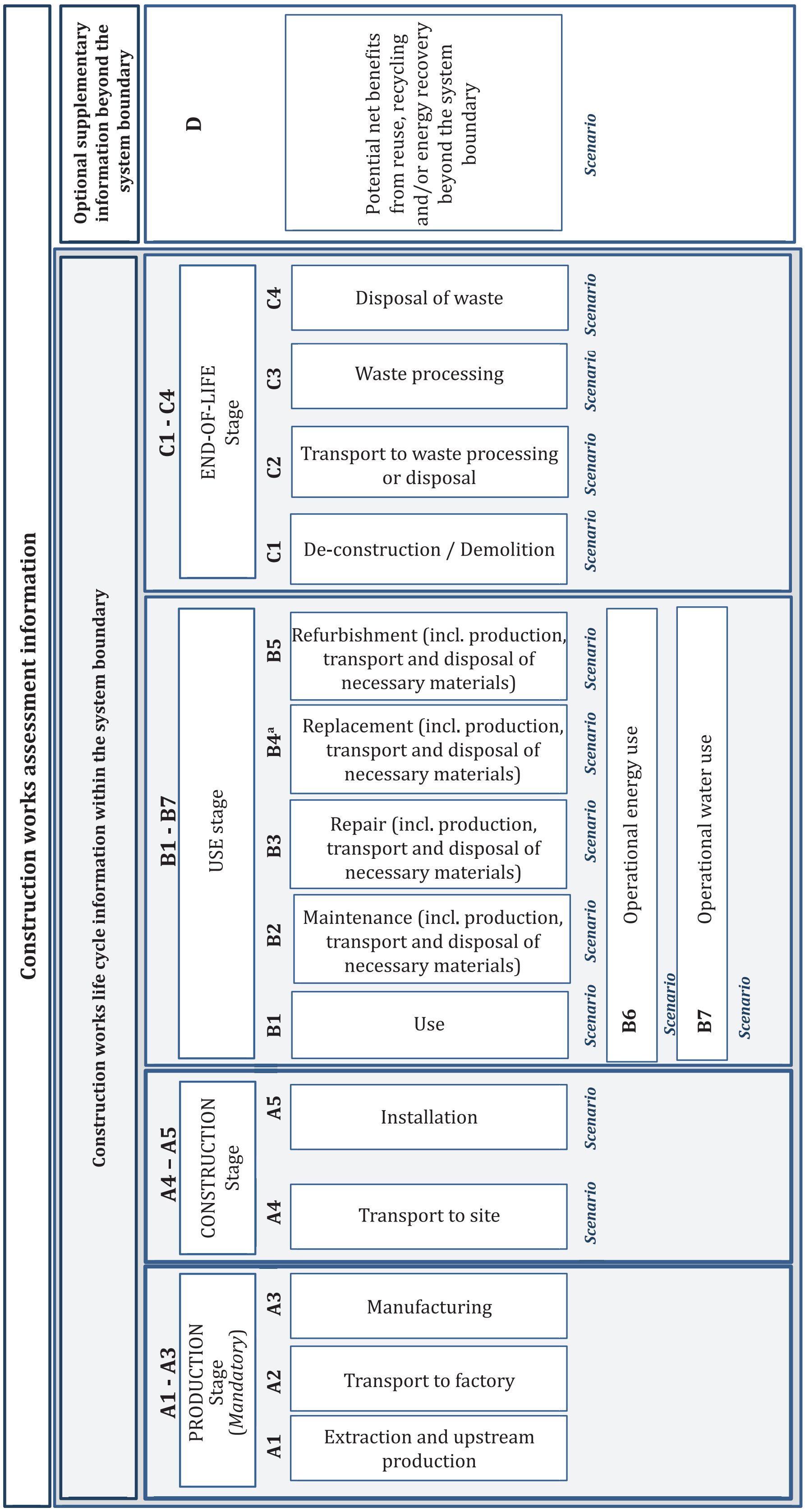
Modelling end-of life scenarios influences the provision of information at the product level when addressing the entire life cycle in an environmental product declaration (EPD) according to ISO 21930. This also applies to the determination of net benefits of building products beyond the system boundaries from Module D (future re-use, recycling and energy recovery), which should be realistic.

Therefore, the EPD should provide all potential scenarios for deconstruction/demolition (Module C1) at the building level.

NOTE End-of-life scenarios also encompass the replacement of products during the use stage (B4 in Figure B.1).

It is necessary to develop probable end-of-life scenarios for the construction works in order to model the full life cycle of building products used as part of the construction works. Information related to end-of-life scenarios of the construction works is required to develop cradle-to-grave environmental product declarations for construction products according ISO 21930. End-of-life scenarios at the construction works level are developed and documented under modules C1–C4 in Figure B.1. End-of-life scenarios should reflect the existing technology and current practices applied in the region where the construction works is located.

End-of-life scenarios generally reflect the current treatment technology for reclaimed material available in the respective country (i.e. the region where the construction works is located). However, they should not use best or worst case assumptions but reflect average and realistic assumptions based on the present national state-of-the-art and common practice.



a Replacement information module (B4) is not applicable at the product level.

Figure B.1 — Common four life cycle stages and their information modules for construction products and construction works and the optional supplementary module D

Annex C
(informative)

Measuring performance

C.1 General

Setting objectives relating to DfD/A can be meaningless if there is no mechanism to demonstrate the progress against these objectives compared to a business as usual scenario. Establishing the baseline performance in the business as usual scenario is therefore a priority to measuring the progress towards DfD/A and subsequent implementation. There are specific areas of performance, which could be measured, either in a quantitative or qualitative sense to determine the baseline scenario against which progress can be assessed.

This Annex provides brief guidance on approaches to measurement practices that can be adopted to set objectives, targets and monitor performance. Ways of ranking and aggregating the measures can also be envisaged as part of an assessment system but the development of such systems is outside the scope of this document.

The measurement approaches are set out in the order of the DfD/A principles without any indication of hierarchy. The selection of an appropriate set of performance metrics and targets will be most effective if it aligned with the specific principles planned and adopted during the development of the client brief.

The performance measures assessing each DfD/A principle can be assembled into a matrix or checklist to guide users in design for disassembly and adaptability; refer to Annex A for an example. In some situations, other tools will be required to perform more detailed analyses.

NOTE There are a number of research activities underway to facilitate integrated performance measurement, such as, “overall re-use potential and/or transformation capacity”, which could be used in the future to present a more holistic performance perspective.

Best practices include the use of a competency checklist (yes/no) indicating the completion of competency actions.

Best practices include the use of a dissemination plan and a checklist (yes/no) indicating the completion of actions set out in the dissemination plan.

C.2 Versatility

Versatility can be measured by the percentage of usable space that has multiple uses on a daily, weekly, or monthly basis, without requiring changes to the main features of the space.

C.3 Convertibility

Convertibility can be measured by the percentage of usable space that has been designed to be converted easily to multiple uses.

C.4 Expandability

Expandability can be assessed in terms of the number of additional floors or percentage of additional floor space possible without major alteration to the foundation and structural system. The percentage of reserve load bearing capacity can also be used to assess expandability.

A “yes or no” assessment of vertical expandability can be made if the structural design of the designated roof area allows for supported loads of at least one additional floor-level of a similar use-type.

Horizontal expandability can be assessed in terms of the amount or percentage of additional lot area not covered by the building area which is permitted to be built on.

NOTE Expandability can be constrained by structural design limits or municipal planning regulations.

C.5 Ease of access to components and services

An ordinal or interval rating scale for the relative accessibility provided by design options can be created. In this way, design options can be ranked. An example might be a 0 to 5 scale, with each point given a clear definition, for example:

0) no accessibility without significant damage to surrounding materials”;

1) limited accessibility with some significant damage to more than 50 % the surrounding materials;

2) limited accessibility with minor damage to more than 50 % of surrounding materials;

3) mostly accessible with minor damage to less than 50 % of the surrounding materials;

4) mostly accessible with only minor damage to less than 25 % of the surrounding materials;

5) full accessibility with minimal work and no damage to surrounding materials”.

A “yes or no” assessment can be made for each connection type, depending on whether it is exposed or not.

C.6 Independence

While independence is a difficult characteristic to quantify, an ordinal or interval rating scale for the relative independence of design options can be created. In this way, design options can be ranked. An example is a 0 to 5 scale, with each point given a clear definition, e.g., “0 — no consideration to lifespan of component, hierarchy and modularity, sequential assembly” to “5 — parallel assembly and open, modular hierarchy”.

Components that are

a) dependent and fixed are characterized by

    i) maximum integration;

    ii) a hierarchy of assembly, which is not related to the component service life and expected time until obsolescence; and

    iii) the application of sequential assembly sequences.

b) independent are characterized by the

    i) application of parallel instead of sequential assembly/disassembly; and

    ii) creation of an open hierarchy of distinct modules.

C.7 Reversible connections

A “yes or no” assessment can be made for each connection type, depending on whether it is reversible. At the subcomponent or higher levels, one can measure the total percentage of connection types that can be reversed to recover materials.

C.8 Avoidance of unnecessary treatments and finishes

At a material level, a “yes or no” assessment is possible: is the material “unfinished” and recyclable or reusable? If the material finish does not inhibit its re-use or recyclability, it satisfies this criterion.

C.9 Supporting re-use (circular economy) business models

Some indicators which could be applied here include:

— percentage (by weight or volume) and value of reclaimed content;

— percentage (by weight or volume) and value of recycled content;

— for each material or component in the construction works:

  — practically reusable or not — based on disassembly requirements and service life versus design life of construction works; for a product to be deemed reusable, there needs to be an application that allows an end-user to economically re-use the product without extensive cleaning or restoration; Re-use can be graded on a continuum, ranging from re-use of the entire structure to re-use of selected materials;

  — practically recyclable or not — based upon ease of separation into material streams and current availability of reprocessing facilities for each material stream at expected grade (e.g. levels of contamination with other materials);

— for refurbishability, a “yes or no” assessment of a product is possible, based on specifics provided by the supplier;

— for remanufacturability, a “yes or no” assessment of a product is possible, based on specifics provided by the supplier.

C.10 Simplicity

Metrics for simplicity include the number of

a) parts per element or component from a comparative perspective; and

b) dimensions or sizes of similar materials (standardization).

C.11 Standardization

The level of standardisation within the built asset can be determined at various levels. This could be through a percentage of the overall build (cost, volume or mass), for each of the following categories:

i) dimensions;

ii) components;

iii) connections;

iv) modularity;

v) interoperability.

C.12 Safety of disassembly

The checklist detailed in Table 2 could be completed, alongside the following metrics:

— durability — service life of each structural element as a percentage of design life of constructed asset;

- accessibility — high, medium, low (through assessing numbers of elements achieving 0/1; 2/3; or 4/5 scores);
- exposed connection — percentage; yes or no;
- reversible connections — percentage; yes or no;
- interdependence — high, medium, low (through assessing numbers of elements achieving 0/1; 2/3; or 4/5 scores);
- avoidance of unnecessary finishes — percentage; yes or no, where applicable;
- simplicity — high, medium, low (based on simplicity assessment);
- standardization — high, medium, low (based on simplicity assessment).

C.13 Durability

Durability is not listed as a DfD/A principle in this document, but it is a key consideration that impacts DfD/A decision-making. Metrics for durability can include the cost of maintenance as a percentage of the purchase price, the service life (years) of a given product compared to alternative products that serve the same function at the same performance level and the "material intensity per standardized unit of service".

EXAMPLE 1 Corrosion-resistant reinforcing steel is used instead of unprotected reinforcing steel.

EXAMPLE 2 If a bituminous roofing membrane lasts 30 years instead of 15, the waste generated per year of use is cut in half.

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