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Design for system retirement

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ABSTRACT

While almost all system design texts identify that designing for life cycle is an essential aspect of system design, only a few make mention of designing for disposal at the end of life, and fewer still provide any guidance how to design to address this important issue. Further, disposal at the end of life is just one of the options in the Retirement Stage of the system life cycle—ideally, the system will be transitioned into another life cycle, on the basis that the longer a system exists in some form, there is lower cost and lower environmental impact resulting from the need to develop replacement systems. A good system design, therefore, should not only achieve longevity of use in the first life cycle of the system but should aim for longevity of use in all subsequent life cycles, until disposal is the only viable option that remains for the system elements. This paper begins by addressing the potential for multiple life cycles of a system, making a distinction between end of life and end of life cycle, and suggesting a useful taxonomy for the terms associated with system retirement. A simple three-step methodology is then presented for the consideration of the issues relevant to design for all aspects of retirement of a system: identify the reasons for retirement, identify the potential retirement methods (making use of the presented taxonomy), and identify the design issues that arise from the consideration of each retirement method. A simple example of the use of the methodology is presented to provide the basis for some discussion and conclusions.

1. Introduction

System design must have a focus on the entire system life cycle, including operation, maintenance and support, and retirement. Blanchard and Fabrycky (2011, 112–113) suggest that, among a number of considerations in systems design, the following life-cycle aspects should be considered: design for sustainability, design for reliability, design for availability, design for supportability and serviceability, design for producibility and disposability, and design for affordability. Blevis suggests the need for designers to seek sustainability by focussing on disposal, salvage, recycling, remanufacturing for reuse, reuse as is, achieving longevity of use, sharing for maximal use, achieving heirloom status, finding wholesome alternatives to use, and active repair of misuse (Blevis, 2007).

Life-cycle issues are becoming increasingly important to designers as such issues have become of much greater interest to business owners, consumers and regulators. Business owners are becoming more aware of the total cost of ownership over the life of the system. Consumers are more conscious of the effect that the operation and disposal of systems has on the environment so environmental factors can be taken into account when making purchases. Regulators are responding to the increased community awareness and are beginning to recognize that some aspects of sustainability require regulation to be achieved. International standards such as the ISO 14000 series (ISO, 2004) have been developed for environmental considerations across the whole life cycle and have been implemented across a variety of sectors (Marimon et al., 2011). For example, in order to reduce the environmental impact of end-of-life vehicles, regulators in the European Union, Japan, USA and Australia require manufacturers to take back their products and recycle them at the end of their useful life (Go et al., 2011).

For designers, these pressures have led to a number of efforts to increase the sustainability and reduce the environmental impact of the system (and is constituent elements) throughout its life cycle. For example, environmentally conscious design and manufacturing (Blanchard and Fabrycky, 2011) incorporates the notion of design for environment (DfE) (Diwekar and Shastri, 2011), which is a proactive activity aimed at prevention of environmental impacts.

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DfE has three major elements (Crow, 2012): design for environmental manufacturing, design for environmental packaging, and design for disposal and recyclability. Within DfE, life-cycle assessment (LCA) provides a framework for quantifying and analysing environmental impacts in the life cycle of products and services (Thorn et al., 2011) and processes (Jacquemin et al., 2012). In support of DfE, there are a number of other design-for-disposal approaches such as design for disassembly (DfD) (Go et al., 2011), design for recycling (DFR) (Kriwet et al., 1995), and design for remanufacturing (DFM) (Hatcher et al., 2011). The Recycling Cycle of Materials (RCM) tool (Candido et al., 2011) provides scientific/technical support in the selection of recycling materials.

While almost all system design texts identify that designing for life cycle is an essential aspect of systems design, only a few make mention of designing for the end of the life cycle, and fewer still provide any guidance on this important issue. Further, disposal is just one of the options in the Retirement Stage of the system life cycle—the others are rarely incorporated formally as design issues. This paper begins by addressing the potential for multiple life cycles of a system (making a distinction between end of life and end of life cycle) and suggesting a useful taxonomy for the terms associated with system retirement. A simple three-step methodology is then presented for the consideration of the issues relevant to design for all aspects of retirement of a system: 1) identify the reasons for retirement, 2) identify the potential retirement methods (making use of the presented taxonomy), and 3) identify the design issues that arise from the consideration of each retirement method. A simple example of the use of the methodology is presented to provide the basis for some discussion and conclusions.

2. System, system life-cycle stages, and system design

2.1. System

The term 'system' is often used to be synonymous with the term 'product'—that is, the technological elements introduced into service to provide the functions required by the business it supports. However, a system is much more than the fielded technological product (hardware, software, and firmware) and is considered to comprise other elements such as processes, people, information, techniques, facilities, services, and other support elements (INCOSE 2011). Consequently, retirement of the system involves more than just the disposal of (some of) its products.

2.2. System life-cycle stages

ISO/IEC15288:2008(E) (ISO/IEC, 2008) defines a "… set of processes to facilitate communication among acquirers, suppliers and other stakeholders in the life cycle of a system". ISO/IEC TR 2478-1:2010 (ISO/IEC, 2010) provides a guide for the life-cycle management of systems based on ISO/IEC15288 and, inter alia, defines six life-cycle stages for a system: Concept, Development, Production, Utilization/Support, and Retirement.

2.3. System design

In the Concept Stage, designers focus on capturing business needs and translating those needs into formal requirement sets for the system. Requirements, including those to support retirement, are prioritized by business owners in accordance with the perceived cost-benefit in the context of the system design and the business purpose. Where there may be an additional cost to design for one or more retirement methods, the business owners will be able to identify the cost of preparing for that eventuality and compare that to the future cost of implementing that method without support of the system design.

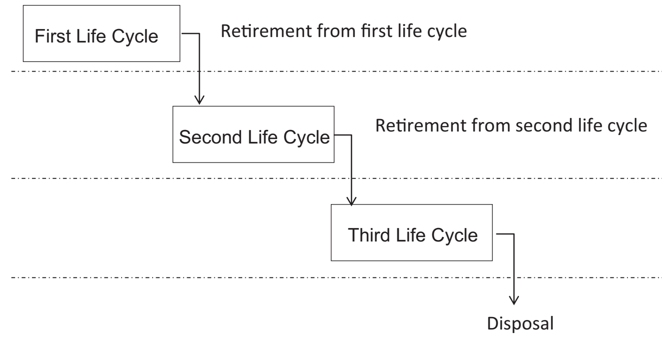

Fig. 1. A system may be retired from a number of life cycles before final disposal at end of life.

In the Development Stage, design becomes more detailed and is more focused on the physical solution, which is then manufactured, produced, or built in the Production Stage. The system spends the largest portion of its life in the Utilization and Support Stages until it is finally retired in the Retirement Stage. Here we focus on the impact that design in the Concept Stage has on the activities in the Retirement Stage.

3. The retirement stage

Of the twenty five processes defined in ISO/IEC15288, the process directly related to the Retirement Stage of the system life cycle is the Disposal Process, which comprises the following activities: plan disposal, perform disposal, and finalize disposal (ISO/IEC, 2008). The 'perform disposal activity' has the following tasks: acquire disposal enabling systems; withdraw operating staff; disassemble the system to facilitate removal for reuse, recycling, reconditioning, overhaul, archiving, or destruction; remove the system from its environment; and conduct destruction of the system (ISO/IEC, 2008).

According to the INCOSE Systems Engineering Handbook (Haskins, 2011), "The purpose of the disposal process is to remove a system element from the operation environment with the intent of permanently terminating its use; and to deal with any hazardous or toxic materials or waste products in accordance with the applicable guidance, policy, regulation, and statutes." Under the heading "Disposal and Retirement", the Guide to the Systems Engineering Body of Knowledge (SEBoK, 2012) says: "Product or service disposal and retirement is an important part of system life management. At some point, any deployed system will become one of the following: uneconomical to maintain; obsolete; or unrepairable. A comprehensive systems engineering process includes an anticipated equipment phase-out period and takes disposal into account in the design and life cycle cost assessment."

The list of disposal options in the Disposal Process of ISO/IEC15288:2008(E) and the Retirement Stage of ISO/IEC TR 2478-1:2010 (ISO/IEC, 2010), as well as the language used in the definitions in the SE Handbook (INCOSE 2011) and the SEBoK (SEBoK, 2012), implies that disposal of the system occurs at the end of its useful life which coincides with the end of the system life cycle. While that may be the case, and the system will eventually require disposal, it is important to recognize that a system may exist in more than one life cycle and that there are other options for a system at the end of its current life cycle within the organization that acquired it. In fact, to improve sustainability (and to approach the final goal of zero waste), the system must be designed to exist in as many life cycles as possible, for as long as possible—also called product multi-use, or closed-loop product cycles (Kumar et al., 2005). In the Concept Stage, a distinction must therefore be made between the end of the system's current life cycle and its eventual end of life. Further, designing for the life cycle requires system designers to address more than just disposal at the end of life because the system may well exist in a number of life cycles throughout which it desirably may be acquired and retired a number of times before reaching its end of life.

3.1. "End of life" versus "end of life cycle"

As illustrated in the example in Fig. 1, a system may be developed from initial design in the Concept Stage of an initial life cycle and then delivered, deployed, operated, and supported throughout that life cycle. If the organization that owns the system changes focus and moves away from the business area for which the system was acquired, the initial owners may sell the system to a second organization which, having completed the Concept Stage of that life cycle, has decided to meet business requirements with a commercial off-the-shelf (COTS) solution, albeit second-hand. As illustrated in Fig. 1, the system then enters a second life cycle, perhaps with a number of its elements (the operating personnel, for example) replaced. When the second organization wishes to replace the system (perhaps because it has become costly to maintain), the system may be sold on to a third organization which wishes to meet its systems design with a modified-COTS solution based on a refurbished second-hand system—again, a number of system elements may be added or removed and other elements added. As illustrated in Fig. 1, the third organization acquires the system, refurbishes it and then fields it in a third life cycle. In this example, Fig. 1 illustrates that the system is uneconomical to repair at the end of the third life cycle, and is disposed of as scrap.

3.2. Design for end of life cycle

Designing for more than one life cycle is important because, if designers assume that there is only one life cycle and design just for disposal of the system products at end of that life cycle, then that disposal method may well be the only option available at the end of that life cycle (or, at least, other options may have been constrained). Yet, for minimal environmental impact, system design should address the system's existence in as many life cycles as possible (on the basis that the longer a system exists, there is lower cost and lower environmental impact resulting from the need to develop replacement systems). A good system design should therefore not only achieve longevity of use in the first life cycle of the system (Blevis, 2007) but should aim for longevity of use in all life cycles until disposal is the only viable option remaining.

3.3. Taxonomy of retirement terms

A survey of related literature highlights that retirement terms (such as reuse, refurbishment, reconditioning, renewal, renovation, remanufacture, salvage, and recycling) are used interchangeably as well as in a number of different forms of hierarchy (which is not at all assisted by the fact that the majority of terms are largely synonyms by their dictionary definitions and common usage). There are subtle differences, however, which begin to matter when considering design for retirement as opposed to simply design for disposal. Before presenting the methodology for design for system retirement, the following taxonomy is offered within which to consider the steps of the methodology. It should be noted that no attempt at disambiguation has been attempted—the terms have not been redefined and are in keeping with their use in the literature.

3.3.1. Recovery

If the system cannot be used as it was originally intended in its current state, it may be able to be recovered in some way—that is, *reused*, *refurbished*, *remanufactured*, or *recycled*. If the complete system cannot be reused, refurbished or remanufactured in some manner, then individual elements may be recovered from the system and put to some other use through salvage, or specific materials may be recovered for recycling.

3.3.1.1. Reuse. If the system is still useful on retirement from one life cycle, it (or major elements of it) may be reused in another life cycle, in two main ways:

1. *As a complete system*. On retirement from the current life cycle, the system may be able to be re-used in a second life cycle in its original role or in a diminished role.
   a. *In the original role*. If the system is of no further use to the organization but is still able to function in its original role in its current state, the system may be retired by sale (or donation) as a second-hand item; or as a trade-in on a replacement system.
   b. *In a diminished role*. Since the system performance may well be diminished due to the wear and tear of operation in the first life cycle, reuse may be in a different—most likely lesser, or diminished—role (Gerrard and Kandilikar, 2007). As a functioning system, it could be reused in a second-tier element of the organization (perhaps in a training area or in a lower-priority/lower-readiness element of the organization). The system may be able to be put to some useful purpose, even within the same organizational context. On a farm, for example, if a tractor has damaged axles and suspension and is no longer road-worthy, the farmer might raise the chassis on blocks and reuse the power take-off to drive a pump to reticulate water.
2. *As separate system elements*. In some cases the complete system may not be able to be re-used but one or more elements are still useful, so the system may be disassembled in order to *salvage* working products, subsystems, assemblies, or components that can be reused individually as spare parts. For example, an organization may salvage elements to retain in inventory as spare parts for sibling systems that remain in service. In extreme cases, if spare parts are no longer available, the business owners may choose to retire an otherwise functioning system so that its elements can be salvaged (cannibalized) in order to keep sibling systems in service.

3.3.1.2. Refurbishment. If the system cannot be reused in its original role in its current state, then some additional work may be undertaken to refurbish or remanufacture the system with the same or similar functionality. After refurbishment, the system may continue operating in its original role. This refurbishment may replace worn parts, renew lubricants and seals, replace coolants, and may provide a new coat of paint. The refurbished (*renovated*, *renewed*, *reconditioned*) system then continues in its current life cycle, or enters its next life cycle (perhaps even with some form of limited warranty). Practices such as refilling toner cartridges for laser printers or recharging coolant for refrigerators are examples of refurbishment.

3.3.1.3. Remanufacture. The system may not be able to operate in its original role without some significant work. In those cases the system may be re-manufactured—that is, returned to a like-new condition, perhaps even with a warranty to match (Hatcher et al., 2011), (Ostlin et al., 2009). To be remanufactured, the system is disassembled and rebuilt using original and replacement parts to meet the original specifications. Further, Cort (2003) makes the distinction that remanufacture occurs once the system has reached the end of its useful life, whereas refurbishment may occur at any point, even within the same life cycle in order to extend the system's useful life. The system could be remanufactured by the original equipment manufacturer (OEM), through contract manufacturing under contract from the OEM or a customer, or through a third-party manufacturer (Hatcher et al., 2011).

3.3.1.4. Recycling. Recycling (Lambert and Gupta, 2005) involves recovering from the system raw materials (including scrap from production processes) that are then recycled, generally into a different form—such as recycling wood for pulp and shredding vehicle tyres for road surface material. In some cases, once the system has been stripped of any useful parts or hazardous materials, it may be scrapped—that is, broken into pieces that are sold as scrap (as might occur for a ship's hull, for example).

3.3.2. Disposal

If the system cannot be recovered by any means, it may be destroyed and disposed of as waste, or placed in storage if no other method is tenable.

3.3.2.1. Destruction. If the system does not contain any useful parts, or any hazardous materials, it may be destroyed and disposed as waste as landfill or, in some cases, it may be incinerated. Destruction is the least desirable of the disposable options because land filling and incineration are not sustainable since all functional and material value is lost (Kumar et al., 2005). Even if a significant portion of the system can be recovered in some manner, however, some part of it may have to be destroyed.

3.3.2.2. Storage. When no other recovery or disposal methods are acceptable or tenable, the system may be placed in storage of some sort. Even if the system is retired by some means other than storage, the information/documentation associated with the system may need to be stored or archived as part of the organization's historical records, often in order to comply with archival regulation(s).

3.4. Retirement of a system versus disposal of a product

So, design for system retirement must consider the retirement of all elements (products) of the system at the end of a given life-cycle, not just retirement of each of the system's elements (or, even more narrowly, not just disposal of each the elements). While it is essential that designers consider the environmental impact of disposal of each of the major physical products associated with the system, they must also consider the "disposal" other system elements such as processes, people, information, techniques, facilities, services, and support elements (as well as which of those elements remain with the system in the next life cycle).

In the next section we propose a simple methodology for design for system retirement.

4. A Methodology for design for system retirement

In order to be independent of life-cycle, a more general view should be taken in order to accommodate all aspects of retirement of all elements of the system as it transitions though a number of life cycles, not just disposal of products at the end of their life cycle. A simple three-step methodology is proposed here for addressing design for retirement:

1. identify the reasons for system retirement,
2. identify the potential retirement methods available, and
3. identify the design issues that arise from the consideration of each retirement method.

Each of these steps is described in more detail in the following sections.

4.1. Step 1: identify reasons for system retirement

The business owners may intend to operate the system until it is no longer economical to repair, in which case system designers need only concern themselves with the issues of disposal. If a true life-cycle approach has been taken to the selection of the system as a business capability, however, the business owners will have addressed whole-of-life ownership costs and are probably more focused on the point at which it is most cost-efficient to replace the system, rather than wait until it has no value and can only be destroyed or sold for scrap, or worse, carry the ongoing cost of storage because no other retirement method is available. If, for example, there is a point in the life cycle at which the owners can capitalize on the residual value of the system, then they will wish to be able to sell it as a going concern—in that case, at that point in time, issues such as recycling and destruction are not directly relevant. For example, a system could still function in accordance with its original requirements but the business owners may recognize an opportunity to replace it with a new generation with lower running costs. Consequently, the original system still has a market value and could be sold or traded in. Alternatively, there may be a point in the life cycle at which it is better to trade in the system before operating costs reach a certain level or warranty periods are exceeded—an approach taken by hire-car companies, for example.

Additionally, even in straightforward, every-day, systems, retirement should be addressed during acquisition. For example, when acquiring a car, the owner is well advised to keep resale value in mind before modifying the vehicle too narrowly to suit their own tastes—any additional modification has the potential to lower the attractiveness of the car on resale, which may reduce further the set of potential buyers or, at the very least, extend the time taken to sell the car.

Consequently, before considering design issues that result from the need to retire the system, the business reasons for retirement must be established when gathering stakeholder requirements in the Concept Stage—it is fundamentally a business-management issue. The business owners should identify the circumstances under which they intend to, or may be forced to, retire the system. While those circumstances will tend to be specific to the system of interest, there are a number of generic reasons why the system may be retired at the end of a given life cycle:

1. The system may no longer be usable and/or supportable.
2. One or more critical elements of the system may be unusable or unsupportable.
3. The system, or one of its significant elements, may be damaged beyond economical repair.
4. The system, or a significant element of it, is being retired because there may no longer be a business need for the system; or the business owner may not be able to afford it.

During the Concept Stage, designers act as agents of the business owners of the first life cycle and consequently take into account the best interests of those customers. Designers have a much broader obligation, however, to look forward as far as possible to identify the reasons for retirement from all future life cycles. This omniscience may be difficult in some cases, but in many (such as is the case for automobiles) the reasons for retirement from any one life cycle will be similar to those for other life cycles and can be identified during Concept Design. In any case, designers must consider the design issues relating to disposal at the end of the useful life of the system, as well as at the end of each intervening life cycle. They must design for the system's life to be as long as possible and therefore support as many retirements as possible.

4.2. Step 2: identify potential retirement methods

Once the reasons for potential retirement have been identified, each can be examined for potential retirement methods, although not all may apply to all reasons for retirement. The identification of the reasons for retirement creates a focus on the business requirements for retirement, which then allows consideration of the ways in which such retirement options may be enacted. In addition to eventual disposal, therefore, the business owners should consider the issues relating to the end of the current life cycle for the system, which may occur before end of life—that is, they should examine how the business intends to retire the system, by such means as sale, lease, or trade-in.

4.3. Step 3: identify design issues for each retirement method

Once the reasons for potential retirement have been identified with the business owners and the potential retirement methods have been identified, designers can identify design issues relating to the products that make up the system. As outlined earlier, the design issues for retirement should relate to all elements of the system, not just the product. However, most heuristics regarding design issues are focused on the design of the product:

1. *Design issues relating to all retirement methods*:
   a. Minimize the cost/effort of enacting the selected retirement method—addressing such issues as specialized facilities, equipment and personnel; transportation; and time taken.
   b. Consider potential markets for the retired system or elements and design to maximize the attractiveness of the retired element to those markets.
   c. Design modular products so the selected retirement method can be invoked for that element.
   d. Assist in the protection of any classified or private information and intellectual property that may be contained in the current system—perhaps by making sure that such information is easy to identify and remove.
   e. Minimize the cost of removal of sensitive system elements (such as cryptographic material) before any retirement method can be invoked.
   f. Ensure availability of design data and drawings to support retirement, so that the system can be sold with all its manuals, or disassembled in the most efficient way, for example.
   g. Define any transition arrangements that may impact on retirement activities.
   h. Observe of any caveats that limit freedom of action—such as might be placed on military equipment by international arms trade agreements, or might be placed on high technology by national sanctions.
   i. Minimize the cost of preparation for retirement—such as packaging and transport.
   j. Ensure materials and components are readily identified (perhaps by labelling) to facilitate the selected retirement method.
   k. Design for serviceability (ease of inspection, cleaning, servicing, and maintenance) so that parts can be replaced by a repair and maintenance process rather than dispose of subsystems or the system.
   l. Design with system elements that have long lives so that they can be recovered readily, even if the system cannot.
   m. Design to allow ready replacement of elements that become obsolescent, or to insert elements based on new technologies as they become available.
   n. Design for disassembly:
      1) Ensure materials can be easily separated—for example, fracture/cut points are incorporated in the design and readily identified.
      2) Ensure adhesives are used sparingly.
      3) Reduce as much as possible the need for specialized skills, tools, and facilities to undertake disassembly.
      4) Include information/guidance regarding disassembly in design documentation.
2. *Design issues relating specifically to reuse*:
   a. Minimize the cost of preparation for sale, trade-in, or reuse in a lesser role.
   b. Design with the requirements of subsequent-life, or second-tier customers in mind, where those are not in conflict with those of the prime customer.
   c. Ensure elements (such as leads and connections) are robust so that the product can have as many lives as possible.
3. *Design issues relating specifically to refurbishment, remanufacturing and salvage*:
   a. Minimize the cost/effort of disassembly.
   b. Avoid the use of hazardous/toxic/harmful materials that make disassembly unsafe or environmentally damaging.
   c. When hazardous/toxic/harmful materials must be used, ensure that the design incorporates mechanisms to contain those materials safely during disassembly, and to dispose of them safely and in an environmentally appropriate manner.
   d. Make use of common components and assemblies in the design of the product in order to decrease the cost of refurbishment and manufacture and to increase attractiveness of salvage.
   e. Design to ensure that elements that may become obsolete are able to be removed readily to be replaced.
4. *Design issues relating specifically to recycling* (see also (Kriwet et al., 1995)):
   a. Avoid the use of hazardous/toxic/harmful materials as much as possible.
   b. When hazardous/toxic/harmful materials must be used, ensure that the design incorporates mechanisms to contain those materials safely during disassembly and recycling, and to dispose of them safely and in an environmentally appropriate manner.
   c. Observe any relevant regulations relating to the ability to recycle any materials used in the system.
   d. Choose materials in the design that are more readily recycled, preferably choose materials that can be recycled using extant techniques.
   e. Minimize the numbers of types of materials (and perhaps even colours) to assist in separating materials.
5. *Design issues relating specifically to destruction*:
   a. Avoid the use of hazardous/toxic materials.
   b. When hazardous/toxic materials must be used, ensure that the design incorporates mechanisms to contain those materials safely during disassembly and destruction, and to

dispose of them safely and in an environmentally appropriate manner.
c. Facilitate destruction and the ability to dispose as waste (in landfill, for example).

6. *Design issues relating specifically to storage*:
   a. Consider the environmental impact of storage so that materials can be stored safely and in an environmentally appropriate manner.
   b. Facilitate the ready removal of any hazardous/toxic materials (or any other materials such as cryptographic material) or any element (such as a classified hard drive) that cannot be stored with the product.
   c. Minimize the cost of preparation for storage, such as disassembly, packaging and transport.
   d. Minimize storage costs—for example, by being able to reduce volume.
   e. Facilitate archival of documentation for storage, even if the product itself is to be not to be stored but is disposed of in some other way.

The design issues identified here, while comprehensive, are still focused in the technological products associated with the system. Designers must also consider the retirement issues associated with the other system elements of processes, people, information, techniques, facilities, services, and support elements. Many of the above issues are relevant to the other system elements but, in addition, designers must take into account the specific business context because the options for retirement tend to be as broad as the range of possible business opportunities rather than the narrower product context implied by the generic design issues. A simple example is useful to illustrate these and other issues associated with the proposed methodology for design for retirement.

5. An example use of the methodology

As a simple but illustrative example, consider a new Medical Centre (the Centre) to be built by a health-care company (ACME Health Services—ACME) which runs a number of such centres across the country. The two-storey Centre is to be built on a vacant lot on the corner of a large suburban shopping centre. For brevity we focus here in the following on just the major options for retiring the facilities component of the system (the building)—the same process would of course need to be followed for each of the other major elements of the system, including equipment, software, information, services, and staff.

5.1. Step 1: reasons for system retirement

During early design, ACME may consider the following seven possibilities for retirement of the Centre:

1. *Option 1*. Business is growing and ACME needs to move the Centre to a new larger location to accommodate further expansion.
2. *Option 2*. Business is going very well but the Centre is to be sold as a profitable venture—perhaps the original business intent was to make a profit from the sale of a flourishing business, or the owner of ACME has decided to retire and is liquidating assets, or the parent company is rationalising business areas.
3. *Option 3*. Business has slowed to the point that ACME will need to withdraw from the Centre—either to other (perhaps more-affordable) premises, or to wind up the business—and to sell the building when a suitable buyer can be found.
4. *Option 4*. Business is going very poorly right across the company and ACME (who may be in receivership, for example) will need to withdraw from the Centre and to sell the building immediately.
5. *Option 5*. Business is not going well enough to justify the full use of the building and other tenants may have to be taken in to keep the Centre profitable.
6. *Option 6*. The building has been destroyed, or is uninhabitable, due to fire or some form of natural disaster (earthquake, storm, flood) and must be replaced.
7. *Option 7*. The building has reached the end of its life and is no longer inhabitable—that is, it is not safe, does not meet the extant building codes, and so on.

5.2. Step 2: potential retirement methods

Given the reasons for retirement that have been identified by the business owners, the following potential retirement methods may be considered:

Option 1. If business is going very well and the Centre needs to move to a larger building, there are two options for retirement of the building. ACME may decide to:
1. put the building up for sale, or
2. reuse the building within the ACME organisation as a leased asset.

Option 2. Since the business is liquidating assets in this option, the only viable economic method for retirement is sale.
Option 3. Again, in this option, sale is the only useful retirement method.
Option 4. Again, sale is the only useful recourse in this option, although there is much more urgency in this option than in Options 2 and 3.
Option 5. In this option, part of the building is to be reused as leased space.
Option 6. If the building has been destroyed, ACME has the option of clearing the current site and:
1. rebuilding the Centre in the current location,
2. rebuilding a building to suit another business need and then selling or leasing the building while moving the Centre to another location, or
3. selling the current site as an empty lot and moving to a new location.

Option 7. If the building has reached the end of its life, it will need to be demolished. ACME has the option of clearing the current site and:
- rebuilding the Centre in the current location,
- rebuilding a building to suit another business need and then sell or lease the building while moving the Centre to another location, or
- selling the current site as an empty lot and moving to a new location.

5.3. Step 3: resulting design issues for retirement

For ACME, the following design issues result for each of the potential retirement methods:

1. *Sale*. Under Options 1, 2, 3, and 4, the building is to be sold. However, under Options 1, 3, and 4, the least desirable business approach for ACME is to sell the building as a medical centre that would allow another provider to set up quickly in competition to them in the location that their clients have become accustomed to attending (in a purpose-designed building). They will no doubt be very keen, therefore, to ensure that the building is not

able to be reused as a medical centre. Ironically, ACME does not have to worry about a competitor under Option 4 where they are selling because the business has failed or is failing, but they will not find it easy to sell a failing business to a like-minded proprietor. In Options 1, 3, and 4, therefore, the building cannot be sold as a medical centre. The following design issues arise because the building therefore must be designed so that it is suitable as a medical centre but can be transformed rapidly and inexpensively for reuse as general-purpose premises before it enters the next life cycle:

a. Any refurbishment that is required must be able to be accomplished as quickly as possible to facilitate the transition to general purpose.
b. The cost of transforming the building must be reduced to an acceptable level, particularly for Option 4 where a quick sale is essential.
c. Any items that will move with the Centre must be able to be disassembled easily and removed from the Centre.
d. The building design must facilitate the easy removal of large pieces of equipment without major structural work.
e. The building design must accommodate the staff transition plan, either on expansion to a new building or as part of a draw-down of services—the provision of services whilst in transition has the potential to provide significant stress on the maintenance of service standards while additional duties are undertaken with reduced staffing levels.

2. *Lease of all or part of building*. Under Option 1, AMCE might minimize the commercial risk of a competitor setting up in the old location by retaining the building and leasing it to one or more commercial tenants (who will presumably be prohibited in the lease from running a medical centre). Under Option 5, part of the building could be leased to one or more tenants in order to provide additional income for ACME. The following design issues arise:
   a. *Transition issues*. Again, as with sale of the building:
      1) The building must be designed so that it is suitable as a medical centre but can be transformed, at an acceptable cost, for reuse (or part reuse) as general-purpose commercial premises before it is offered for lease.
      2) Any refurbishment must be able to be accomplished as quickly as possible.
      3) The building design must facilitate the easy removal of large pieces of equipment that will move with the Centre or move out to accommodate new tenants.
      4) The staff transition plan must be accommodated with minimum stress on staff and services.
   b. *Access issues*. If ACME is to lease the whole building under Option 1 or sublet under Option 5, the building design must account for more than one tenant requiring access to the building. Since the building is on a corner block and on two floors, subletting may place significant constraints on the layout of the floors, as well as constrain the location of internal features such as lifts and stairwells, and the location of external features such as doors, windows and signage.
   c. *Shared facilities issues*. Sharing the building will require sharing facilities such as ablutions and utilities such as waste disposal, and perhaps the ability to account separately (meter) for water, electricity, and gas usage. The building should be designed to accommodate these aspects (or at least to be able to add them on quickly and cheaply when required).
   d. *Security/privacy issues*. If part of the building is to be leased while the Centre is still present in a reduced capacity, the design of the building must accommodate issues such as the security of pharmaceutical products and privacy of patient records when there is a second tenant present, perhaps even after Centre hours.
3. *Clearing of the site*. Clearing of the site is tantamount to destruction as an option for disposal on retirement. Consequently, the designers must take into account any opportunity to recover materials or at least ensure their safe destruction.

6. Discussion and conclusions

Note that, in the Medical Centre example, most of the requirements identified to address retirement issues would be relatively straightforward to include in the building design, largely without any significant additional cost. In most system development, the cost of incorporating a requirement correctly in the early stages of system design is considerably less than the cost of implementing that requirement once the system is in service—-even in software-based projects, where changes are perceived to be able to be made readily, the difference can be two orders of magnitude (Davis, 1993).

Life-cycle issues such as zero waste, multi-use products and closed product loops must be addressed during the Concept Stage, or at least the early parts of the Development Stage. Designers of the first life cycle must consider design for all possible future life cycles and the retirement from each (that is, the transition between life cycles), including the eventual disposal of the system at the end of life. Although there is always a design imperative to ensure that disposal methods are sustainable and environmentally friendly, design for retirement must take a view broader in order to accommodate the business issues associated with the transition between life cycles. In the Medical Centre example described here, designers must aim to minimize the environmental impact of the system's products, but they must also design to minimize the cost of retirement to the parent company, design for the protection of the privacy of patient records, design for the human aspects of the transition of the Centre's staff as the system moves from one life cycle to another, as well as design to accommodate many other issues.

If design in the first life cycle accounts for all possible life cycles, design for retirement is clearly a benefit to society in general—long lives are necessary to achieve the aims of sustainability, zero waste, and closed product loops. Although the principal focus of initial design is on retirement at the end of the first life cycle and disposal at the end of the last, designers should attempt to design to accommodate as many retirement options as possible. However, in doing so, the cost of designing for all life cycles will be borne principally by the owners of the first life cycle—the original business owner or manufacturer. Up to a certain point, it is in the financial interests of the business owner of the first life cycle to design for the next life cycle and for a long life, in order to maximize the residual value of the system on retirement from the first life cycle. However, the financial imperative for bearing the costs of retiring from all future life cycles may not be so impelling to a business which will have long since retired the system. Consequently, to provide incentive to the owners of the original system to take future life cycles into account, public regulation may be required—as Bernard shows with regard to remanufacturing (Bernard, 2011). While regulators may identify mechanisms to ensure that manufacturers take back products such as batteries, mobile phones and even automobiles at the end of their lives, it is not so clear how similar policies may be applied to all systems, such as in the construction industry, for example, where there may be a number of system owners throughout the system's life and neither the system provider nor the original owner may be available at the end of life.

None-the-less, system designers must be cognizant of the ultimate disposal of the system, and they must also accommodate the fact that the system will no doubt exist in, and be retired from, a number of life cycles before that time. System design should therefore focus on the retirement aspects which will include the issues associated with final disposal at the end of the system's useful life but will also include the requirements to transition between life cycles as often as possible before the system reaches its end of life. Three major steps are proposed here to support design for retirement: identify the reasons for retirement, identify the potential retirement methods available, and identify the design issues that arise from the consideration of each retirement method.

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