THE DURABILITY PLANNING MATRIX:
A USEFUL TOOL FOR ACHIEVING SUSTAINABLE BUILDING ENVELOPES

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INTRODUCTION

In response to growing public interest in sustainable construction, building professionals are turning to sustainable construction standards and rating systems to select building systems for optimal environmental benefit. Examples of emerging standards and rating systems affecting building envelope design and selection include the LEED™ Green Building Rating System (USGBC, 2009), the proposed *Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings* (ASHRAE, 2009), and the proposed *Sustainability Assessment Standard for Single Ply Roofing Membranes* (NSF, 2009).

Because the materials making up the building envelope are constantly exposed to harsh weather conditions and expected to perform without failure for many decades, sustainable building envelope products and systems must exhibit a significantly high level of durability in order to extend service life and minimize overall environmental impact. However, some researchers have expressed concern that many of the emerging sustainable construction standards and rating systems place too little emphasis on product durability (Hoff, 2007; McKay, 2007).

In the course of their professional participation in the development of consensus-based sustainable building envelope standards, the researchers identified a process-based approach to address long-term building envelope durability. This approach, based on a definition of durability embodied in the Canadian Standards Association *Guideline on Durability in Buildings* (CSA S-4875, 2001), provides a conceptual framework to identify the critical determinants of durability, propose strategies to minimize the effects of these determinants, and develop an action plan and timetable to implement these strategies.

Starting with the definition of durability and the quality management processes suggested by S-4875, the researchers developed a factorial approach to durability that may be embedded within a matrix format. This paper will review the features and benefits of this matrix approach, starting with a brief review of the durability paradigm proposed within

S-4875 and concluding with a detailed examination and critical analysis of the key matrix elements as well as the matrix as a whole.

WHAT IS DURABILITY?

The Canadian Standards Association *Guideline on Durability in Buildings* (CSA S-4875, 2001) provides one of the most recognized definitions of building durability in North America. According to this standard, durability is defined as the ability of a building or any of its components to 1) perform its required functions, 2) in its service environment, 3) over a period of time, and 4) without unforeseen cost for maintenance or repair. In contrast to the simpler dictionary definitions, durability as applied to buildings must offer more than mere survival: it must also be capable of performing required functions. In addition, these functions must be performed not only for a long time, but for a specified period of time. And finally, although normal deterioration may obviously occur, there should be no unforeseen cost associated with this normal deterioration. Given the importance of these distinctions, each of these concepts should be carefully examined in order to fully integrate durability into sustainable building envelope design.

Required Functions

While many building components and systems may have a single required function, modern roofs and walls fulfill many roles. As the primary line of defense against water intrusion, the building envelope must block the intrusion of moisture in many forms, including rain, snow, hail, ice, and vapor. In addition to resisting moisture, the building envelope plays an important role in capturing and directing water to storm drainage systems. And as an equally significant contributor to the building's thermal envelope, modern building envelopes must resist the movement of heat and cold at ever-increasing levels as energy costs continue to rise. Finally, the building envelope may serve as an important work platform for the building, supporting and protecting critical equipment that must be serviced periodically. And with the development of vegetated "green" roofs, "living" walls, and a wide variety of clean energy production systems, the role of the building envelope as a service platform continues to expand.

Each of these important functions must be addressed within any sustainable building design in order to ensure that the most sustainable building envelope is indeed selected. And if any of these required functions is omitted or ignored, the usefulness of the design may be significantly compromised.

Without Unforeseen Costs

The use of the word "unforeseen" reveals several key concepts to be considered to fully integrate durability into sustainable building envelope design. First, the possibility of unforeseen cost suggests that planning is required to ensure that no costs are indeed unforeseen. In addition, there is an equally strong suggestion that some level of cost should be expected (or foreseen) for the building component or system to achieve meaningful durability. As a consequence, any deficiency regarding requirements for monitoring and maintenance may compromise the usefulness of any sustainable building envelope system.

Over a Period of Time

The period of time in the CSA S-4875 definition of durability is commonly referred to as the service life of the building component or system. Obviously, any failure for a building envelope system to achieve its intended service life may seriously compromise the effectiveness of any sustainability standard in directing design choices and materials selection.

DURABILITY PLANNING

In addition to providing a useful definition of building durability, S-4875 also provides a comprehensive methodology and framework to make decisions on durability. The guideline addresses important elements of durability planning, including quality assurance, methods to predict service life, design and construction considerations, and operating and maintenance programs. Generalizing from the durability planning recommendations in the standard, the following processes appear to be the primary steps in developing an effective durability plan for any building envelope system:

1. **Identity durability determinants**. Failure analysis from field studies and other sources may help building designers identify which design, material, installation and service factors hold the most value in optimizing the service life of the building envelope.
2. **Identify durability intervention strategies**. Using the recommendations derived from failure analysis research and industry best practice guidelines, the building designer can identify specific intervention strategies or countermeasures to prevent or mitigate degradation of roof service life. These strategies or countermeasures may take a number of forms, including initial design enhancements, ongoing inspection and maintenance procedures, and major repair initiatives of key building envelope components and details.
3. **Develop an action plan and timetable**. Using the recommendations of S-4875, the building designer can develop a long-term action plan to be incorporated into ongoing building management activities.

These key steps in effective durability planning may appear obvious. But the wide variation in service life data for building envelope systems suggests that what may be obvious has rarely been implemented on a broad scale by building designers and owners. And if the sustainable building movement is to fulfill its long-term mission to reduce environmental impact, durability planning must become a vital and integral part of the design, construction and management of sustainable buildings.

THE DURABILITY PLANNING MATRIX

Introduction

By combining the key characteristics of durability as defined by S-4875 with the suggested steps in the durability planning process, a planning matrix may be constructed to address each critical dimension of building envelope performance in a methodical fashion. Starting with a delineation of the service environment and required system functions, the matrix may help identify the best criteria, or durability determinants, on which to base project decisions. Using these durability determinants as the primary project criteria, the roofing professional may then explore the best design, material and application strategies to address these critical criteria. After the initial design and material selections are completed, the durability determinants within the matrix may then direct the building professional to consider the longer-term requirements of the building system for different service life periods. Critical issues addressed by examining service life issues within the matrix may include critical quality processes such as commissioning programs, inspection schedules, maintenance procedures and major repair activities. In addition possible trade-offs in the contributions of each of these activities on overall service life may be evaluated. Finally, the matrix may direct the building professional to consider end-of-service issues, such as removal, disposal, replacement and potential recycling opportunities.

The Durability Planning Matrix

Although the durability matrix has been designed as a holistic approach, it may be divided into four phases for discussion and analysis:

- **Assessment**: Service Environment / Required Functions / Durability Determinants
- **Implementation**: Design / Materials / Installation
- **Realization:** Commissioning / Maintenance / Renewal
- **Decommissioning**: Removal / Recycling / Evaluation

A graphic illustration of the relationship of the four phases of durability planning and related project criteria is provided in Appendix A of this paper.

Assessment. During the assessment phase, the matrix may be used to identify the significant characteristics of the service environment and the important functions the building system must perform. In turn, these environmental and functional requirements may be used to identify the durability determinants critical to the successful delivery of the functional requirements. As an example, for a roofing system located in a hail-prone region of the country and serving as a platform for equipment requiring frequent maintenance, the ability of the roof system to resist impact and traffic loads may be key durability determinants. This application of the assessment phase of the matrix is illustrated in Figure 1:

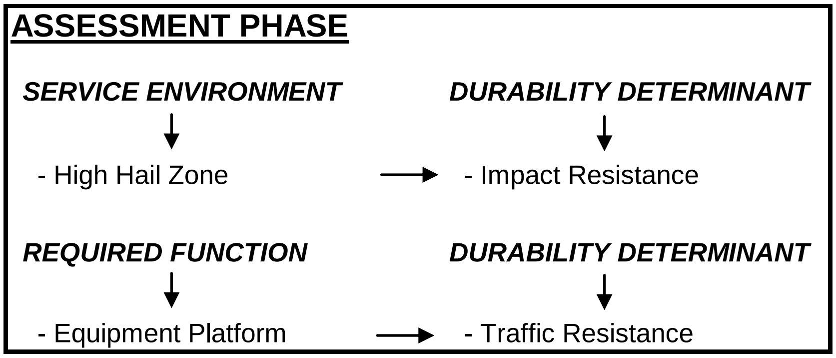

Figure 1: Durability Planning Matrix: Assessment Phase

Implementation. During the implementation phase, the matrix may be used to explore the role of building system design, material selection and installation practices in addressing critical durability determinants. And this exploration of suitable practices in turn may be used to develop specific design, material and installation specifications for the project. Continuing with the previous example, if the critical durability determinants of a roofing system are impact resistance and traffic resistance, then specific design, materials and installation strategies may be identified that would effectively address the challenges of these durability determinants. As a possible design strategy, the specification of a protective roof walkway system to effectively direct maintenance traffic to and from equipment without damaging the roof surface might be considered. As a possible material selection strategy, only materials meeting or exceeding specific hail test requirements might be specified. In addition, a minimum compressive strength might be specified for the roof insulation. As a possible installation strategy, a prohibition for metal fasteners and plates directly beneath the roof membrane surface might be included in the specification. This application of the implementation phase of the matrix is illustrated in Figure 2:

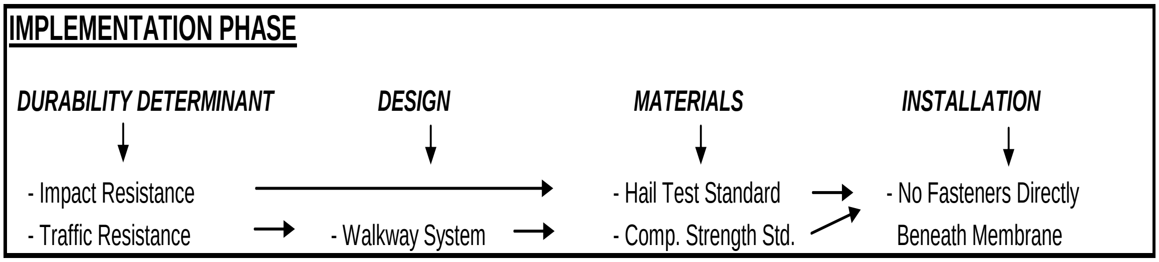

Figure 2: Durability Planning Matrix: Implementation Phase

Realization. During the realization phase, the matrix may be used to explore the role of project commissioning, periodic maintenance and planned renovation practices in addressing critical durability determinants. Looking at the critical durability determinants of impact resistance and traffic resistance in the current example, specific commissioning, maintenance and renovation strategies might be identified that address many of the challenges of impact and traffic loads. As a possible commissioning strategy, a uniform rolling load might be applied to the roof surface to verify that no underlying projections from fasteners or other sources compromise the roof system integrity. In addition, maintenance work might be monitored on the roof to verify that the walkway system is indeed being used as planned to reduce roof traffic impacts and direct traffic movement. Possible maintenance strategies might include inspection of the roof system after all hail storms as well as periodic inspections of the walkway system and roof surfaces adjacent to rooftop equipment to check for damage or deterioration. As a possible renovation strategy, the roof walkway surface might be scheduled for removal and replacement at a future date prior to possible deterioration due to weathering. This application of the realization phase of the matrix is illustrated in Figure 3:

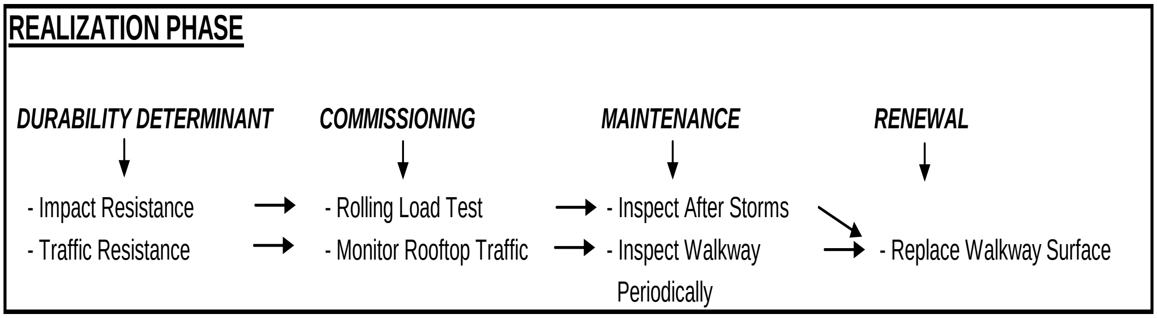

Figure 3: Durability Planning Matrix: Realization Phase

<u>Decommissioning</u>. At the end of the useful service life of the building system, the matrix may be used to guide the effective removal and recycling of the system components. Although the current example focuses exclusively on impact and traffic resistance, one additional key durability determinant should be added at this phase: the environmental impact of the decommissioning process. In order to optimize overall durability and service of the materials used within the building system, the reuse and recycling of these materials and the minimization of waste must be considered along with the critical durability determinants identified previously. And in order to consider effective reuse and recycling, it may be important that the building system components be disassembled with minimal damage to materials that may be reused or recycled. In the current roofing example, the structural elements of the walkway system (railings, platforms, etc.) might be designed for disassembly in a manner that allows re-use on the replacement roof. In a similar manner, there may be removal strategies to minimize damage to the roof insulation and membrane in order to facilitate their effective recycling. During the decommissioning phase, the matrix may also be used to evaluate the success of the original durability plan and apply the lessons learned to the proposed replacement system. This final evaluation process effectively transforms the durability matrix into a virtuous cycle allowing for continuous improvement of the design, installation and beneficial use of building systems and components. This application of the decommissioning phase of the matrix is illustrated in Figure 4:

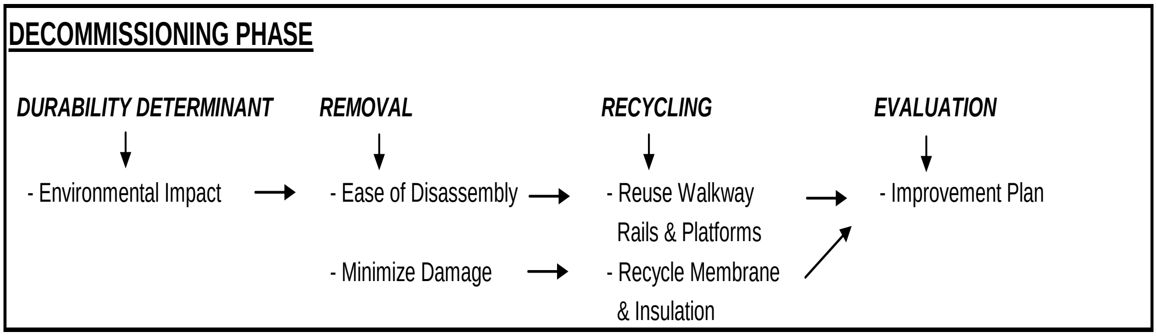

Figure 4: Durability Planning Matrix: Decommissioning Phase

The Durability Matrix as a Whole. As suggested previously, the durability matrix is designed as a holistic tool to address long-term building system performance. And when the matrix is viewed as a whole, it may be apparent that considerable feedback and interaction among the four phases should be expected. At each phase, strategies may be identified that require addition or revision to previously identified strategies. As an example, if periodic inspection of a key building component is identified as a critical strategy in the realization phase of the planning matrix, then the *inspectability* may be a critical issue to be addressed during the assessment phase of the matrix. In a similar manner, if effective disassembly of certain components is critical to reducing waste and increasing recyclability during the decommissioning phase, then *ease of disassembly* should likely be addressed during the implementation phase of the matrix. This holistic view of the durability planning matrix is illustrated in Figure 5:

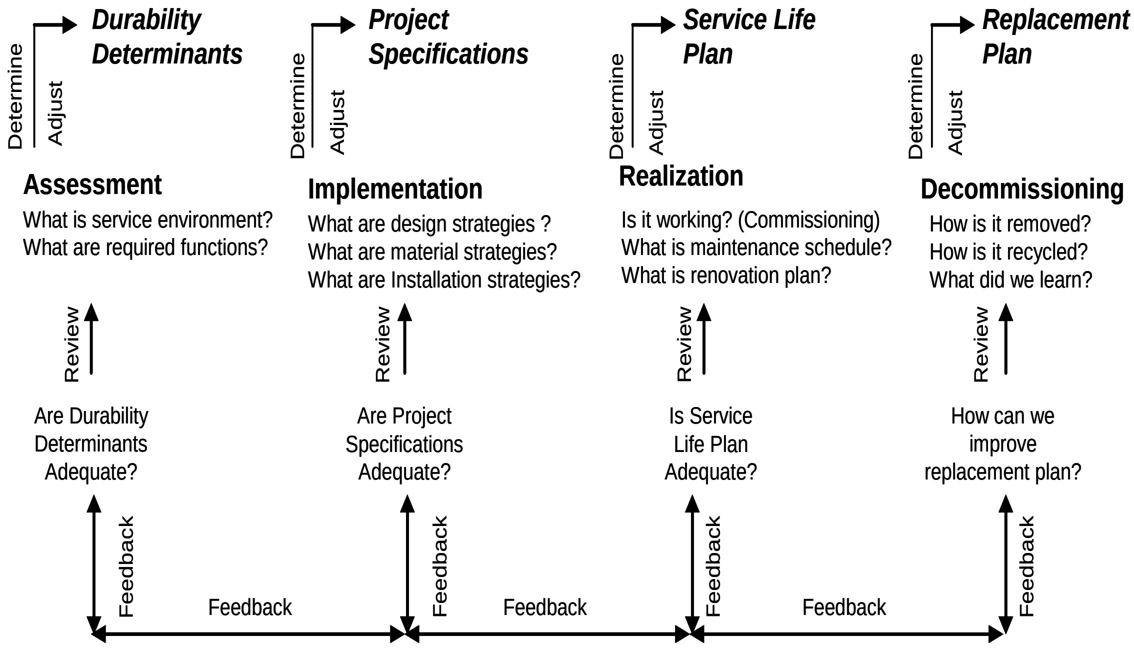

Figure 5: Durability Planning Matrix: Process Flow

DISCUSSION

As suggested previously, many of the aspects of the durability planning matrix may appear intuitive. But combining these intuitive approaches in a relational model may provide building professionals with a useful tool to address many aspects of building system design and operation in a single process. And because the matrix may increase interaction and feedback between these individual process phases, the overall planning process driven by the matrix may provide more optimal solutions to building system durability and performance.

The durability planning matrix also may provide an effective way to evaluate different combinations of material, design and service options to determine which combination offers the lowest overall environmental impact. As a result, the matrix may lead to improved evaluation and selection of the most suitable durability options for a particular building application. The use of the matrix may also facilitate rigorous evaluation of trade-offs between increasing roof system durability in the initial installation phase versus a more incremental approach of planned system maintenance and repair interventions during the latter operational phase of the building.

Finally, the durability planning may help stimulate and direct industry research activities by identifying critical gaps between critical durability determinants and available countermeasures to address these key durability issues. As an example, long-term needs for material recycling and reuse identified in the matrix may stimulate research to explore new approaches to make the disassembly of building envelope systems easier without adversely impacting in-service performance.

FUTURE RESEARCH

In order to refine the features of the durability planning matrix and test its usefulness in practical application, the researchers plan on applying the matrix to published case studies of building envelope projects, supplemented by interviews with design principles associated with the case studies. The goal of the proposed research will be to evaluate how effectively the matrix classifies and relates data from existing case studies in terms of durability planning and how effectively the matrix identifies possible durability planning omissions within the narratives of the case studies. The proposed research will address these questions by enumerating the service environment and required function factors identified in each case study and comparing them against the identified durability determinants. In addition, the research will identify key durability-related design, material and installation specifications in each case study and compare these specifications against the identified durability determinants. Finally, the researchers will look for any durability-related building management strategies such as commissioning, maintenance, or planned renewal contained within the case studies. The researchers anticipate that a preliminary review of this research may be included in their presentation of this article at the RCI 25th International Convention and Trade Show.

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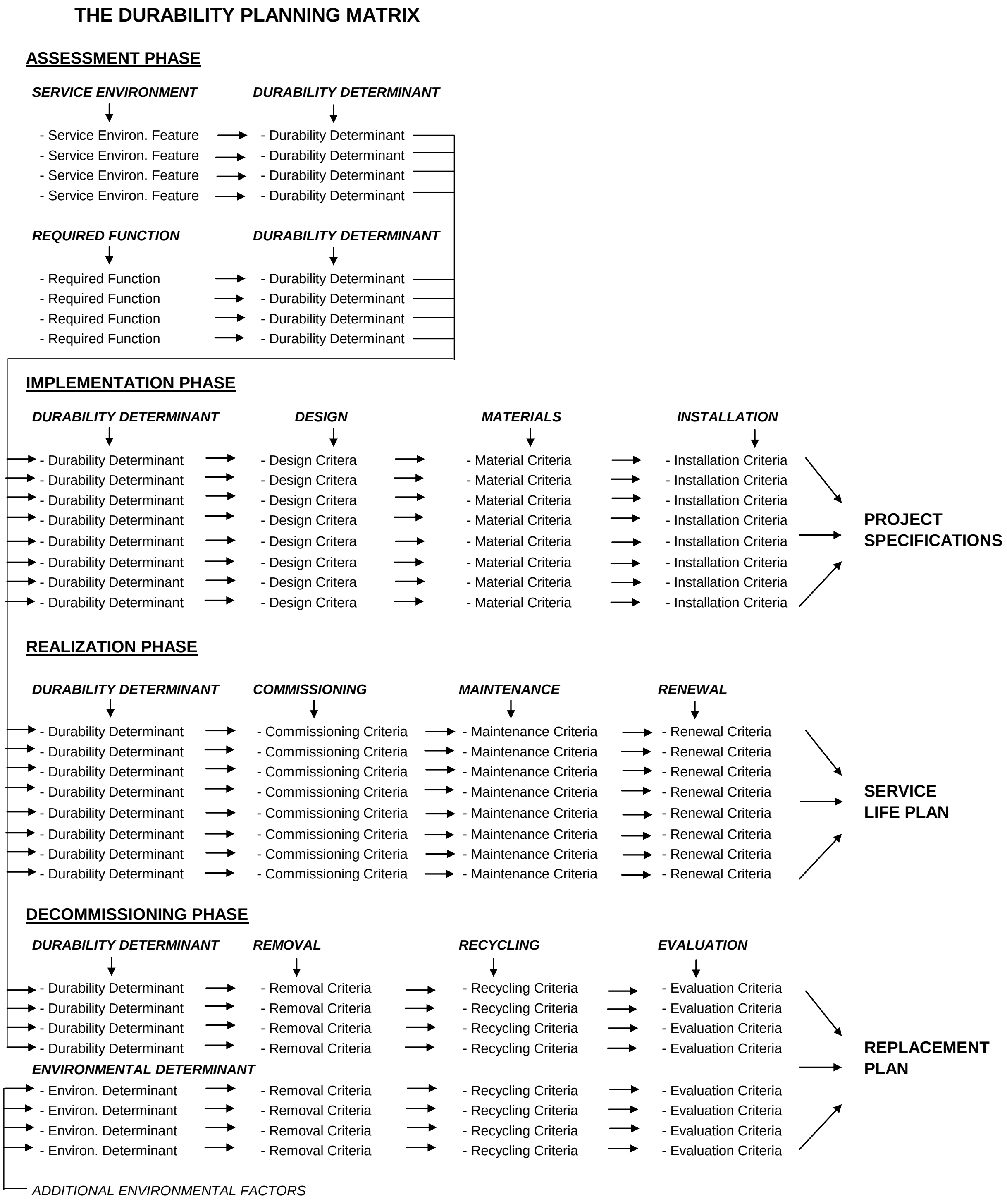
APPENDIX A

THE DURABILITY PLANNING MATRIX



THE DURABILITY PLANNING MATRIX

ASSESSMENT PHASE

SERVICE ENVIRONMENT	*DURABILITY DETERMINANT*
- Service Environ. Feature	- Durability Determinant
- Service Environ. Feature	- Durability Determinant
- Service Environ. Feature	- Durability Determinant
- Service Environ. Feature	- Durability Determinant

REQUIRED FUNCTION	*DURABILITY DETERMINANT*
- Required Function	- Durability Determinant
- Required Function	- Durability Determinant
- Required Function	- Durability Determinant
- Required Function	- Durability Determinant

IMPLEMENTATION PHASE

DURABILITY DETERMINANT	*DESIGN*	*MATERIALS*	*INSTALLATION*	
- Durability Determinant	- Design Critera	- Material Criteria	- Installation Criteria	**PROJECT SPECIFICATIONS**
- Durability Determinant	- Design Critera	- Material Criteria	- Installation Criteria	
- Durability Determinant	- Design Critera	- Material Criteria	- Installation Criteria	
- Durability Determinant	- Design Critera	- Material Criteria	- Installation Criteria	
- Durability Determinant	- Design Critera	- Material Criteria	- Installation Criteria	
- Durability Determinant	- Design Critera	- Material Criteria	- Installation Criteria	
- Durability Determinant	- Design Critera	- Material Criteria	- Installation Criteria	
- Durability Determinant	- Design Critera	- Material Criteria	- Installation Criteria	

REALIZATION PHASE

DURABILITY DETERMINANT	*COMMISSIONING*	*MAINTENANCE*	*RENEWAL*	
- Durability Determinant	- Commissioning Criteria	- Maintenance Criteria	- Renewal Criteria	**SERVICE LIFE PLAN**
- Durability Determinant	- Commissioning Criteria	- Maintenance Criteria	- Renewal Criteria	
- Durability Determinant	- Commissioning Criteria	- Maintenance Criteria	- Renewal Criteria	
- Durability Determinant	- Commissioning Criteria	- Maintenance Criteria	- Renewal Criteria	
- Durability Determinant	- Commissioning Criteria	- Maintenance Criteria	- Renewal Criteria	
- Durability Determinant	- Commissioning Criteria	- Maintenance Criteria	- Renewal Criteria	
- Durability Determinant	- Commissioning Criteria	- Maintenance Criteria	- Renewal Criteria	
- Durability Determinant	- Commissioning Criteria	- Maintenance Criteria	- Renewal Criteria	

DECOMMISSIONING PHASE

DURABILITY DETERMINANT	*REMOVAL*	*RECYCLING*	*EVALUATION*	
- Durability Determinant	- Removal Criteria	- Recycling Criteria	- Evaluation Criteria	**REPLACEMENT PLAN**
- Durability Determinant	- Removal Criteria	- Recycling Criteria	- Evaluation Criteria	
- Durability Determinant	- Removal Criteria	- Recycling Criteria	- Evaluation Criteria	
- Durability Determinant	- Removal Criteria	- Recycling Criteria	- Evaluation Criteria	
ENVIRONMENTAL DETERMINANT				
- Environ. Determinant	- Removal Criteria	- Recycling Criteria	- Evaluation Criteria	
- Environ. Determinant	- Removal Criteria	- Recycling Criteria	- Evaluation Criteria	
- Environ. Determinant	- Removal Criteria	- Recycling Criteria	- Evaluation Criteria	
- Environ. Determinant	- Removal Criteria	- Recycling Criteria	- Evaluation Criteria	

ADDITIONAL ENVIRONMENTAL FACTORS