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MODULARITY IN SUPPORT OF DESIGN FOR RE-USE

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1 Introduction

We explore the structuring principle of modularity with the objective of analysing its current ability to meet the requirements of a 're-use' centred approach to design. We aim to highlight the correlation's between modular design and 're-use', and argue that it has the potential to aid the little-supported process of 'design-for-re-use'. In fulfilment of this objective we not only identify the requirements of 'design-for-re-use', but also propose how modular design principles can be extended to support 'design-for-re-use'.

2 Modular Design and Re-use

Modular design involves the creation of artefact variants based on the configuration of a defined set of modules. Modules are commonly described as a group of 'functionally' or 'structurally' independent components clustered such that 'interactions are localized within each module and interactions between modules are minimised' [1]. The principle aims to create variety, reduce complexity and maximise kinship in designs and across product families. Due to the fact that individual module functions and/or structures must eventually combine to realise the overall function/structure of the artefact, the modules can never truly be independent and must be defined together with the system to which they belong. Thus, further 'between module' or 'interface' constraints must be considered for modules to be successfully configured to meet overall system requirements

In exploring why modular design so readily maps to the *'re-use'* perspective we consider some of the major benefits of the approach, including: efficient upgrades; improved design understanding; improved knowledge structures; improved knowledge management; improved knowledge utilisation; reduction in complexity; reduction in costs; rapid product development [2, 3, 4].

These benefits support increased utilisation of experiential knowledge for new product development and thus provide an approach on which to actively support 're-use'. However, despite the existing evidence as to its benefits, 'little work has been done on these research issues' [3] and 'modularity has been treated in the literature in an abstract form' [5]. That is there is a need for approaches 'to determine modules, represent modularity, optimise modular design and assess the impact of modularity on the design process' [5].

3 Supporting ‘Design for Re-use’

There is a current drive towards modular structuring of products, motivated by the body of evidence as to its benefits. Despite significant correlations between the two, currently no modular design methodology specifically emphasises support for ‘re-use’. In the ‘re-use’ field studies have shown ‘design for re-use’ can have a significant impact on the realisation of ‘re-use’ related benefits [6]. Since it suffers from the most notable lack of support, of all the re-use processes [7], the potential for a modular design methodology/tool to support this process is examined. Modular Design in support of ‘design for re-use’ would be better facilitated by:

- Supporting the dynamic knowledge generated by the designer within the designer’s different viewpoint requirements, as the design proceeds from the abstract to the concrete, and mapping knowledge relations between these for improved design understanding.

- Supporting module generation based on various viewpoint and/or lifecycle objectives and facilitating a mapping between each to optimise module definition and design.

- Supporting the re-use of generated modules and their associated knowledge through the provision of an explicit formalism for design knowledge, dependency knowledge and module definitions.

- Facilitating the exploration of ‘design by re-use’ by mapping potential design changes/decisions onto the previous modular solution and its associated development knowledge.

3.1 Current approaches

Current approaches fail to fulfil the requirements of a modular design methodology for re-use, as outlined above. The majority of approaches focus solely on a particular viewpoint, generally a functionally or structurally orientated one. Existing approaches to modularity can be grouped into 3 distinct categories: those based on function, on the potential means or technical solution of realising this function, and finally on physical parts and/or components.

Modularity from a functional viewpoint is the focus of research by Huang and Kusiak [5], where sub-functions, those that must initially be realised to fulfil the overall artefact function, are grouped or clustered to form ‘functional’ modules based on their relation to, similarity to, or dependence on one another. Chang and Ward [8] and Erixon [9] provide examples of ‘behavioural modularity’ based on the technical solutions or means of fulfilling the functional criteria of a design. The component/part view and its inter-relations are the focus of Sosale et al [1], and Kamrani [10]. Here termed, ‘structural modularity’ its focus is predominantly on later-life cycle objectives i.e. low level ‘nuts and bolts’ assembly, process planning, service, maintenance, parts re-use, recycling and disposal. Here, Sosale et al are seen to focus on modularity for recycling and disposal whereby well defined physical parts are grouped into modules based on their similarity in areas such as life span, material, maintenance level, disposal method, recycling capabilities, etc.

Kamrani [10] expresses concern that ‘conceptual design modules’ and those of a ‘functional to technical nature’, cannot meet the constraints of later stages of design. Likewise, it can also be argued that due to the nature of ‘structurally’ orientated modules they fail to capture and/or explicitly represent knowledge from earlier conceptual phases of design or more generalised knowledge. There is a need to develop a methodology which allows the designer to examine and express modularity throughout the design process to promote a deeper understanding of: the nature and evolution of modularity; life-cycle objectives and modular trade-offs; and to promote systematic extraction and representation of design knowledge from project inception '*for re-use*'.

3.2 Modular approaches that consider more than one viewpoint

There is increasing recognition that modern design methodologies require to support the multiple viewpoints of design within a coherent and integrated structure [11-13]. Viewpoints, within the context this research, represent structured views of 'engineering design' required by the designer in order to evolve the engineering design process to a suitable conclusion [14]. The prime concern of this research however is the support of the design life-cycle phase, from 'requirement to artefact definition', and how best to support the knowledge generated through this '*for re-use*'. Secondly, we define a life-cycle objective to be the expression of a required and/or preferential need with respect to an individual or group of artefact stakeholders from various stages of the entire artefact life (of which the 'design process' can be considered only one part i.e. customer, designer, manufacturer, assembler, user, maintainer, disposer).

Salheih and Kamrani [13] note that the principle of modularity 'can be applied in product design, design problems, production systems, or all three'. Thus acknowledging the need to support different aspect of the product life-cycle with the modular principle. However, although the methodology deals with 4 stages of design, modularity and its associated benefits are neither expressed nor attained until late in the design process. Thus abstract knowledge important for the maintenance of knowledge for re-use [15], is not supported, nor modularised, and consequently the approach fails to maintain design knowledge 'for re-use'.

Jiao and Tseng [12] plan for modularity across 'views' but their interpretation differs. 'Engineering design' is dealt with in only one view, the technical view, while the others constitute alternative stages in the life cycle of a product. However, their "views" are independent in that issues relating to different business functions are dealt with in different views.

4 A Modular Design Methodology for Re-use

Current approaches do not adequately formalise, nor maintain, the knowledge behind defined modules nor facilitate mapping between different viewpoints of the 'engineering design process' and consequently they are too inflexible to fully support '*design for re-use*'. The authors' proposed approach focuses solely on views in the 'design process' with the intention of furthering our understanding of relations and constraints within, and across, viewpoints to aid the realisation of modularity from project inception. By developing methods to define and manage modularity from the higher level 'functional' view to 'lower level' parts, geometry and physical characteristics, we aim to take into account life-phase modular needs during design while utilising the principle as a tool to extract, manage and enhance design knowledge 'for re-use'. For successful support of '*re-use*', 'a modularisation strategy must be incorporated at project inception' [16] and be evident throughout the product development process and beyond. The difficulties in achieving this support include the notion that modularity is not a constant property (what is modular in one viewpoint may not be in another) and that modularity can be achieved in different forms (different modular structures support different modular objectives). It is suggested that a deeper understanding and more adequate support of; 'within', 'between' module, and across 'viewpoint' relations would aid in the management of such difficulties. Relations are far more complex than the 'functional dependence' or 'physical link' of relations utilised in current approaches to modular design. There are complex dependencies involving functional, mechanical, information, energy and material relations and constraints.

4.1 The components

The following presents novel 'modular design methodology for re-use' which aims to address the previously outlined issues and inadequacies of modular design support. The methodology consists of 4 main elements: a knowledge formalism, an interdependency matrix application, a clustering mechanism and a mapping mechanism.

4.1.1 Element 1 - Knowledge Formalism

The methodology will utilise elements of a previously developed knowledge formalism [17]. The formalism takes a Multi-Viewpoint Evolutionary Approach to formalising both current working design knowledge and knowledge related to the domain. Thus, it has the ability to support and formalise knowledge of an evolving design over the viewpoints inherently adopted by the designer as shown in figure 1. As we are predominantly concerned with supporting 'design for re-use', a process carried out during design itself, our initial focus is on the CWK formalism.

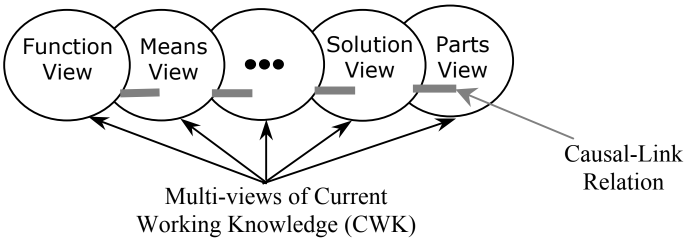

Figure 1 -Multi-viewpoints of CWK in design

The approach allows the designer to formalise knowledge within viewpoints as concepts (encapsulating knowledge of the designer's ideas of the design) with attributes (input matters, output matters, behaviour properties, principle properties, parts, etc.) and constraints (both on the concept and attributes; see Figure 2a) and relations between concepts (Figure 2b). Concept constraints indicate application conditions whilst attribute constraints represent dependencies between individual attributes. Between concept relations can have a type (Has-kind, A-kind-of, A-part-of, Has-part, Functional-dependency, Physical link) and a direction (see Figure 3). Relation constraints consist of pre and post relation constraints. The formalism also notes a causal link relation across viewpoints, Figure1.

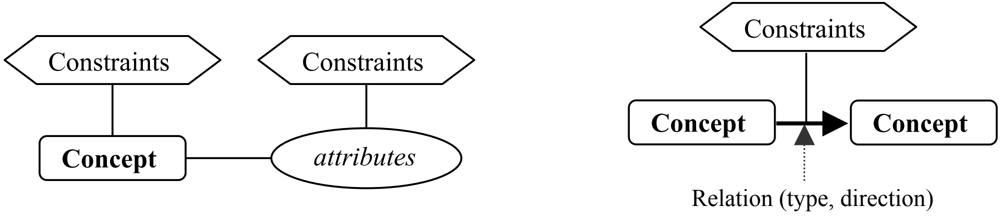

Figure 2 (a) - Concepts, attribute and constraints (b) Relations between concepts

This formalism is utilised as it supports the evolution of a design whilst defining relation/dependency knowledge between concepts both within and across viewpoints of design.

4.1.2 Element 2 - Interdependency Matrix Application

A matrix application (see Figure 3) can provide a representation of the formalised concepts, relations and their constraints, which aids in the formalisation, detection and analysis of; concept dependencies, concept duplication/redundancy, potential modular solutions based on matrix interpretation rules and other grouping/clustering techniques (element 3), and module definition.

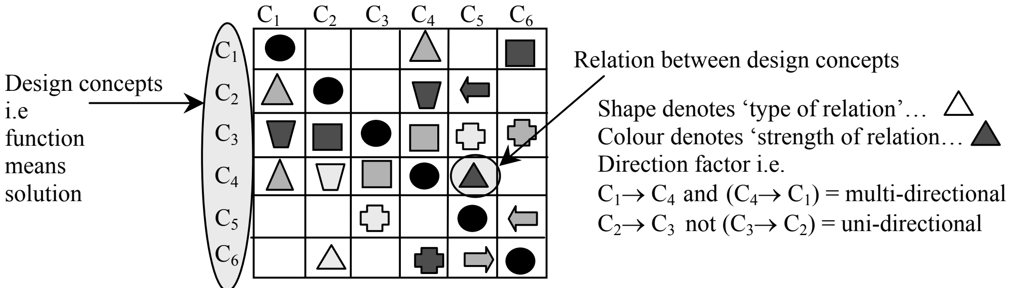

Figure 3 - An Interdependency Matrix Application

4.1.3 Element 3 - The Clustering Mechanism

Various clustering and grouping techniques are currently under investigation to support the module design and optimisation process. The techniques are required to support module design based on a number of criteria, including:

- Maximisation of internal relations between concepts.
- Minimisation of external relations between concepts.
- Concept, attribute and relation constraints.
- Significant lifecycle objectives i.e. manufacturing, maintenance, technology life-spans etc.
- Maximum and minimum module number and size.

4.1.4 Element 4 – The Mapping Mechanism

A mapping mechanism is required to support modularisation from project inception and capture knowledge of the evolution of the modular design solution. The mapping mechanism is a key element of the methodology's 'design for re-use' support as it allows capture of both the final solution and associated development knowledge to permit a deeper understanding of 'how' and 'why' the solution developed from the abstract to the concrete. The mechanism would also support analysis of the effect of a change in 'modularity' focus i.e. change of constraints, life cycle objectives and/or module size/number. Further, when utilised in a 'by re-use' scenario the mechanism could allow analysis of the impact of design changes and support partial re-use of the design solution (modules) and their associated knowledge.

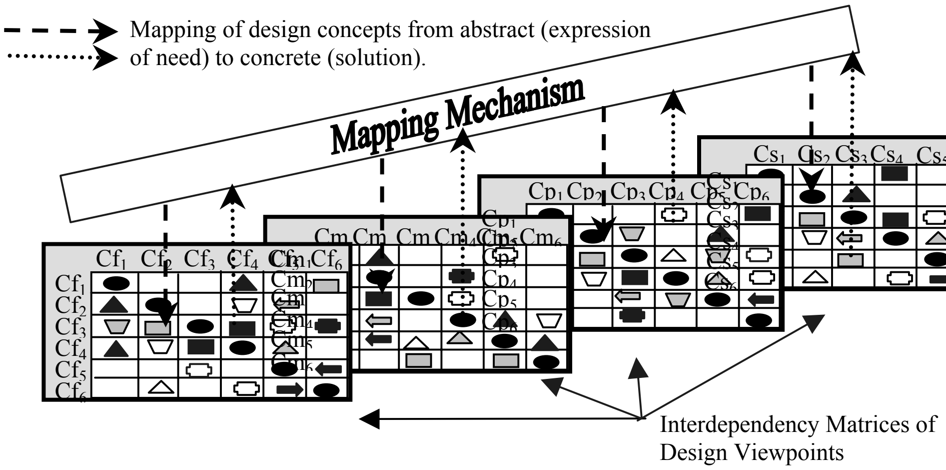

Figure 4 - Mapping Mechanism

4.2 The application process

The envisaged application process of the above methodology involves an iterative application loop which supports the generation of modules as the design evolves from the abstract to the concrete as shown in figure 5.

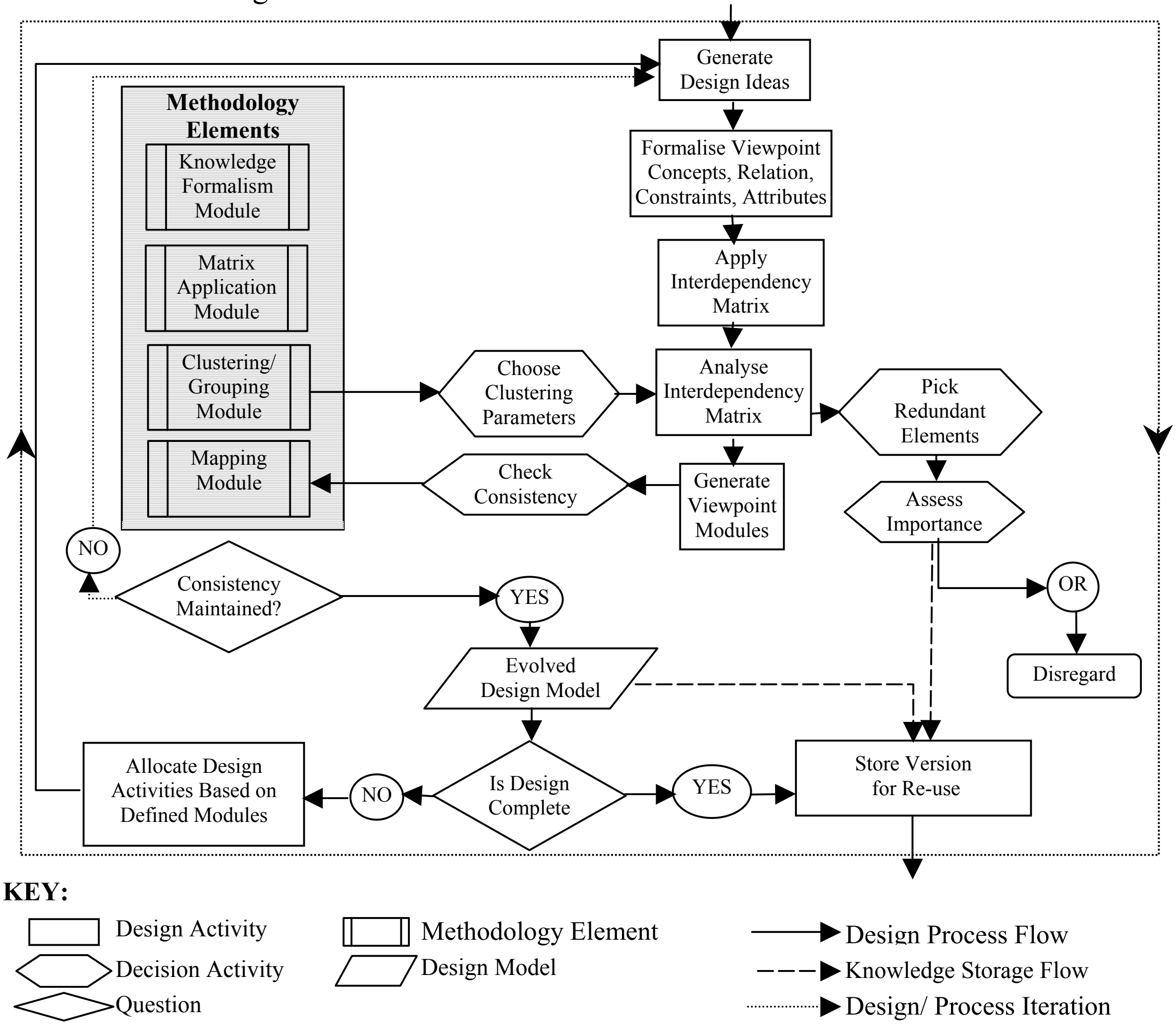

Figure 5 - Envisaged Methodology Application Process

4.3 The Application Field

The methodology is currently under development in the field of marine design in conjunction with BAE Systems Marine Ltd (Forward Design Group) and Alenia Marconi Systems. The marine field was chosen based on the findings of a previous study in the area which highlighted a significant correlation between support for the process of 'design for re-use' and the achievement of 're-use' related benefits [6]. More specifically, we focus on the potential modularisation of the engineering (hardware) design of a weapons systems command console. The console was chosen for a number of reasons including:

- **New Generation Console Development**: The console is currently undergoing a significant redesign which results in easier access to documentation on previous generation consoles, and the ability to analyse the results of the methodology's application against both the new console design solution and the process undertaken to achieve it.

- **Sufficient Complexity**: The console's requirement to integrate a number of differing functions, mechanisms and technologies is expected to result in the development of a more robust methodology.

- **Embodiment of Ship Design Issues**: The console must take into account a number of ship design issues, including:

  Ship Class Maintenance, which requires that all previously designed ships in that class must be of similar outfitting to ensure adequate integration of all ship systems. As the design and manufacture of a naval ship class can span decades this is an especially pertinent issue in the design of a console which embodies technologies subject to rapid development (processors, video, VDU's, control mechanisms, etc).

  System Integration, which requires that elements of individual ship systems (propulsion, waste water, navigation, communications) must be designed to not only integrate within the individual system to which they belong but the ship as an entire system.

  Long in Service Life Span, which requires specific emphasis on both the robustness of components and the minimisation of retrofit requirements of individual ship systems.

  Thus, these issues provide a case with significant life-cycle objectives on which to base the development and analysis of the methodology.

5 Conclusion

The correlation between the principles of modular design and the requirements of 'design for re-use' has been presented. The main issues that attribute to the inadequacy of current modular design approaches in supporting this process have been highlighted and discussed. To address these issues a 'modular design methodology for re-use' has been presented that is currently being developed in a bid to provide better support for the relatively neglected process of 'design for re-use'.

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