6 THE INTEGRATION OF SYSTEMS LEVELS AND DESIGN ACTIVITIES TO POSITION CREATIVITY SUPPORT TOOLS

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When beginning to investigate 'creativity in detailed design' it becomes apparent that the literature and discourse regarding the terms; conceptual and detailed design are confused at a point or definition. Is detailed design the design of components at low systems levels or is it activity that occurs in every design process? In this paper the authors argue the latter. An integrated process is described emphasizing the differences between the systems levels of design and the design activities process. The integrated model will help to position future research into the support for creativity in detailed design.

Keywords: Design process, Systems levels, Creativity.

1. INTRODUCTION

Creativity research in design has traditionally focused on ideas at the conceptual level, where the working principles for a design solution are explored evaluated and selected.

The extensive body of work undertaken[1–3] and has led to generation/identification of potential definitions, measures, influences and methods for influencing creativity, all primarily focused around supporting the conceptual design activity. However, embodiment and detail design have remained largely unexplored and unsupported in terms of the need for creativity. Yet, the importance of creativity throughout the design process has been pointed out for many years, suggesting that the designer *"must be creative in all stages"*.[4]

1.1. Background

It is argued that at later stages it is more difficult to be creative and that this activity is largely unsupported. It has been observed in industry[1] that engineering designers are now using CAD, analysis and imaging software tools for creative purposes, which is beyond their intended use. Thus specialized creativity tools for embodiment and detailed design activities need to be generated to support these activities.

In previous research the authors have investigated into creativity support for engineering design at the early stages of the design process. As a result of this research several recommendations were agreed for implementation by the case company. Though the creativity support tools were focused on the early stages of their innovation process, the company was keen to promote the use of such tools for use throughout the company. After further discussion it was realized that creativity at later stages of the design process may take a different form and have quite different needs for support.

As part of a new research project, entitled 'Creativity for Embodiment in Detailed Design', this paper will provide some underlying theory to help position this research. Most importantly, it will make a clear theoretical distinction between where previous work has affected creativity in design and thus where future work will be positioned.

1.2. Research Questions

Several key research questions arose due to the background information, the first two will be explored within this paper enabling investigation into the final three questions during forthcoming research work.

Research Questions:

1. What is conceptual and detailed design and what is its relationship to the design systems level and process of design activities?
2. What characterizes the later stages of the design process from the early stages?
3. What is the role or potential role of creativity in the later stages of design?
4. What characterizes the different design problems or tasks and what are their influences on the design activities process?
5. And, how might these various tasks be supported in terms of creativity?

1.3. Contents of Paper

When considering the design process from the perspective of creativity it was realized by the authors that the current view of the process may be misunderstood. When terms such as conceptual design and detailed design are referred to, there is large confusion and often miscommunication between whether these are in reference to a stage of the design activity process or designing at a particular systems level of complexity.[5]

It is proposed in this paper that the 'design process' should refer to the types of activities carried out by an engineering designer when given a design task and is independent of the systems level that the task is set. Though this is implicit or at least not argued against in a number of the core test of engineering design texts[5,6] in many, the relationship between the design activity and the systems complexity are entangled.[7–11]

In the following section the author will describe in detail the systems levels of a design and will clear some confusion caused by similar hierarchical structures. In Section 3 a description will be given on what the authors believe to be the design activities process. Section 4 then aim to integrate the modular systems hierarchy with the design activities process answering research questions one and two. The final section will report the implications of this theoretical work presented in this paper along with proposals for future research.

2. DESCRIBING DESIGN SYSTEMS LEVELS

Firstly, what is a system? This can cause some confusion in itself. There are a number of defined systems hierarchies within engineering design literature, consisting of a combination of conceptual and tangible elements of an artifact.

Of the numerous core engineering design authors that cover standard design practice and principles, 3 similar hierarchical tree structures emerge that could be considered to deal with hierarchical systems levels. Namely, these regard objectives trees, function structures and modular structures. These hierarchies describe the breakdowns of objectives to be achieved by a design, the functions a design is to achieve and the physical modularization of an artifact.

To add further confusion, in the 9 windows systems operator,[12] a tool commonly used under the banner of TRIZ, the system under study is to be placed relative to a sub system and super system. Here the super system is used to allow the system to perform its function, suggesting as examples, 'paper' as the super system of a 'pen being used to write' and a 'wrench' as the super system of a

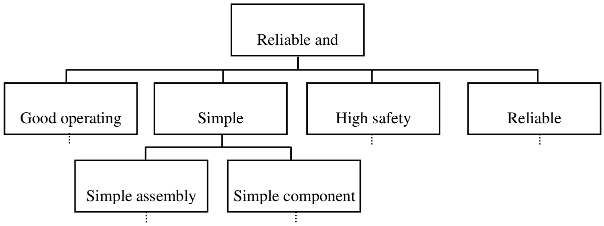

Figure 1. Example objectives tree. Source: Ref.7

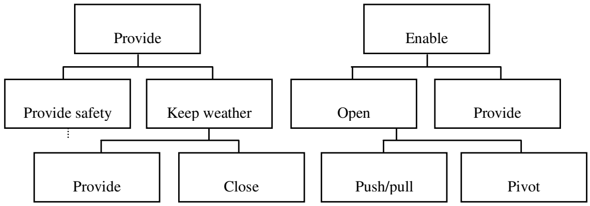

Figure 2. Functional tree of a car door. Source: Ref. 11

'nut'. The subsystems are defined as features or components of the system enabling it to achieve its function suggesting the 'ink flowing through nib' as a subsystem of the 'pen being used to write' and the 'thread' as a subsystem of a 'nut'. The following subsections will deal with objectives trees, function structures and modular systems.

2.1. Objectives Trees

If the objectives trees are considered, the overall objective of a design is decomposed until elemental objectives levels. This should be carried out early in the design process and then refined after a solution principle and layout is decided upon. The objectives refer to the performance parameters related to the important 'wishes' from the design specification by which the design and its overall function can be tested. The objectives give little indication as to what the design is for or what physical form it comprises of.

The above description of objectives at different hierarchical levels (Figure 1) does not provide large distinction between the different functions to be achieved at the various systems levels so much so that Cross.[13] uses examples of each interchangeable. However, there is deemed enough distinction for many authors to separate objective trees from function structures.

2.2. Functional Structures

Function structures are similar to objective trees. Here the primary functions of an artifact are decomposed in into sub-function, representing an overall artifact function without reliance on physical structure.[14] The use of function decomposition and functional structures is very popular throughout the engineering design research community. It is regularly used to abstract a desired function and at this abstracted level find analogical matches to introduce solution from mechanisms, systems[14,15] and even nature[16,17] that have previously been functionally decomposed.

In Suh's[18] description of a function hierarchy of a lathe, each function is attributed to a module on his physical hierarchy. However, this suggests an uncoupled design where each physical component or design parameter relates to a single function which in reality is not always the case.

2.3. Modular Systems

In accordance with Suh's view, modules are defined to relate to the physical structures of an artifact and relate with a one-to-one correspondence with functional structures.[15] In this type of systems hierarchy a machine, product or artifact is broken down, typically from overall system to subsystems, then to parts and components.

Moving down the hierarchy, as modules are further and further decomposed into smaller more specialized modules, each module can be considered to be more detailed relative to the modules at higher systems levels. Also, when moving up the systems levels, modules are considered relatively more conceptual than those at lower levels. When this is considered, it is understood, that when conceptual design is referred to by engineering researchers, this can sometimes relate to the design of modules at high systems levels. When referring to the design of low systems levels the term detailed design will commonly be used.

The type of hierarchy shown in Figure 3 will be further considered throughout this paper where it will be analyzed against the design activates process. It is agreed b the authors that the design activities within engineering design are driven by mixture of the fulfillment of objectives, achieving functions and embodying the various modules.

3. DESCRIBING DESIGN ACTIVITIES PROCESS

The quest for the consistent (descriptively) and useful (prescriptively) generic engineering design process is considered perhaps the holy grail of design research. This section will, most importantly with regards to this paper, review and draw conclusions of the most well referenced design process models found within the literature. In the final subsection the reader is informed of alternative representations of the design process.

3.1. Linear Process Models

From a review of literature there are several ways of representing the design process, but by overwhelming popularity it take the form of a linear sequence of stages with feedback loops for refinement. In previous research the general agreement of design authors on common, often synonymously named stages, was demonstrate. Virtually all linear process models could fit within a 6 stage framework comprise the four major design phases: 'analysis of task, 'conceptual design', 'embodiment design' and 'detailed design'. The authors argue that these four stages form the design activities process used in the integrated model in Section 4.

Preceding these four phases is the 'Establishing a Need' phase, where the driver for the design is recognized. Following the four major phases is the 'implementation phase', which is included by several authors, explaining what happens when the final engineering 'drawings' and instructions are completed. The implementation phase contains only post-design activities and is therefore not the focus of this paper.

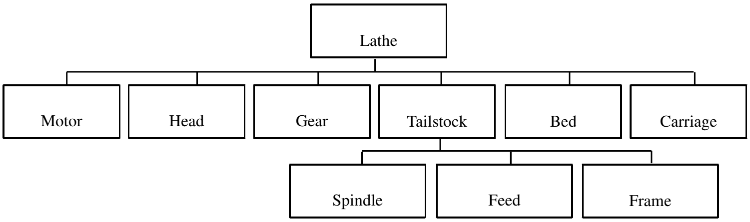

Figure 3. Example of physical systems hierarchy. Source: Ref. 18

Table 1. Example design task or brief for modules at different systems levels.

Module	Design task
A	To design a transport solution to use an existing infrastructure of lockable mounting and payment units to alleviating traffic in a city centre.
Aa	To design a drive train for the a lockable public bicycle designed in module A
Aac	To design a crank set to suit the drive train layout designed in module Aa

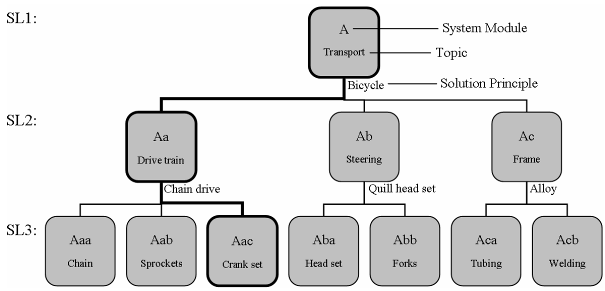

Figure 4. Example systems hierarchy for the design of a mode of transport.

3.2. Other Representations

There are a number of notable differences between the models, of particular interest are the divergent convergent models, which include controlled convergence[11] and the double diamond.[19] These divergent convergent models differ from the traditional linear style by assuming some form of integrated evaluation and selection of ideas and concepts. This is potentially a useful outlook on design from a creativity perspective, as separating the generation and evaluation periods is considered good practice for both lateral thinking and brainstorming.[20]

Another slightly atypical form of representation can be described as a 'knowledge space model'. Here it is assumed that a certain quantity of knowledge must be gained for each phase of the process in order to complete a design. These spaces can be filled in random order or sequence, though there are certain dependencies inbuilt within each design project, i.e. one space cannot gain anymore relevant information until knowledge is gained in another space. A prime example of this type of representation is the C-K theory[21] which describes design as a process of movement between a concept space and a knowledge space. These types of model are probably valid and representative of actual design activities, though it is clear that their high level description makes them less useful to designers.

3.3. Integrating the Systems Level of Design with the Design Activity Process

If we take a new product or service development project as an example (see Figure 4), each engineer will be tasked with designing a module at the various systems levels (SL's). Here systems level 1 (SL1) is considered to be the highest systems level, where as systems level 3 (SL3) is a relatively low systems level. Table 1 provides some contexts to the types of design tasks or mission statements driving the design of the system modules in Figure 4.

Figure 5 describes the design activities process that occurs within the design of each module. It can be seen how the end of a design activities process feeds down (α) to create the brief, mission statement or design task for the design of the various modules at the lower systems levels (Figure 5 shows this connection from module A to module Aa from Figure 4). After the analysis of task and conceptual design phases it is possible to challenge the preconceptions made by the design brief and move to a higher systems level. This can take affect at the conceptual design phase (β) where the overall solution principal is altered, this often being the defining process of step change or radical

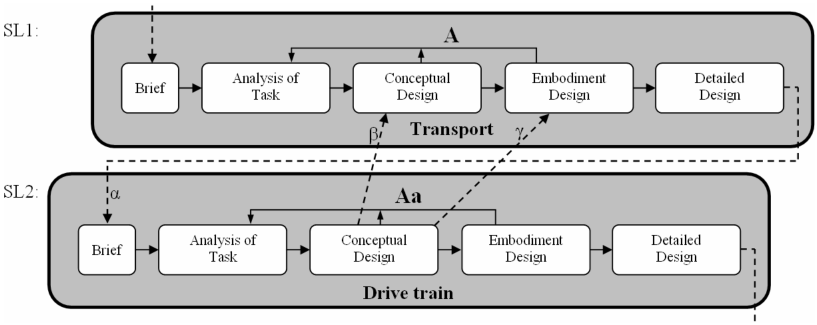

Figure 5. Design activities process contained within each module of the systems hierarchy.

innovation. Moving to a higher systems level can also take affect in the embodiment design phase of the higher systems levels (γ), altering the modular layout of the current systems level or connection points between modules but using the same solution principle.

Table 2 details what each of the activities within a systems level contains for the example systems hierarchy shown in Figure 4.

4. DISCUSSION

In this section the two research questions are addressed in light of the theory suggested in the previous section, that the design systems hierarchy (Section 2) and the design activities process (Section 3) are different and can be integrated.

4.1. What is Conceptual and Detailed Design and What is its Relationship to the Design Systems Level and Process of Design Activities?

During the theoretical work shown in the previous section, the design process is hypothesized to occur at every systems level. This suggests that the conceptual design phase and detailed design phase occur independently of the systems level and the complexity or intricacy of the artifact being designed. However, systems level is likely to have impact on the time spent at each stage. At low systems levels which are more highly constrained the conceptual design activity may be quickly passed over particularly when a parametric or selection design will suffice.

Though the example given was a simple modular example, the authors believe this theory hold try for both modular and integrated design. However, in integrated or uncoupled design the process is expected to be more erratic switching between systems levels more frequently.

4.2. What Characterizes the Later Stages of the Design Process from the Early Stages?

As suggested in previous work[1] the early stages of the process are dealing with functions and behaviors or solution principle. The later stages are more concerned with structure, layouts and communication. Although at different systems levels, different tools and information sources may be used during these stages it is hypothesized that the types of design activity remain the same. The implications of this hypothesis may suggest that similar creativity tools can be used in the design of modules at different systems levels so long as they are used during the correct activity.

5. CONCLUSION

The integrated model proposed in Section 4 proved to be an interesting convergence of ideas with the function means law[5] and its relationship with domain theory.[22] The function-means trees model the

Table 2. Example design tasks at the various systems levels.

	Analysis of task	Conceptual design	Embodiment design	Detailed design
A	To analyze market opportunities, constraints, functions and objectives	To produce and choose a concept to fulfilling the brief. In this case a bicycle.	To produce the preliminary layout of the chosen concept forming SL2	Documentation of dimensioned layout, module interaction points and brief for Aa.
Aa	To analyze, understand and contest the brief. To expand the functional systems and objective trees.	At a routine level, to produce a concept to fulfill the brief of Aa. Example: Chain drive To change the solution principle of SL1 (β). Example: using scooters instead of bicycles. To reconfigure the modules of SL2 (γ). Example: using connecting drive train to front wheel	To layout the routine concept from the previous stage to forming SL3 and the layout and interactions between the modules.	Documentation of dimensioned layout, module interaction points and brief for Aac.
Aac	To analyze, understand and contest the brief. To expand the functional systems and objective trees.	At a Routine level, to produce a concept to fulfill the brief of Aac. Example: Crank set To change the solution principle of SL2 (β). Example: Using a belt drive. To reconfigure the modules of SL3 (γ). Example: introducing a chain tensioner.	To layout the routine concept from the previous stage laying out the components and the assembly of parts in SL4.	Documentation including Manufacturing drawings for components, parts lists, assembly instructions etc.

relationship between the functional hierarchies and the physical or behavioral hierarchies. However this shows not relationship to the well excepted model of Pahl and Beitz's[7] 4 stage design process. Hubka and Eder[5] show this relationship in the completeness and maturity of technical systems during the design process where it states all functions are modeled first followed by all layouts and the detailed assembly drawings. This differs from the model proposed in Section 4 which states that at each systems level a task is clarified and solutions conceptualized, embodied and detailed before moving on to the next systems level.

If the model proposed in this paper proves to be an accurate description of the engineering design process it could lead to bespoke creativity tools being created for either the design activity, independent of the systems level.

5.1. Future work

It is important to look more closely at the types of design task at each of the systems levels, and how these may affect the design activities in order to help validate the theory presented in this paper. It is through understanding how the different types of problems, at the various systems levels affect the design activity, will give insight into to scope for creativity support for each design activity at each systems level.

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