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The quality of a design will not exceed the knowledge of its designer; an analysis based on Axiomatic Information and the Cynefin Framework

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Abstract

Knowledge is essential to the product designer. It contributes to a better understanding of the difficulties in a design. With the right knowledge, design errors can be recognised in the early stage of product design, and appropriate measures can be applied before these errors escalate and delay the project. The axiomatic complexity theory, part of the Axiomatic Design methodology, can warn the designer in this process by disclosing his lack knowledge to fully understand the design. The Cynefin framework is a sense-making framework that distinguishes an organisational situation within four contexts. The state of relevant knowledge is the most important parameter to determine the actual context where an organisation, system, or design process is currently located. When knowledge is acquired, the context changes. Axiomatic Design and the Cynefin framework are applied in this paper to characterise the relation between the quality of the design and the knowledge of its designer. It is investigated if one follows the other, and how prompt that relation is. The outcome is that the quality of a design is proportional to the accumulation of applied knowledge to the product design. Therefore the quality of the design follows knowledge implementation but does not exceed the level of relevant knowledge of the designer. Knowledge should not be restricted to the designers only. Other people, e.g. production- and maintenance-engineers, will also need the knowledge to take care of the product as the life cycle advances.

1. Introduction

In a high-tech world with interdisciplinary product challenges, product designers are facing a wide range of design problems. For a well-engineered and distinctive product design, the designers have to challenge themselves by putting the best of their capabilities into their work; when finished, the product design has become a reflection of their powers. A designer, as referred to, is usually not a single person. In practice this is actually a group of people, with various specialisms, to address problems with various natures. The design process starts with the marketer, who translates 'Customer Attributes' (CAs) into 'Functional Requirements' (FRs). Secondly, there is the product designer who relates FRs to 'Design Parameters' (DPs). Finally the production engineer finds 'Process Variables' (PVs) that match the DPs. In large projects, every profile is found more than once, with a specific focus on various technological or organisational domains. The group of people that is responsible for the design process is in this paper further referred to as 'the designer'.

Methods for systems engineering, or engineering design, help the designer to break down complex problems that are difficult to understand into smaller parts. The smaller individual parts can then be optimised in a limited context, as long at the input and output relations between parts are understood. Axiomatic Design (AD) is a framework of methods that assist the designer during various stages and activities of the design process [1]. The goal is to enable the designer being able to make the right decisions along the product development process. Knowledge is essential when creating a design. Knowledge enables understanding of the difficulties in a product design. Most design errors will be recognised in the early stage. Appropriate measures can be

applied before these errors escalate and delay the project. AD leads the designer through the design process and indicates when essential knowledge is missing. The designer is then able to gather the missing knowledge to take steps that timely remedy the problem. The Cynefin framework is an analytical decision making framework that was developed by Snowden [2]. Cynefin relates to a 'place of multiple belongings'. The Cynefin framework originated in the practice of knowledge management. Snowden calls it a 'sense-making' model where data precedes framework and patterns emerge from the data instead of the other way around. It consists of four contexts, basically fields of action, in which an organisation or system can be found, and a fifth space when the actual context is unknown. Knowledge is in the Cynefin framework the most important parameter to determine the context where an organisation, system, or problem is currently located. When knowledge is acquired, the context changes. An interesting feature is that the model also supports context changes when knowledge disappears.

This paper investigates the relationship between the knowledge of the designer and the quality of the design. AD and the Cynefin framework enable the investigation. It examines how knowledge is applied and how it can be secured to ensure that the product will always function properly from cradle to grave. The research question is formulated as:

- *How does the application of knowledge lead to increased quality of a design?*

Knowledge, as applied here, refers to the definition of knowledge the in axiomatic complexity theory [3, 4]. Complexity, which is a measure of uncertainty in achieving the FRs, can be reduced by the application of knowledge of the designer. Therefore, knowledge may be considered as: 'the general erudition of the designer that is applied to formulate DPs that satisfy the FRs of a product design'.

This paper is organised as follows: Section 2 clarifies the axiomatic concept of 'Information' or 'Entropy'. Secondly it explains the Cynefin framework. Section 3 applies the two methods to investigate the essence of knowledge to the designer and what may happen if knowledge is lacking. Section 4 discusses the findings and summarises conclusions.

2. Applying AD and the Cynefin Framework to Chart Knowledge

2.1. Information or Entropy in a Design

'Information' or 'Entropy' may be considered as chaos in design. Information in AD is derived from the information technology using a logarithmic measure of Boltzmann's entropy according to Hartley [5] and Shannon & Weaver [6]. According to this theory, information is inversely related to the probability of success. Probability is the central theme of AD around which the axioms are carefully wrapped. Knowledge is applied, in good accordance with the nature of the axioms, to maximise the probability of DPs satisfying FRs. Knowledge is therefore the most important enabler to

address information and consequently increase the probability of a design to function as expected. Suh describes three types of information in AD, 'Total' information, which consist of 'Useful' and 'Superfluous' information [1]. Useful information is information that affects FRs and their relations to the other domains. Superfluous information does not affect the relation of FRs and the other domains. Therefore, superfluous information is no information from the axiomatic perspective. Puik & Ceglarek decomposed information in the axiomatic context [7] as shown in figure 1:

- Total information; the total information content or full entropy of the design as defined by Suh [1, p.149];
- Useful information; the part of total information that affects the relation between FRs and DPs [1, p.148];
- Superfluous information; information that does not affect the relation between FRs and DPs [1, p.148];
- Axiomatic information; useful information due to a discrepancy in design ranges and system ranges as will lead to 'Real' complexity [3, 7];
- Unorganised information; useful information that is not recognised as such due to ignorance of the designer [7];
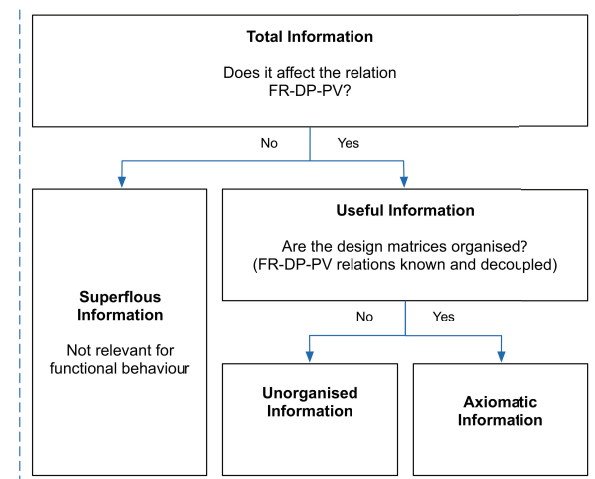

Fig. 1. Overview with types of information and their relations

2.2. The Cynefin Framework

Cynefin is a decision making framework that can be applied on organisations, systems, or even complex social environments [2]. It was applied, evaluated and refined at the IBM Institute of Knowledge Management [8] and later expanded to be used as a leadership model [9]. Cynefin has not yet gained much drag within the AD community or even product development in general, but with the view on information in AD as reported by Puik & Ceglarek [7], both methodologies appear to connect and harmonise well together.

The framework consists of three basic types of systems; 'Ordered' systems, 'Complex' systems and 'Chaotic' systems. Ordered systems are divided in to two types: 'Simple' ordered systems and 'Complicated' ordered systems. In the centre of the four contexts is a fifth field added: 'Disorder'. Together this leads to the Cynefin framework as shown in figure 2.
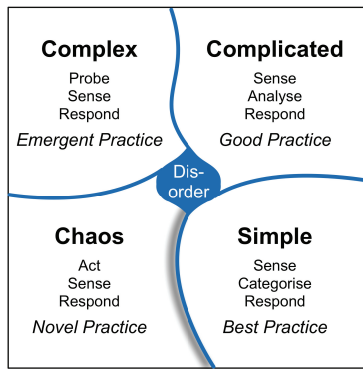
Fig. 2. The four contexts of the Cynefin framework. When in disorder, the actual context is not known

- In the simple context, cause and effect relationships are clear, predictable, repeatable, and generally linear. The systems in this context are self-evident to every reasonable person. The decision model of the simple context is sense-categorise-respond. Good response in these situations would be to watch what is coming in, match it to previously determined categories and decide what to do. The simple context is the context of 'best practice';
- In the complicated context, there is a logical relation between cause and effect, but it is not self-evident and therefore requires expertise. An analytical method is needed to solve problems, or an expert could be called in. The decision model therefore is sense-analyse-respond. The complicated context is the context of 'good practice';
- A complex system is a system without causality. Cause and effect are only obvious in hindsight, with unpredictable emergent outcomes. The decision model is probe-sense-respond. Carrying out experiments is a key characteristic; a successful outcome is enhanced, a bad outcome is suppressed. Actions lead to a novel way of doing things. The complex context is the context of 'emergent practice';
- A chaotic system shows no relation between cause and effect. The goal should be to restore order. The decision model therefore is to act-sense-respond. Actions will be new and unconventional. This is the context of 'novel practice';
- Disorder is the space when it is not clear to which context a situation should be appointed.

The boundaries between the contexts are transitions that can be taken without specific effects, except for the boundary between the simple context and the chaotic context. This boundary is referred to as the 'Complacent Zone' or the 'Cliff'. The danger is that once a system is in the simple context, people start to believe that things are simple by nature. It may lead to the belief that things are always ordered and that success from the past is proof that systems cannot fail. The result is that the actual position moves to the border and at a given moment falls over the cliff into a crisis.

2.3. Synergy between Axiomatic Design and the Cynefin Framework

Although originally from a completely different background, AD and the Cynefin framework have a number of similarities. First, for both methodologies, knowledge is enabling for the determination of the status of a system. Secondly, both methods deal with the level of organisation in systems or contexts. AD, as was shown in figure 1, has unorganised information and axiomatic information, the latter dealing with an organised design matrix and therefore also to be considered as 'organised' information [7]. Cynefin recognizes unordered and ordered spaces that are quite comparable to AD. This will be explained further in the next section.

3. The Essence of Knowledge to the Design

The earlier referred investigation, based on information or entropy in design [7], has led to the belief that the quality of a design never exceeds that of the designer. A 'good design' in the hands of an ignorant designer will not be recognised as such. The ignorant designer will not understand how the design matrix was optimised and what the FR-DP-PV relations are. Optimisations in the perception of the designer will in the best-case lead to reinvention of the wheel; they might lead to a different good design, but probably will degrade the level of the design. The reason for this is that it may not be assumed that that an ignorant designer will produce a good design without the ability to understand the design matrix. As a result, the design matrix will be unclear, at least not decoupled, and the information content of the design will increase.

3.1. Relation of Knowledge and Ignorance of the Designer

The question is how the designer's ignorance and knowledge are related to the information content in a design. The answer is found in figure 1; a coupled design matrix negatively affects the relation FR-DP-PV and therefore increases the useful information content of the design. Superfluous information is not affected. Unorganised information, being a part of useful information, is directly affected. The axiomatic information content may increase depending on the way the design matrix is restored and if optimisations of the design are lost. This leads to the understanding that

$$IGN_{Designer} = I_{Useful} = \frac{1}{K_{Useful}} \qquad (1)$$

or

$$Q_{Design} = K_{Useful} = \frac{1}{I_{Useful}} \qquad (2)$$

where $IGN_{Designer}$ is defined as ignorance of the designer in the field where it matters to the design [3], and I_{Useful} is useful information as the sum of unorganised and axiomatic information conform figure 1. K_{Useful} is the relevant knowledge of the design and is equal to Q_{Design}, which is a

measure for the quality of the design. These statements are with proviso that there were sufficient time and means for the designer to apply his knowledge to the design.

3.2. Knowledge in Axiomatic Design; How is it Applied & Where is it Located

The state of a design is kept in the axiomatic domains by defining its design relations (CAs, FRs, DPs, and PVs). The relations are intrinsically static; only by external activity of the designer the relations of the design will change (figure 3).
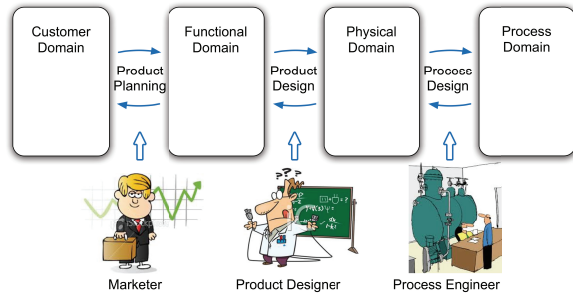

Fig. 3. Axiomatic knowledge application

As was explained, 'the designer' actually refers to a design team and more than a single expertise is needed to bring a complex design task to a good end. To investigate how knowledge is applied to reduce the information content it is essential to understand where information and knowledge are located. AD is definite about this; missing or unclear relations between the domains cause the information content of the design to increase. Clear relations, that are defined in uncoupled (or decoupled), design matrices reduce the information content. Respectively the product planner, the product designer, and the process engineer of figure 3 apply knowledge to the design in order to structure the relations between the domains and thus reduce the amount of information. When a sloppy marketer fails to define good relations between CAs and FRs, the FRs will not represent the qualities that a customer expects of the design. As a result, DPs and PVs will be incorrect too. Information in design can originate at either one of the three places where relations between the domains are established; product planning, product design, or the process design. Information typically tends to escalate through the successive domains in the right hand direction (when applying the method of zigzagging).

The design process does apply knowledge to the design but that knowledge is not transferred into the design. Knowledge 'application' leads to reduction of the information content, not the knowledge itself, as the knowledge itself remains with the designer. Relevant knowledge and understanding as applied to a 'Good Design' has provided optimal relations between the domains and, as a result, the information content in the design has disappeared. Knowledge may be lost by various reasons e.g. staff turnover, but can be written down in reports for application by future generations. This secures important data about the design and makes it easier for the successive designer to understand the design considerations by levelling knowledge to that of the initial designer.

3.3. Information in the Cynefin Framework

Analogue to AD, knowledge plays a significant role in the Cynefin framework. It is for a great deal responsible for the dynamics of Cynefin. The two upper quadrants, *complex* and *complicated* are domains that rely heavily on knowledge. The lower two lower contexts *chaos* and *simple* are characterised by the absence of knowledge. The unordered space on the left side indicates that the information content in the system is high. The ordered space indicates that information is low. This is shown in figure 4.
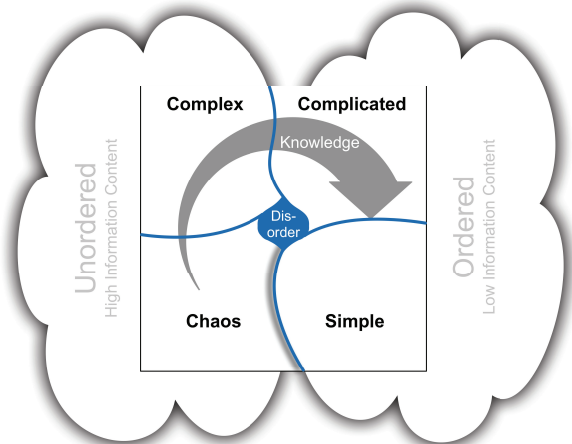

Fig. 4. The Information content and knowledge development in the Cynefin framework

Chaos deals with a lack of relevant knowledge and this explains the absence of causality between cause and effect. This causality arises in the *complex* context and is eventually restored when the move to the *complicated* context is made. This can be compared by decoupling the design matrix in AD, which leads to elimination of unorganised information. The *complicated* context addresses axiomatic information by making the system robust. The information content of a robust system is low because both unorganised and axiomatic information contents are addressed. This is reached at the boundary of *complicated* and *simple,* where all knowledge-based processes have been converted to rule-based processes.

Rule-based processes are characteristic for the simple context. Knowledge is no longer expanded but has been applied to the system. The role of the product designer, as was explained in figure 3, is slowly decreasing. This would happen when a product is in the production phase. Production workers will have little problems to maintain production operational due to adequate engineering and the engineers may be phased out of the project. Here lies a significant risk; as long as variances of external influences are within the operating windows of the procedures as foreseen, everything goes well. If these external changes are of an unexpected nature, which was not foreseen by the designer, the production workers cannot address problems since a suitable procedure is non-existent. Knowledge is needed to recover and the project may find itself in the 'complacent zone' and fall over the 'cliff'. The team of designers has to be brought back in the arena to restore the problem; as knowledge to

develop the project is not situated in the project but stays with the designer, the team of figure 3, or at least a part, is needed to apply knowledge to the project and restore stability. In this process, the cycle of the Cynefin framework is run through in clockwise direction entirely.

4. Discussion and Conclusions

The investigation started with the research question how the application of knowledge would lead to an increased quality of design. Equation (2) indicates that the quality of a design is equal to the knowledge of the designer and inversely related to the information content in the design. However, a look at figure 4 learns something different; knowledge is coupled to the vertical axis of the Cynefin framework, but information is coupled to the horizontal axis. This indicates that knowledge and information are not directly related. The explanation is that the Cynefin framework shows the stage during which knowledge is implemented, and AD monitors the quality of the design as the effect of the implementation of knowledge. This causes a phase difference between knowledge application and the information content of the design as it decreases during this process. Since information in design and the quality of the design have a direct and reciprocal relation, quality laggingly follows knowledge implementation. The quality matches the knowledge of the designer if a designer is given enough time to implement it. Ultimately, the quality of the design may not be expected to exceed the total knowledge of the designer. However, the quality of the design can keep increasing when the designer is learning on the job, since his newly acquired knowledge may be implemented right away.

4.1. Strengths of Cynefin, Applied to the Development Process

Applied knowledge is secured in the design but the knowledge itself stays with the designer. Knowledge itself may be reported in the product documentation. Documenting knowledge of the designer is laborious and may be seen as a dreadful process. It may be considered to be a strength of the Cynefin framework that it clearly explains what might happen if the knowledge of a design is not secured; in the simple context, knowledge is mainly caught in procedures. But these procedures are static and will not adapt to external changes that were not foreseen. Therefore, new problems cannot be explained or addressed by the 'old procedures'. The operations will move to the complacent zone in anticipation of the unfortunate scenario of dropping over the cliff. Securing knowledge alone is not enough to prevent this from happening. Production and maintenance engineers will also need the capability to apply the knowledge to unforeseen problems during the lifecycle of the product, to guide it from cradle to grave as planned. Knowledge is not just reserved for the designer, but should remain in the project. Keeping people, who carry the knowledge, in the project may do this. It can also be secured by documenting project findings but it is still a prerequisite that there are project members who are able to acquire the knowledge and apply it accordingly.

4.2. Weaknesses of this Approach

The Cynefin framework belongs to the cognitive sciences. As it is a sense-making model suitable for exploration in situations where data precedes the framework, it starts with the situation of the designer and the current state of product design. From there on it studies the knowledge development and knowledge application. Cynefin is not a not a categorisation model which judges the product design for its qualities. Therefore it will not provide a gatekeeper's function to advance the product development process to the next stage when targets are met. It even does not indicate if the designer's knowledge is applied to the product design in the right manner. Determination of the position in the Cynefin framework can therefore be difficult. However, appointing the right position is a prerequisite to determine the right strategy and when this fails, the benefits of the method lapse. If the actual context is unknown, the designer finds himself in *disorder*. In this case, the designer typically will address the problem in the most reliable way for him, which probably is not the best approach for that particular situation.

4.3. Limitations

The product design process only uses a limited part of the Cynefin framework; only the complex and complicated contexts are the most obvious positions for product development. With only two quadrants in use, the method loses resolution when analysing problems in the development process. This problem was not investigated yet.

The position in the Cynefin framework does not represent the general status for the project but only that of a particular problem in the design. Therefore it cannot be applied as an indicator for project progression.

4.4. Further Observations

Relevant knowledge is a prerequisite during the product development process to get a 'good design'. Once this knowledge is applied, the design relations have been established. Knowledge itself, as the ability to analyse and understand a design, does not inherit into the design itself. It also cannot be figured out by reverse engineering since it has no presence in the design. If not secured, it remains a privilege to the designer.

4.5. Scope for Extension

If it would be possible to expand the Cynefin model to indicate that the end of a certain context is reached, it could provide with a warning function to alert the designer that the way of working needs adjustment to fit the next context. Such a function could be implemented by looking at the cause and effect of design decisions. AD may support this by the status of the design matrix commending the step to a next context. This was not investigated yet.

5. Conclusions

The Cynefin framework can serve as a valuable addition to AD. It focuses on the designer rather than the product design and will advise in the most optimal approach when addressing the respective stages of the design process. It not only clarifies that the implementation of knowledge does lead to a qualitative increase in the product design but it also makes aware that time is needed to integrate this knowledge in the product design. The quality of a design indeed does generally not exceed the knowledge of the designer.

Designers should document the knowledge needed for the design and how this was implemented. This secures the knowledge for later use. Other stakeholders will benefit from the secured knowledge further in the product life cycle.

6. Acknowledgements

7. References

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