A Framework For Product Development

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Abstract

Since the introduction of Integrated Product development in 1985 [1], industry has widely been using this model to understand and articulate their design, business and production activities. Recently, however, the picture has started to alter, as the nature of industry's business has had to adapt to a much more complex world and in many cases, Integrated Product Development is no longer a sufficient way of describing industry's product development activity. This paper uses the model of Integrated Product Development as a start-point to exploring the changes that industry has been undergoing over the fifteen years since it was introduced and attempts to make pointers in the direction of a new framework for product development, which should guide industry in the future.

The key research challenges that this paper identifies include: developing a framework that identifies and supports a multi-aspect approach to product development; understanding the strategic conditions that affect product development; developing a coherent approach to product quality based on product-life thinking; addressing environmental needs in a proactive manner through innovation techniques; and understanding both organisational and technical knowledge-management for improved product development.

1 Background

The product development research area has evolved from the area of engineering design, based upon the recognition that important aspects such as need, market, business, innovation and technology management. These fuse together to form a field of competencies with its own professionalism and need for clarification through research.

In the 1980's, the concept of Integrated Product Development (IPD) was created by Andreasen and Hein [1]. IPD has acted as a guide to industry ever since, highlighting the need to concurrently address the product, production and market situations when developing products, and providing a structured framework into which product design should fit.

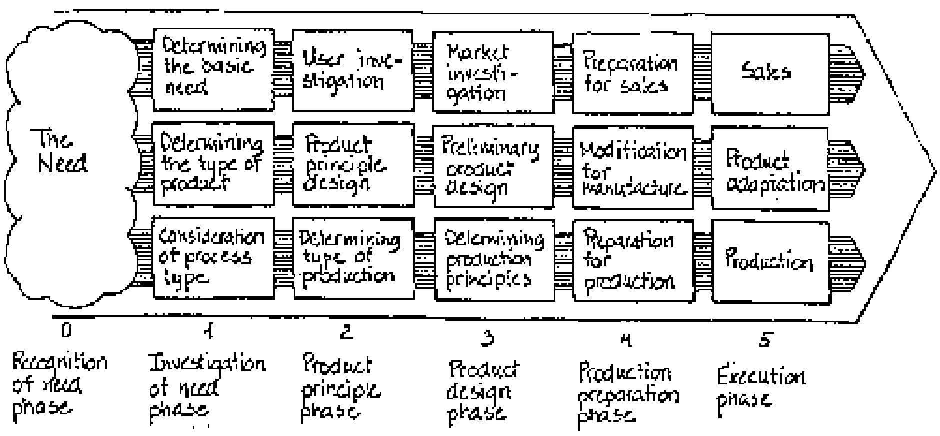

Figure 1: IPD model (Andreasen & Hein, 1985 [1])

However, fifteen years after the articulation of IPD, industry has developed and moved on, so that IPD no longer fits ideally to many industries' actual product development activities. Causes for these changes include:

- product quality developing to very high levels and becoming an accepted norm rather than a competitive lever;
- differences in expectation, interpretation and perception of quality between the customer and the company (and furthermore internally within the company) are causing a number of gaps, leading to low competitive edge;
- environmental concerns being translated into a range of product design efforts, and re-shaping the direction of industry development;
- products becoming technologically more complex and combining technologies that were previously left as discrete solutions (i.e. mechatronic products);
- the introduction of the concept of product families, where many products share the same basic architecture and certain base-components, but have an array of end-variants, to provide a continued product range;
- the further development of the product family concept to the activity of modular design, where the product is not only capable of being a family member, but also up-gradeable, easily repairable, and interchangeable;
- a significant shift in the way that products can be defined, due to the fact that they increasingly come as a package of hardware, software and services – industry is increasingly regarding the physical artefact (the former definition of a product) as carrier to the growing range of services that they provide;
- globalisation and uncertainty induces companies to create new product concepts and markets;
- the need for companies to find another means of competition – time, cost, quality, flexibility, (and to a certain extent, environment) have all been key competitive dimensions for industry over the past twenty years, all of which satisfy the customer's basic needs/desires. Industry is seeking the next competitive dimension.

These issues have driven industry to search for a new framework for product development that can cope with these many aspects.

This paper identifies a challenge to create a vision for a new product development framework, which both represents and guides industry in its systematic approach to creating products.

2 Why A New Framework For Product Development?

2.1 The need for structure

On evaluating IPD, we can see that its purpose was to represent a recognition of co-ordinated strategies towards product development, and to present a paradigm which combined design with the roles of marketing and production, focusing on needs and business. In essence IPD was a definition of professional behaviour in product development.

Industry has since moved beyond this model, due to the need to perform and compete in rapidly changing markets, with ever increasingly complex technology. These constant changes have given rise to a number of issues in product development, which should be addressed, in order to understand and articulate them in a new framework.

2.2 Current issues in product development

Together with the Department of Control & Engineering Design at DTU, five Danish companies have established, and are now supporting, a research programme named P* (Product Development Programme). Initiated in 1998, this programme has led to deep insight into the needs and interests of Danish industry. Based upon emerging theory and scoping studies carried out in the P* companies, a number of issues have been identified, which are not currently covered by integrating models of product development. The following eight themes crystallise the areas of significant importance in product development, which industry is seeking insight into:

- life cycle oriented design and the universal virtues;
- product structuring (e.g. platforms, modular engineering);
- integration of technical disciplines (e.g. mechatronics);
- environmental issues;
- product quality;
- the role of IT in product development processes;
- human-machine interaction; and
- innovation.

3. Current issues and their ramifications on product development

The challenge in building a new framework for product development is that a number of aspects must be integrated. These include:

- organisation: structures, processes, tasks, management systems, teams, individuals;
- product development types or tasks: innovation, development, consolidation, variants;
- integration of product life orientation and multi-disciplinary work patterns.

In addition, there are important aspects and approaches that should be added, such as:

- techniques for determination and utilisation of re-use patterns of any kind in product development;
- identification of the interaction between a method and the related platform of understanding;
- use of visualisation and graphical modelling of complex aspects in product development;
- use of the theory of design co-ordination for identification of framework dimensions;
- patterns of where and how innovation fits into product development.

The following paragraphs are an excursion into the eight themes that have been identified as key factors which are challenging, or are set to challenge industry. They also provide an explanation to industry's development away from the IPD model.

3.1 Life cycle oriented design and the universal virtues

During the 'cradle-to-grave' life of a product, many different people will interact with it, each in a different context and with a purpose different to the others. Life cycle oriented design requires the designer to consciously consider the totality of the life cycle of the product and all the stakeholders who interact with the product, and create a product with the appropriate properties to fulfil everybody's quality expectations.

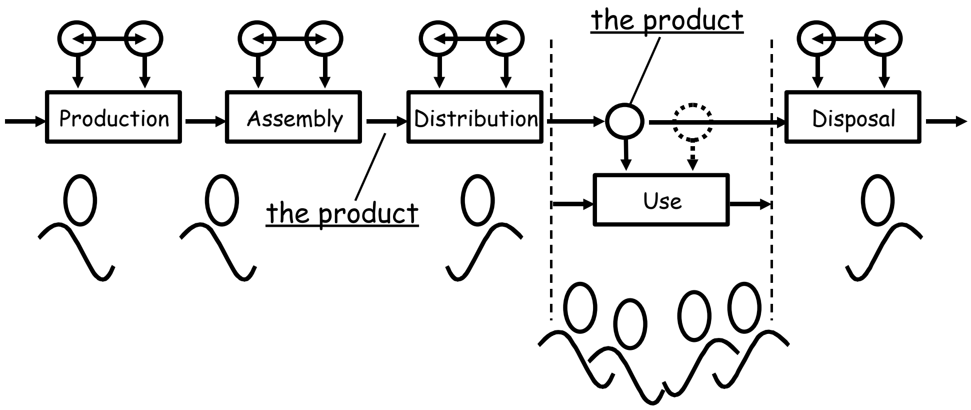

Figure 2 - Simplified life cycle model showing only a few life phases

Figure 2 shows a simplified model of the product life cycle with only a few life phases depicted. The 'use' life phase is clearly the most significant of these and the most complex to understand. In the use life phase, the product is an active element of a technical process, which creates a transformation of some kind. Hubka's theory of technical systems [2] provides a theory base for describing the relationships between the transformation process, the technical system, the human operator and the surrounding environment. In other life phases (e.g. 'assembly'), the product is the subject of the technical process and is acted upon by another technical system (e.g. an assembly system). The product development process itself may also be modelled using this theory – here the transformation process is of data and information into a design description of the product. The two process streams will meet when the product is launched into series production.

In order to create a model of the product life cycle, it is necessary to determine each of the discrete 'meetings', which will occur between the product and the stakeholders. Clearly some meetings occur only once in the life cycle (e.g. those associated with the original manufacture of the product), whereas others occur many times (e.g. those in the 'use' life phase). During a meeting, the product will interact with other (complementary) technical systems, users and stakeholders. The effectiveness of the activity in each meeting can be measured using the so-called 'seven universal virtues' (see Figure 3), i.e. quality, time, cost, efficiency, flexibility, risk and environment (after Olesen, [3]). Since the product participates in each meeting, its functionality and properties have consequences in all of these measures. As a result, the seven universal virtues may be utilised to measure the effectiveness of each phase of the product life cycle, to compare alternative design solutions, or to clarify product development objectives.

The principles of life cycle oriented design are evident in all product design activities. Current design practices demonstrate that there is a high level of conscious design effort seeking to improve the quality of products, not just in the 'use' life phase, but also in other life phases (e.g. manufacture, service and disposal). 'Design for X' tools have been devised to provide designers with procedures, data, information, and working principles, which enables them to address life cycle issues in the early stages of the design process. However, in practice, the implementation of a life cycle oriented design approach is fraught with difficulties. From our observations of design practice, we can typically see that:

- identification of the life cycle phases and 'meetings' is often incomplete;
- identification of the stakeholders is also incomplete;
- the commitment to thinking with a life cycle orientation is weak;
- designers have a poor awareness of how products actually behave in real life; and
- optimisation of the design for specific life phases may be at the expense of 'whole life' benefits.

Consequently, the product design process is hindered by:

- incomplete, multi-stakeholder criteria in the specification of goals;
- inappropriate communication of specifications;
- design flaws with ugly trade-offs, blind spots, and unforeseen life cycle dispositions;
- no supporting mindset common to the design team;
- an inability to overview the life cycle needs and simultaneously evaluate solutions in all life phases (this seems particularly pertinent with computer-based design);
- designing as if there was no prior experience to draw upon; and
- weak argumentation for alternative solutions.

If life cycle oriented design is to be successfully implemented in product development, then we require a working approach that can support the product definition, creative, synthesis, evaluation and process control aspects of product design.

3.2 Product structuring (e.g. platforms, modular engineering)

Andreasen's theory of domains shows the relationship between the processes that occur in the product life cycle and the elements of the product, which carry the required functionality and properties [4]. The original domain theory, which identified four domains, has been modified to three domains[5]: transformation, organs, and parts (Figure 3).

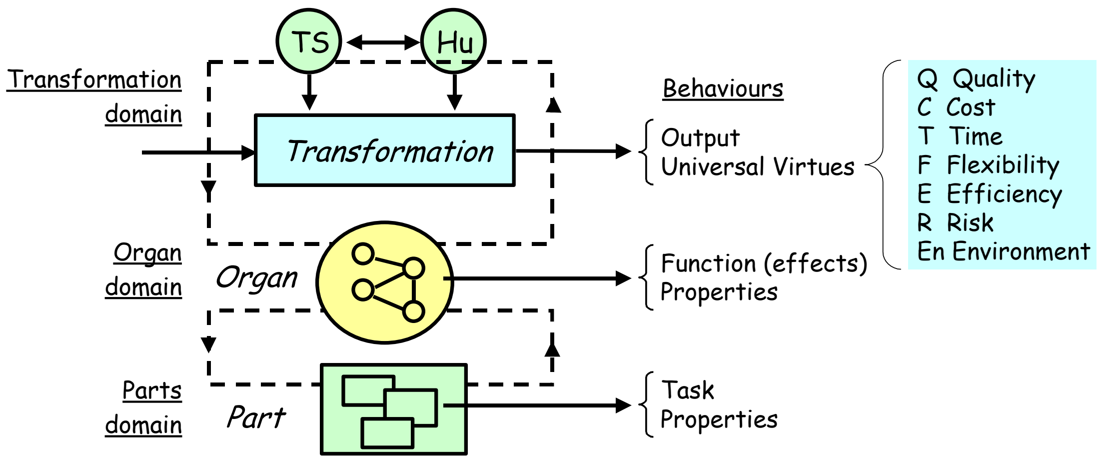

Figure 3 - Modified domain theory (Andreasen [5])

The domain theory provides a means to describe the purpose of the constituent elements of a product, defining organs as function carriers and related properties. Parts are the discrete components that create the physical structure of a product.

This theory base enables the structure of a product to be considered from three, functionally related viewpoints. One of the current challenges in design research is to use this theory to explain how and why products are structured in a specific manner. For example, we observe that manufacturers, particularly of volume products, are utilising product platforms and modularity as the basis for their product families (or at least are working towards this scenario). The arguments for this product structuring approach are:

- platforms enable cost-effective production of product variants, allowing customers to obtain high quality products of near individual specification;
- platforms utilise similarities of function and solution (even reuse), avoiding unnecessary work, reducing risk, maintaining quality assurance and enabling faster and better product development;
- platforms reduce complexity by decomposing the structure into independent units (modules), allowing better perception and understanding of the product structure.

Initially, modularisation and standardisation were means for stable markets and products. Today the challenge is to create platforms that allow flexibility and agility in product definition. Visible platforms are shown to the customer who benefits from a product family with many different variants in the marketplace. Invisible platforms help the organisation to be flexible, save money and to leave a basis upon which to become innovative in the future. However, there are limits to the approach: the same platform can only be added a finite number of times, due to the psychological needs of the customer to see ‘new’ products. The difference between traditional design carryover and platform strategy seems to be the management of knowledge related to the platform’s issue (e.g. functionality and properties). Platforms could be perceived as limiting creativity in product design, yet in fact the level of creativity is freed from areas of danger and low interest to areas where the uniqueness of each variant is manifest. Platforms require separate product development processes in which the platform is defined; all subsequent product variants thus need to be anticipated. Consequently, the platform has to be designed to integrate with design solutions which have not yet been generated in detail (Figure 4).

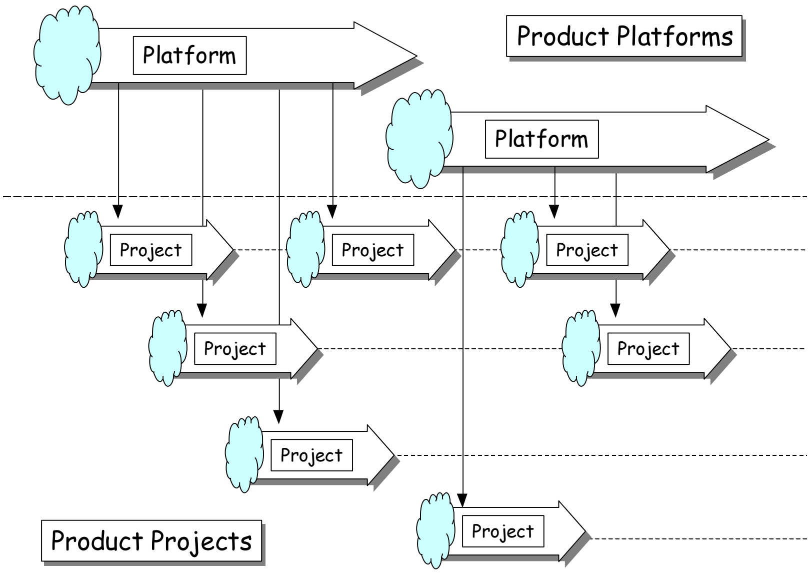

Figure 4 - Product development of platforms and platform variants

The challenge for research is to be able to explain the phenomenon of platform thinking and modularity and to relate the product structure to the technical and business goals of the organisation, customers and other stakeholders.

3.3 Integration of technical disciplines (e.g. mechatronics design)

Modern products are becoming increasingly more sophisticated in the way they function. This leads to vastly increased technology complexity. Increasingly, products are being created, by means of an intricate collaboration between mechanical, electronic and software technologies. Products that contain a blend of these three particular technologies are known as mechatronic products.

An example of a mechatronic product is a printer, connected to a PC. The task of obtaining a printed sheet of paper from a word processing package is a careful co-ordination of: *software* signalling a printer to start and supplying it with data; *electro-mechanical* components driving the printer and feeding the sheet of paper through the printing process; and *electronic* circuitry to feel and signal the proximity of the paper and the progression of the whole printing process. This *electronic circuitry*, in turn, communicates with software to inform the user (via the computer) that the page has been successfully printed.

The organisation of the process of developing products with so many cross-disciplinary interactions is presently not fully understood, and current models only naïvely describe the process. IPD, for example, evolved in one discrete domain (namely mechanical engineering) and therefore does not consider the co-ordination of the design activities across multiple disciplines such as mechanical, electronics and software. There is a need for robust explanations and models of mechatronic product development.

An understanding of how to organise mechatronic product development is crucial, if industry is to utilise fully the potential it has in its product development resources, to gain exciting and well functioning products that combine the technologies in an optimal and elegant manner. It is understood that methodical design is presently in a more mature state in the domain of mechanics than of electronics and software, which indicates that effort is required to be able to fully understand the activities of electronics and software design. However, by its nature, software has a stronger tradition for discipline and structure than electronic and mechanical design. We must therefore be able to sufficiently understand all three (m-e-s) disciplines and their working practices, when considering an integrating model.

There are a number of problems which must be overcome before a systematic approach to mechatronic product development can be adopted. Buur [6] identifies three of these difficulties, thus:

- designers have difficulty in describing or discussing mechatronics design;
- it is difficult to divide and manage activities when designing a part/product that contains mechanical, electronic and software elements; and
- the function of mechatronics concepts is not verified until very late in design.

These difficulties often result in products with *evolved* mechatronic properties, due to an uncoordinated design effort, rather than as *planned* mechatronic properties of the product.

There is a need for industry to be proactive in the development of mechatronic products and to make conscious decisions about where and when to 'cut the cake' – i.e. in deciding which parts of a product are to contain mechanical, electronic and software technology. One solution to the three difficulties mentioned by Buur could be to identify and build bridging models to help us to understand how to make decisions about the early, optimal sharing of tasks when developing mechatronic products. Such bridging models should be independent of the mechanical, electronic and software domains, so that they may act as truly neutral decision-making bridges. Hubka's laws of vertical causality [2] and Andreasen's domain theory [5] may provide in-roads into identifying a bridging model, where the combination of a functions-means tree and the process domain could provide a means for identifying where mechatronic decisions *were* made in existing products. However, we still need to be able to learn from these post-mortem examples and become pro-active in our mechatronic thinking, providing models that help us to shape future products.

3.4 Environmental issues

Environmental issues have been on the agenda for some time now, but tend to come in waves, depending on industry sector and culture. In Europe, many of the clean-up issues are now being dealt with by national, European or international (ISO) standards and regulations, making it increasingly difficult (legally and economically) for companies to drop below agreed acceptable environmental levels. There is still a large gap, however, between the present activities of industry and the targets of sustainability, laid out on a global level in the Bruntland Report [7]. Present eco-design strategies in companies tend to suffer from a lack of overview; eco-design is still managed from a reactive, rather than pro-active stance. There is a need to be able to integrate the basics that we are now beginning to understand about eco-design into product development.

Eco-design is more than simply the establishment of a number of technical adjustments in a product. If industry is to move beyond its present state of treating environmental issues as a series of single 'DFX' issues (design for disassembly, design for recycling, design for reusability etc.), a life-cycle approach to eco-design is necessary, where we consider the technical, semantic and sustainability performances of the product.

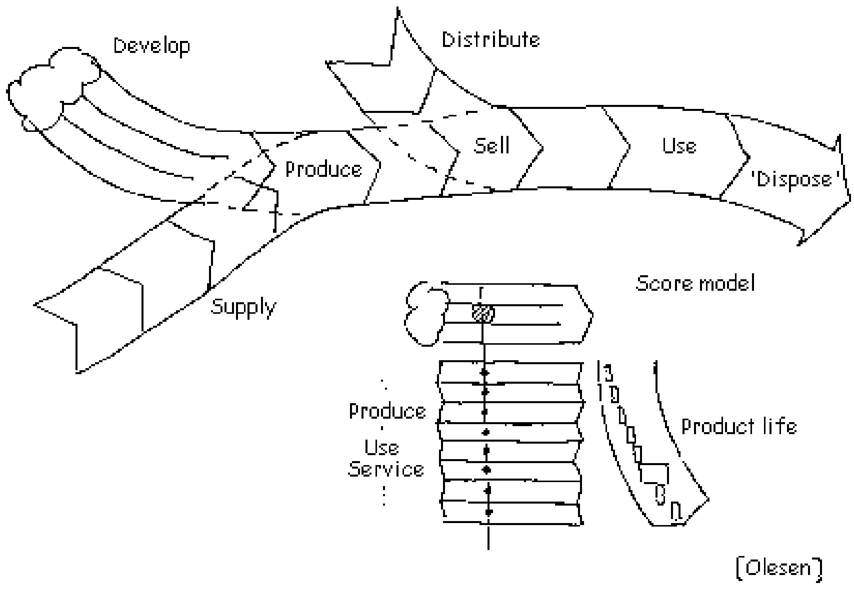

Figure 5 – The product life dimension (Olesen [3])

By taking a life cycle view we enable ourselves to look beyond the boundaries of the traditional product development activity and consider the destiny of the product that we are developing.

We can learn from the discipline of quality about how to get closer to the customer, the product and the product's life-cycle [3]. We can learn from innovation theory about how to how to make strategic, radical leaps when conceptualising and developing our products, and the way in which re-addressing our core business can give different solutions to environmental problems that will occur with the products that we are developing.

A new product development framework should address the issue of eco-design by taking a life-cycle approach (combined with a similar approach to product quality) and by making a reasoned attempt at designing for sustainability, starting by establishing working definitions.

3.5 Quality

Product quality is presently the most significant competitive advantage of market leaders (Simon [8]). Design for Quality (DFQ) focuses upon creating high quality products with appropriate quality properties that satisfy the needs of everyone who has a stake in the product during its life cycle. Hughes summarised the task faced by all product developers as follows:

"We need to create differentiation between ourselves and our competitors in the mind of the customer …we require that our customers perceive and believe our products to be better than our competitors … customers have become much more sophisticated in the factors which they include in the purchase decisions ….we need to find those extra factors which will deliver such a high level of customer satisfaction." (Hughes [9])

The qualities required in a product can be organised into different classes of quality, Figure 6.

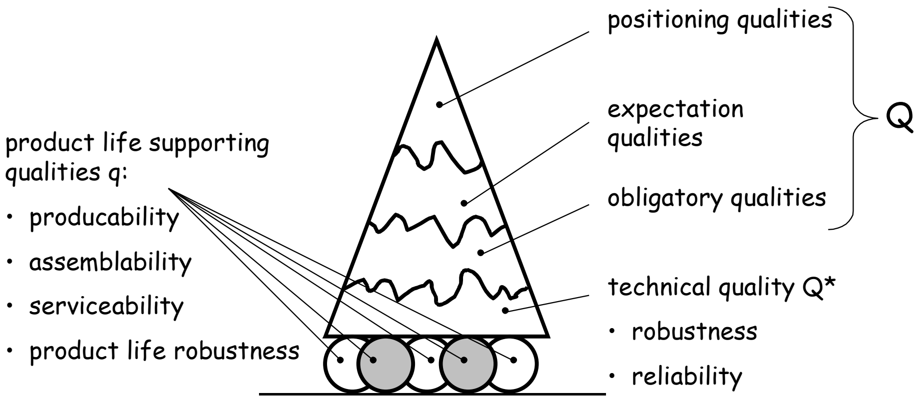

Figure 6 - Classes of quality (Andreasen & Hein [10])

However, the current quality focus is imprecise and incoherent, and requires sound methodology in order to understand and deal with the phenomena. The means necessary for building this methodology include: the establishment of insight and ability to synthesise quality; the understanding the product life aspects; visualisation and communication of qualities; and the creation and utilisation of facts on the resulting product life qualities.

Mørup [11] presents probably the most complete description of DFQ, in which existing and new quality techniques and theories are unified into a framework for DFQ, containing eight main elements, arranged in three aspects:

- *DFQ pre-conditions* – strategy deployment, quality organisation, product technologies, and measuring system for quality;
- *structured product development* – DFQ procedure;
- *supporting methods* – tools and techniques, methodical design, and quality mindset.

Mørup also introduces two new quality concepts (big 'Q' and little 'q'):

- *Q-quality* is the customer's qualitative perception of the product;
- *q-quality* is the internal stakeholder's qualitative perception of the product in relation to their product related tasks.

This framework describes the totality of conditions, approach and techniques necessary for effective DFQ, whilst not being prescriptive in the detail. This allows specific theories, tools and techniques to be inter-changed with alternative/new approaches whilst preserving the overall goal of DFQ. The concepts of Q and q qualities enable the qualitative perceptions of the product to be divided according to stakeholder type. This approach recognises the significance of all stakeholders (internal and external). It also accommodates the changes in level of the customer's expectations, which occur with time, and/or the introduction of new products in the market. However, the exploitation of the DFQ approach, is almost negligible, and most researchers and industrialists alike appear blind to the DFQ framework.

Quality is a perception in the mind of the customer when they interact with the product and evaluate its properties. Other objects, meta-products (Monö [12]), influence the quality perception of the customer. Meta products influence prejudice, status, nostalgia, group affiliation and identity. Consequently, the achievement of quality is a highly individual, qualitative experience which is difficult to predict. Perhaps the reluctance of researchers and industrialists to embrace the DFQ framework stems from the fact that quality and DFQ both have soft, qualitative aspects that defy easy definition or solution. Certainly there is a strong belief amongst managers that quality is cared for by quality-related tools and procedures (e.g. QFD, FMEA, DFMA, CAD, TQM, and ISO9000). Yet there are no procedures that deal with 'perception', 'value', 'feeling', and 'mind-set', nor is there a substantive body of research results to guide us in these 'soft' aspects of design. It is, perhaps, no wonder that DFQ has failed to be implemented successfully in its entirety.

The challenge for design research is to provide deeper insight in to the soft aspects of quality and DFQ. For example, understanding the quality mind-set and how it is developed, understanding the perception of quality and its relationships to the product characteristics, and what mix of skills and knowledge is required to create high quality products. Insight is required about the relationships between quality, the product life cycle, meta-products, and innovation. In the theory of technical systems and domain theory, the treatment of functions is strictly limited to technical functions. Efforts to integrate technical functions with semantic functions in the design theory will help product developers ensure that semantic properties are evident throughout the product, and that clear messages about functionality and quality are conveyed to the customer. Finally, researchers and industrialists need to embrace the DFQ framework and demonstrate how their results and practical experiences add to the development of Design For Quality. Only then will we achieve consolidation of approach, and have a proper, integral understanding of this complex dimension of product development.

3.6 The role of IT in product development processes

Today, product developers in the manufacturing sector rely heavily upon IT and computer facilities throughout the product development process. The evolution of three-dimensional modelling and analysis systems enables complex models of the structure and behaviour of a product to be created. These models provide core information about the form, geometry, dimensions and structure of individual parts, sub-assemblies or complete artefacts, which can be used for synthesis, analysis, optimisation, simulation, visualisation, and manufacturing. The product data model (PDM) provides important core information, which is accessible to all members of the product development team.

Collocation of the product development team (a practice favoured in concurrent engineering), is less important when the routine, procedural tasks of product development are identified and performed using computer technology. The necessity is for access to the PDM. The expansion of the world-wide web and the Internet allows for the possibility of 24-hours per day product development, with teams geographically located around the world sharing a common information database. The devolution of design tasks to suppliers has required them to utilise similar computer systems to their customers to enable exchange of data and information. The implications are that suppliers often need to support several different types of similar software to ensure compatibility with all customers.

Application packages tend to define the working procedure, determining the minimum levels of information required before a task can be computed and force the designer to be more systematic in their methods. Consequently, increased use of computer-based tools will create an almost self-determining product development process as a result of the tools selected. As experience through use grows, so will the confidence to perform product development in a completely virtual environment.

The necessity to be able to integrate design models and exchange product information with customers and/or suppliers means that future product development practices cannot ignore the role of the computer and its influence on the development process. The original IPD framework could not anticipate the expansion of computer capability or availability, so it does not provide a robust role for IT. A new framework, must properly describe the role of IT and computer applications in the product development process.

3.7 Human-machine interaction

The transformation domain [4] shows a human operator working with a technical system to carry out a technical process. The interaction between the human operator and the machine has significant impact upon the effectiveness of the process. As the complexity of products increases and more functionality is offered, the need to create user friendly interfaces becomes even more pertinent.

Mechatronic products provide many degrees of freedom for the designer, particularly in defining which functions are handled by the user and which by the machine system. Strong, semantic properties are a necessity at the human-machine interfaces to enable the operator to understand how to use the machine, when to perform certain tasks, and how to react on the operations performed by the machine. The consideration of a broader cross-section of people who might operate a machine often provides critical insight into how to improve the interface. For example, developing products to be used by the elderly or the young demands products that are easy to hold or less physically demanding to use. In these cases, the human-machine interface is designed to be easier to understand or operate; properties that will benefit *all* operators.

Immersive virtual reality is the state-of-the-art for simulating product interactions. This technology allows designers to fully simulate the operation and use of their designs from the perspective of the operator. Again the focus on the life cycle of the product will enable the completeness of interactions to be considered. Human-machine interfaces will be more sensitive to the human senses with interactions occurring in natural manner (e.g. voice control, haptic feedback). The interface will be more flexible with the information it feeds to the operator, providing only the data relevant to the process being performed. However, it is evident that designers will have to work even closer with human scientists to achieve deeper understanding of the behaviour of the operator when working with machine systems.

3.8 Innovation

It could be argued that product innovation is the next product development paradigm. Companies see innovation as a way in which to make step changes to their products and to their businesses, and as such there is a desire to understand and to master product innovation. Industry needs to understand the definition and practice of innovation more deeply, if it is to master and utilise innovation tactics to maintain competitive edge.

We must also make a space for innovation in product development, and understand how innovation shapes the product development process.

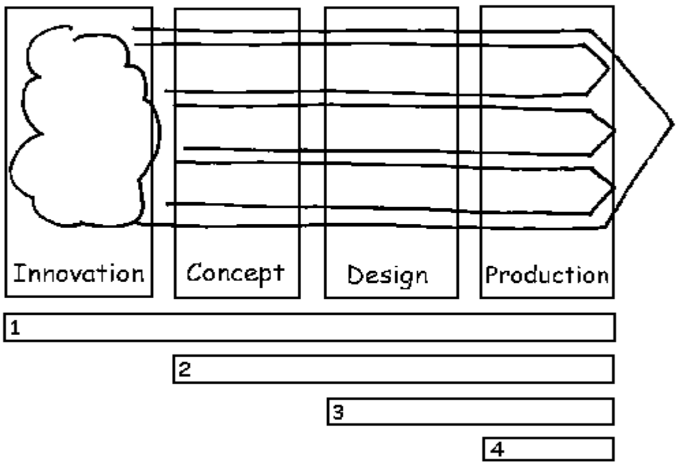

Figure 7 – Levels of innovation within product development

On studying current innovation theory, many definitions presently cloud the view. Current understanding ranges from innovations being possible at varying levels of the product development process (as shown in Figure 7), to innovation being an activity that changes the whole business strategy and definition of core business (for example a shift up the value chain, from merely selling a product to providing a service, and thus taking responsibility of the whole product life cycle). One explanation could be that whole industries are situated on a particular level of innovation (for example the car industry could be argued to be situated on level 3 in Figure 7, whereas the home computer industry, on level 1).

Industry would also like to be able to measure product innovation, and to develop 'a nose for innovation', which entails a deep understanding of how to make business leaps through constantly renewed product development strategies. Product innovation requires that product developers learn the necessary skills for innovation, that their mindset is adjusted to being innovative, and that their working environment that encourages the innovation process. These high demands must be incorporated in a product development framework.

4. Vision of a new working approach to product development

From our observations in this paper we see product life oriented design as the backbone of any new framework for product development. In their quest to create products that satisfy a broad range of stakeholders, product life thinking enables companies to take an insightful approach to quality, environmental issues, innovation, and product structuring. The growing complexity of product development clearly requires a new working approach, that can cope with: product variety; integration of complex technologies; extended product development practices; and the necessity to compete in a global marketplace.

We observe that there is a greater necessity to focus on the early stages of product development, where the strategy is defined and the requirements for the product are set. We note that the downstream product development activities (e.g. embodiment and detailing) have well-defined procedures, enabling a systematic approach to their execution. Consequently, we perceive that the activities of the product development process can be divided, allowing different working practices, which will be undertaken in two different types of environment; these we call the 'war-room' and the 'machine-room'.

The purpose of the war-room is to provide:

- a working environment for the design team;
- an information resource to be shared by all;
- a means of communication;

- a stimulus for creativity and product synthesis;
- a means for supporting life cycle oriented design;
- a means to monitor the progress of design work; and
- a means to support quality assurance efforts in design.

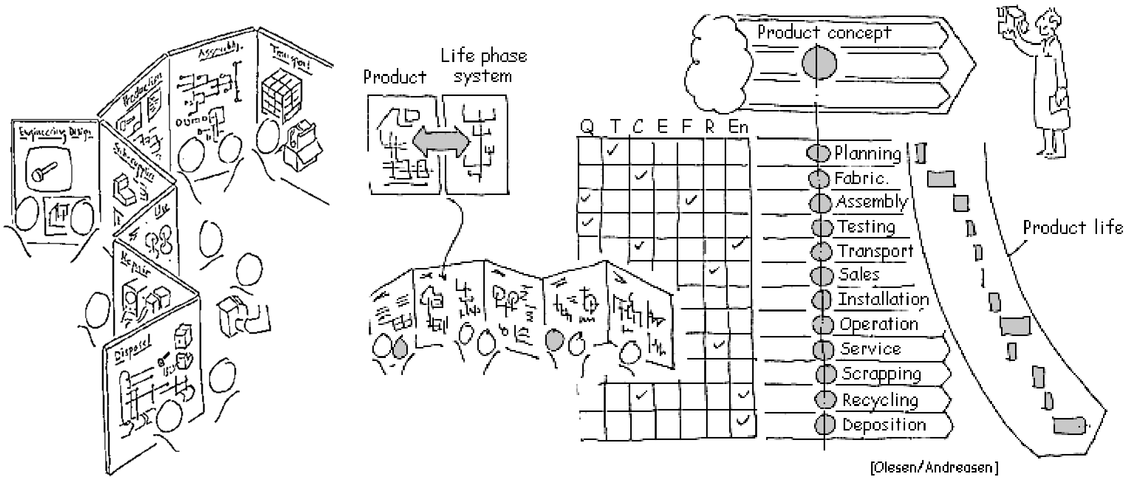

Figure 8 - Multi-boards depict the product life cycle allowing thorough evaluation of proposals

Creating a good working environment for the design team is a crucial role of the war-room. Display boards will provide the focal point of the working area (Figure 8). The multi-board concept is a proposal for supporting life cycle oriented design, which we believe, overcomes many of the weaknesses observed with current design practice. The product development team uses the boards to document the product life cycle, with each meeting of the product and associated stakeholder considered separately. All kinds of graphical and textual information (e.g. illustrations, notes, sketches, diagrams, photographs, printed text, data sheets), are displayed. The boards are not a sophisticated information technology medium; if anything, they are the reverse! They remain accessible throughout the product development project enabling anyone in the product development team to view them, modify them, or add further information to them. The use of the multi-board favours using scenarios to describe life cycle events. The scenarios provide an effective means of describing life cycle events and the meetings, which occur between the product and a stakeholder. The resulting model of the product life cycle will enable the team to fully represent multiple-stakeholder criteria and ensure design effort considers all needs.

One role of the war-room is to develop a life cycle oriented mindset amongst all members of the product development team. Using the boards to document the product life cycle will enable the team to share a common understanding of who all the stakeholders are, what their needs are, and what functions, qualities and properties the product must have. Where several potential concepts emerge, the multi-board display allows for the comparison and evaluation of the alternative concepts against all life cycle needs, and appropriate choices can be made for more detailed design development in the machine-room.

During the product development process, the war-room is used for strategic activities: specifying goals; controlling unification of requirements between stakeholders; seeing the consequences of one life phase requirement upon another (dispositions); identifying the supporting product life systems; and agreeing upon the 'guiding stars' for innovative product concepts, synthesis and review. The war-room is an environment that will foster dialogue and creativity amongst the team. Product design proposals can be properly adjusted to integrate fully with the project goals, synthesis can be co-ordinated on a continual basis throughout the project, decisions can be made with a full awareness of the life cycle consequences, and emerging results documented by modification of the multi-boards (Figure 8).

The routine, procedural and well-defined tasks of product development occur in the machine-room. After cutting the cake, these tasks can be distributed through the extended product enterprise (i.e. into the supply chain). Computer-based activities and processes are at the heart of the machine-room. Many product development processes are already carried out using these means, and the trend is that more will follow. The technology will save time during development, enhance the number of prototype alternatives that can be assessed, whilst cutting development costs. Consequently, product developers will gain more time and resources for the strategic activities of the war-room. The results emerging from the machine-room will be continually fed to the war-room, where their consequences will be evaluated and controlled.

This war-room/machine-room vision provides a flexible approach to product development, maintaining overview throughout the project, whilst adopting the best of current practices.

5. Towards a new product development framework

The purpose of a product development framework should be to create vision, guidance and contributions towards an understanding and methodology, which should lead industry to higher competitive ability and efficiency. We consider the issues highlighted in Section 4 to be essential ingredients of a new framework. Our goal is to create a framework which can carry types, procedures, models and methods for industrial product development, focusing on the understanding, insight, values and motivation of individuals.

To achieve this aim, we require consolidation of theory, research results and industry practice. This paper has highlighted the areas of significant importance to industry, which will form the basis of a new framework for product development. There is clearly a challenge enhancing and in co-ordinating these areas of research significance, in order to unite them in a single framework.

The goal of a new framework will be to enable product development of the future to satisfy the needs of industry and its customers, whilst being sympathetic to the demands of society at large.

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