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Growth of Axiomatic Design through Industrial Practice

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Abstract—This paper discusses the advances of axiomatic design, both as a design approach in industry and as a research field. It is demonstrated that the growth is based on industrial practice and a vision of design theory. The information presented in this paper is based on experience from implementation of axiomatic design in industry in Asia, the USA, and Europe. Specifically, this paper presents strategic implications of implementing a new design method within a company, two generic implementation approaches, risks and benefits of each approach based on actual implementation cases, and some examples of products developed by industry by using axiomatic design. The paper also points out the importance of continued teaching and research in the area of axiomatic design. It outlines a typical course for industry given at MIT and presents issues for future research.

Keywords: design theory, axioms, industrial application, education and training, research

1. Introduction

This paper shows how industrial practice is contributing to the advancement of design theory. Axiomatic design theory provides a valuable framework for guiding designers through the design process to achieve positive results in terms of the final design object. Design theory[1] is the field that is concerned with relating the following fundamental areas: the design process, the design object, designers, specific field knowledge to understand and solve a design problem, and available resources. Axiomatic design theory and its support (in the form of training and tools) have proven very effective in meeting goals for the improvement of product development in companies around the world.

Since the first CIRP Workshop on Design Theory (held in 1992 at MIT), the use of axiomatic design has increased dramatically in industry. To date, companies in Asia, Europe and the US have successfully trained engineers in this method[1] and begun integrating it into their product development efforts. Many significantly improved and innovative products, processes, and even approaches to performing corporate planning have resulted.

This paper will provide an update on the use of axiomatic design in industry. This will include benefits realized in industrial practice, generic approaches to implementing axiomatic design, conclusions from industrial implementation of axiomatic design, strategic value of axiomatic design, and implications for academia in terms of teaching and research. For readers unfamiliar with axiomatic design, please consult references [10] and [11].

[1] In this paper no distinction is made in the use of the terms "theory" and "method". A design theory is a body of knowledge relating two or more of the fundamental areas; a method is a procedure or tool to help with a particular design task. Axiomatic design theory contains a set of methods.

2. Benefits of AD Realized in Industrial Practice

In this section, several examples of industrial applications of axiomatic design will be presented to support the conclusions of this paper and to give the reader an understanding of the benefits of the method and the broad scope of its applicability.

Many products, processes and corporate plans have been developed using axiomatic design. A few of these—the development of a depth-charge initiator, a corporate business plan, a new design process, and an analysis of reliability in wafer-processing equipment—will be briefly discussed below.

Depth-charge initiator [6]

The depth-charge initiator project was a redesign project, where the existing product consisted of more than 350 moving parts. This complexity made the device less than 100% reliable, and this project was initiated with the goal of reducing the part-count; it was assumed that the reliability would thereby improve.

The designer conducting this project began by stating the top-level FRs in a solution-neutral environment. This enabled the designer to consider other conceptual solutions, rather than just modifying the original solution. The designer progressed using both the zigzag decomposition process and the first axiom to generate a new type of initiator sensor, reducing the number of moving parts by a factor of 7. This result was achieved, not by trying to integrate parts of an existing design, but by carefully evaluating what functions the design should satisfy and what options the designer has available to realize these functions.

Corporate business plan [6]

The business plan developed using axiomatic design was created in a two-day exercise involving all the top managers of the company. It had been realized that previous business planning exercises had not led to a shared understanding of the contents of the previous business plan. In order to have continuity between the previous and the new business plans, the business planning exercise began by taking the previous business plan and analyzing it using the framework of domains provided in axiomatic design.

For this purpose, three domains were used, and these were referred to as the goal, strategy, and activity domains. These correspond to the functional, physical and process domains in conventional axiomatic design. The next step was to create hierarchies in the design domains using the goals, strategies, and activities identified from the previous business plan. This analysis led to the identification of goals (FRs) that had no corresponding strategies (DPs), strategies without corresponding goals, and so forth. The group of executives then determined whether or not to "fill in the gaps," (for example, come up with strategies to meet goals that were currently not being pursued) or to drop these goals. When all gaps were filled in and agreement had been reached on the top-level goal, it was possible to ask whether the decomposition of this goal was sufficient, or if new sub-goals needed to be introduced.

The exercise led to an overview business plan presented on one page that was easy to communicate to all employees. Supporting this page was a document detailing each goal, strategy, and activity, identifying specific resource allocations, etc. It has been found that the main document has served as a roadmap for the executives to be able to recreate their thinking through the business planning exercise. Based on the first business planning experience using axiomatic design, this company has now developed the next business plan following the same approach and similarly developed its equal opportunity plan.

Re-engineered design process [6]

In one company a new design process based on axiomatic design is being implemented. This implementation is part of a project to reduce product development time by 50%. Early indications are that this process will post improvements better than that. Several findings regarding how this process has helped reduce time have been made in this project. The company now knows when it is making crucial decisions. Decisions are being made based on more objective rules; previously, managers would normally have an influence over decisions solely which was relative to their position. Information regarding the decisions made using axiomatic design is now being linked to the company's CAD system, so that this information is not lost for future redesigns or changes. Furthermore, focus on functional requirements rather than physical implementation has enabled the company to remove some unnecessary requirements. This made it possible for the company to abandon a complex design and to go with a much simpler technical concept. Finally, engineers within the company have found that they now have a framework that allows them to effectively communicate about their designs.

Problem analysis of processing equipment [13]

A manufacturer of equipment for processing silicon wafers was presented with this problem statement by its customer: improve mean time between failures by a factor of two. This was an ill-defined problem, and dealt with reliability of an already existing product. How did application of axiomatic design theory prove useful in this case?

Its contribution was realized in better understanding the problem and in possible solutions which were brought out through application of axiomatic design theory. Here the process followed was one of problem analysis. The output of this process was information about the design object (the machine) in terms of its FRs, DPs, and design matrices. Experimentation, combined with the axiomatic design framework, was used to understand the performance of the system and its relation to changes in DPs.

Based on this analysis, the company identified a coupled subsystem which contributed to the overall system failures. Then it proposed and evaluated several alternative designs, again using axiomatic design. The benefits for the company in this case were an improved overall understanding of the system performance, the pinpointing of a specific subsystem as a problem area, the ability to rule out the current subsystem design as unacceptable (coupled), and the subsequent proposal of multiple alternative concepts.

"Operationalized axiomatic design"

One company has been using what may be called "operationalized axiomatic design" under the name "robust design" [9]. "Robust design" has been developed based on ideas from axiomatic design (especially the information axiom) and Taguchi's methods, by a small group of engineers in this company. This group has then been given the responsibility to "sell" this approach internally to project teams and departments. Several short seminars introduce the approach. Then, after interest is created, a short course is given to those interested. At the end of this course the engineers are asked in a questionnaire to identify problems for which this approach is suitable. Then workshops are organized in which engineers from the "robust design" group work together with the project engineers to solve the problems which have been identified. Some of the cases which have been solved by this group are presented in [7, 8].

Benefits of AD compared with prior practice

Generalizing from the case descriptions above, it has been found that axiomatic design can provide the following benefits:

1. By defining project requirements in solution-neutral language, specifications filling several binders (as in a manufacturing requirement specification) have been reduced to fit onto one page. Proper division of the problem into domains has focused the design process on the functions of the system by eliminating specific solutions from the specification. This has lead to a more efficient process for generating innovative solution alternatives.
2. Use of the independence axiom in problem analysis has proven very powerful. It has helped many companies to quickly identify coupled designs.
3. In prior practice (before the introduction of axiomatic design theory), FRs kept changing throughout the design process; especially problematic were changes in the high-level FRs. Use of axiomatic design imposed a more disciplined process.
4. Axiomatic design theory has provided a framework for understanding projects. People now have a shared understanding about what it is that they are discussing (requirements, constraints, solutions, etc.).
5. Decision making has improved considerably throughout the design process. Before, flawed decisions were made,

and decisions were made without even the realization that they were being made.

6. Before using the framework provided by axiomatic design theory for describing problems, decisions were made based on authority. Then the person with the highest position had the opinion that was the most correct. Now, axiomatic design has provided an objective framework for evaluating differing alternatives.
7. If a project has little or no flexibility in the choice of solution (such as at the end of the product development cycle), then implementation of axiomatic design theory has been difficult—particularly the use of the axioms—because the identification of a bad design is unacceptable at that point. Conversely, axiomatic design works very well in projects where a clean-slate approach can be taken.

3. Generic Approaches to Implementing AD

The aim of this section is to generalize experience from working with industry to implement axiomatic design. Some examples of results from this work was introduced in the previous section. Two generic implementation approaches have been identified “diffusive” and “top down”. These are described below. In the next section some observations and conclusions regarding these approaches are presented.

3.1 Approach 1: Diffusive

The first approach to implementing axiomatic design theory is here called the diffusive approach. In the diffusive approach, each company is distinguished by having internal “experts”, people with knowledge of the full axiomatic design theory and who are made available as a resource to others in the company.

In introducing axiomatic design theory, the expert (or group of experts) has the freedom to move around the company and to provide assistance to the design engineers who have responsibilities for the projects within the company. Various approaches has been followed to first raise interest in the company. A general trend is that once the number of projects on which axiomatic design has been successfully used grows, interest has spread to others within the company (engineers, managers, etc.). When sufficient interest has been generated, structured training courses have been held as discussed in section 6.

These courses have taught the full theory, and participating engineers have been free to use, with support of the trainers—or to not use—any portions of the theory which they feel would be worthwhile. A key component of the training courses has been the active participation of engineers who have previously learned the theory and have since been using the theory within the company. These engineers have shared their experiences and have even led parts of the training.

Based on this training, certain teams have decided to use methods of axiomatic design on their existing projects. Such projects were not created specifically to use axiomatic design, but have been existing projects within the company. These projects have both built internal competence in the new design methods and have demonstrated their usefulness. Upon completion of the projects, the team members have dispersed and spread their knowledge of axiomatic design to new teams. Thus, interest and competence in axiomatic design has spread within the organization.

3.2 Approach 2: Top-down

The other generic approach to implementing axiomatic design is more imposed. Companies following this approach usually send several engineers to a one-week axiomatic design training course (in some cases a one-semester course) either on-site or off-site and then build up a group of three engineers with the full-time responsibility to support the company’s implementation of axiomatic design.

Leaders within the company have had a strong vision of the goals which they desire to achieve for the product development process. The process and the viewpoint of axiomatic design have been chosen as the means—from among several options—to achieve this vision.

Axiomatic design has been spread through the engineering departments by holding one-day, in-house seminars. These seminars focus on the basic concepts of the axiomatic design process and do not include the rigorous application of the design axioms themselves. The goal has been to achieve a consistent view about the design process—how it is that the company performs design. The seminars use case studies that have been developed in-house so that the participating engineers will buy into the theory and understand better how to apply the method to their problems.

4. Conclusions from Industrial Implementation of AD

This section details the benefits and the risks of different approaches for implementing axiomatic design and identifies some necessary infrastructure to be able to appropriate the value generated in implementing axiomatic design. The observations are complemented by a summary of conclusions about implementation which have been drawn from these experiences.

4.1 Approach 1: Diffuse AD through the Company

This approach is to provide an in-house expert who has the freedom to move around the company to wherever his or her expertise is most useful at any time. This person can then work as a consultant normally and as a trainer when requested. As more and more engineers see the results of this work, they will want to learn the method in order to improve their personal performance. This approach is described more fully in [1].

Benefits

- The method is not perceived as a threat by the engineers; it is there if they want it.
- The method is used only with people who are interested and committed to learning it.
- With each project in which the method is used, the chances for improved results are high.
- When allowed to participate at their own initiative, people enjoy participating in something new.

Risks

- The company must have the ability to recruit or train an in house expert.
- Interest may not grow at the desired time and/or place.
- It may be perceived as a slow way to introduce the method.
- It is hard to predict where the method first will be used and how it will diffuse (see [1]).
- Use of the method will likely be nonuniformly distributed within the company.

Required Infrastructure

- One full-time, in-house expert is needed per 100 engineers.
- If not proficient in group work, all engineers will need to receive training in teamwork and team dynamics.

4.2 Approach 2: Top-down Implementation of AD

This approach is to prescribe to the engineers that the corporate standard for doing design is to use axiomatic design. Training and consulting support are then provided for them to become proficient with the method. The training can be provided by consultants at first and later by in-house engineers as the internal competence is developed.

Potential Benefits

- If it works, this is the fastest way to get all engineers to use axiomatic design.
- Management's commitment to the new method is more visible.
- Acceptance of the method is more uniformly distributed.

Potential Risks

- Are there enough trainers and consultants available within the company?
- Do managers have enough knowledge to manage and to support this process?
- Are all managers committed to implementing the method?
- Much resistance could be created among designers.

Required Infrastructure

- Engineers and managers must share a strong vision of the future look and function of the company's design process once the method is implemented.
- There must be strong, committed leadership managing the implementation of the design process.

4.3 Summary of Experience

Several general conclusions have been drawn from experiences with each of these approaches. These may be classified into two categories: observations about the process of implementing axiomatic design and observations about the benefits of using axiomatic design as compared with prior practice. The conclusions regarding implementation are given here. The ones about benefits of using axiomatic design are given in section 5.

Implementing axiomatic design

1. Engineers have to have a shared view of the company's overall design process and be able to relate their work to that shared view in order to apply the appropriate method to their problems.
2. It is more difficult to teach people how to use the axioms than to teach the concepts of the basic process.
3. Implementing axiomatic design from a top-down approach requires a lot of support. Much energy must be invested to maintain momentum. A critical mass of experience and competence must be reached after which the use of the methods becomes self-generating.
4. Seminars should be used to introduce designers to the theory and should employ examples to which the designers can relate. Then, if they are interested, the engineers can further develop their knowledge by consulting experts or by reading available material.
5. If users understand the basic concepts of axiomatic design (domains, solution-neutral environment, zigzagging, decomposition points), then no documented instructions—in the form of tables, handbooks, or checklists—are necessary.
6. To teach the theory, general examples are required to illustrate the axioms, but specific examples from the company are a must to generate acceptance for the method.
7. There is a risk that the company misses other better design methods (existing now or which may emerge in the future) if the focus is on implementing a certain approach rather than improving performance. See, for further discussion [5,12,13].

5. Strategic Value of Axiomatic Design

This section of the paper discusses the reasons for introducing a new design theory in a company from a corporate strategic perspective. Axiomatic design has been implemented in industry because it is seen as a way to create sustainable competitive advantages through improving the design process [6]. In general, as discussed by Ghemawat [2], a sustainable competitive advantage requires three things: commitment, scarcity, and appropriability. These three characteristics will be discussed with regards to a company's decisions to implement new design theories and specifically a decision to implement axiomatic design.

5.1 Commitment

The decision for a company to implement axiomatic design in its design process is one which involves commitment. This is defined as "the tendency of strategies to persist over time" [2 p. 14].

From a strategic investment perspective, two types of design methods and tools exist: tools and methods that require a minimum of training and are easily available (for example through the purchase of a software package) and tools and methods that require a significant training effort as well as some organizational changes to be implemented. A reversible investment involves a minimum of risk (for example, software licenses can be divested). On the other hand, an investment with commitment is risky because the company must carry out several projects in which it capitalizes on the investment (in this case, opportunity and actual costs incurred while its engineers acquire knowledge of design methods and tools and while they are reorganized).

Making investments that causes strategies to persist over time is insufficient for a company to derive a sustained competitive advantage; the investment must have two additional characteristics, and successful implementation of axiomatic design by industry has been characterized by these two conditions: scarcity and appropriability.

5.2 Scarcity

Scarcity exists when there is an excess demand (relative to supply) for the acquired sticky factors[2]. Discussions with companies that are currently implementing axiomatic design have shown that the perceived scarcity value provided by axiomatic design comes from its unique <u>zigzagging decomposition process</u>, its <u>decision rules</u> (the axioms) used during new designs, and its ability to <u>identify coupled designs</u>. As is shown in section 2 of this paper, these features have enabled the companies that use axiomatic design to recoup their investment in implementing this design method

[2] These factors are specialized, untradeable, and durable [2 pp. 18-19].

and to give them a competitive edge by enabling the development of more competitive products in less time.

5.3 Appropriability

The appropriability condition is a measure of the ability of the organization's owners to pocket the scarcity value. In implementing axiomatic design in industry, the appropriability condition has been satisfied by effective implementation approaches and creation of suitable infrastructures to support the design process. This includes committed management, an appropriate organization, and sufficient support (as shown in section 4).

Threats to the appropriability condition are non-owners seeking to further their own interests who may be able to siphon off some the value created by the design method; this is referred to as the threat of *holdup*. The non-owners, particularly employees, may also squander some of the value; this is the threat of *slack* [2].

5.4 Summary

According to Ghemawat [2], all three conditions—commitment, scarcity, and appropriability—must be satisfied in order for an organization to be able to create a sustainable competitive advantage. The findings presented in this paper show that it is possible for companies to satisfy these conditions while implementing axiomatic design.

To spread the use of design theories, researchers in academia should strive to make their research results a less risky investment for companies. This can be done in two ways: first, by implementing its design methods in software (as has been done for quality function deployment, theory of inventive problem solving, and design for manufacturing and assembly) and second, by educating more students in design theory so that individual companies do not have to invest in training.

6. Implications for Growth of AD within Academia

This section covers implications for academia. Based on the experiences of industrial learning and use of axiomatic design theory, several conclusions can be drawn. These will be described in two categories here. The first deals with how to effectively teach axiomatic design, and the second deals with further knowledge about implementation which needs to be developed by academia, by industry, or by both.

6.1 Teaching Axiomatic Design

Axiomatic design has been taught as a formal subject, using material based on the book by Suh [10], as a full course for MIT students and has been taught at MIT to engineers from industry and to professors during summer sessions over the past five years. In addition, courses have been taught at several industries in the form of two-day seminars or full-week courses. The reader is referred to a recent paper for more details about the specific companies which have participated [11]. Complementing the courses, an application-oriented book is planned, and software is being developed which can guide inexperienced users of axiomatic design in applying the theory to their problems. [3]

In this section, the general content of the courses will be described, and lessons learned from industry participation will be summarized. Lessons have been culled from the authors' experiences, questionnaires from the summer sessions, and direct feedback from industry [11].

Course outline

The course has consisted of both lectures and hands-on work. The latter has consisted of interactive discussion, in small groups, of practice problems and of project work. The practice problems have come from Suh's book [8] and from more recent cases from industry (including those discussed in section 5). The project work has consisted of application of the theory to a problem relevant to the engineer's work at his or her company. The sequence of main lecture topics has been as follows:

Introduction to axiomatic design
Overview: the design process
Overview: concepts of axiomatic design
Problem formulation
Synthesis
Analysis: axiom 1
Analysis: axiom 2
Documentation
Large-system design
Implementation: case studies

Summary of lessons concerning teaching

It has been observed that application of axiomatic design theory to particular problems is a non-trivial task for designers inexperienced in the use of the theory. To alleviate this, a consequence for teaching is that more in-depth cases need to be used for illustration during training. These would follow the development of new product(s) from project initiation to completion and would show how axiomatic design theory is used throughout. Thus, they would include both multiple layers of the design hierarchies and the definition of FRs (that is, shift the designer's focus on the problem to a function orientation).

By tying the examples to the process of design, users of axiomatic design theory can better see how to apply it to their work. This is in contrast to focusing on examples from the point of view of the ultimate product (or process). In this case the use of the theory may be evident, but often is not, particularly if the problem is not from the same field of engineering (mechanical, electrical, etc.) in which the engineers work. (The development of software to help designers to follow an effective process will be discussed later in this paper.)

Several companies have developed their own training courses based on a process-focused approach, and the use of company-specific examples to illustrate axiomatic design concepts is highly recommended.

Courses in industry have ranged in length from four hours to thirty hours. The timing of the courses has also varied from being taught during sequential days to short sessions stretched over several weeks. Depending on the objectives for the sessions, each of these formats has proven useful. To create awareness of the design theory (among managers and engineers), a short talk is all that is needed. To change people's mindset—their way of looking at problems—more time needs to be spent actively working with the methods. Thus, a longer course which includes the specifics of their use is effective. Furthermore, to produce quantifiable results on a specific project, facilitators need to work with a group of engineers who have been introduced to the methods—preferably in multiple sessions, spread out over time. This type of internal support is required for axiomatic design theory to penetrate into the everyday practice of the company's engineers.

6.2 Further research

This section draws upon the work presented in the previous sections to present a picture of current, and a vision of future, interaction between industry and academia with regard to the development, implementation, and distribution of design theory. This section addresses the implications of recent industrial experience for the further development of axiomatic design theory and its associated tools.

While axiomatic design has proven to be very successful in some specific projects, its widespread use by practitioners in industry has been hindered by the current state of the theory, the state of teaching materials, and by the state of tools developed to aid designers in the implementation of axiomatic design.

The previous sections have addressed questions of how companies can apply design theories internally. Knowledge generated from such efforts is critical to the individual company, but much of the knowledge generated by such efforts is of more general interest than that. Such knowledge has important implications for academia and for development of the knowledgebase of design theory.

Academia transfers knowledge of design theories to industry, but knowledge transfer should not be a one-way communication. Here will be outlined three areas of further work. These range from mostly academic issues to industry projects with cooperative work in between. Knowledge will be of use for further development of design theories (a mostly academic practice), for development of a knowledgebase for implementation (both an academic and an industrial concern), and for the development of general standards and tools for industrial practice (an industrial, less academic interest). The three areas discussed are the following:

1. theoretical development,
2. implementation, and
3. dissemination and use.

Theoretical development

Development of axiomatic design theory is here defined as a general advancement of knowledge about design, and its application, which is in accordance with the principles of axiomatic design; it is not to be equated with the addition of new axioms. (Although, new axioms, if created, would be considered a theoretical development.)

The objective of axiomatic design is to enable users of the theory to approach design problems—a broad range of problems, as shown in section 5 and elsewhere—with a systematic view and to arrive at better decisions, quicker, at less cost.

The ease with which individuals learn and use axiomatic design theory varies from person to person; therefore, the application of axiomatic design to specific problems becomes itself very experience-based and somewhat ad hoc. To alleviate this problem, theoretical foundations are needed to deal with the process of design and to deal with the information requirements of designers.

Given these theoretical foundations, the development of tools (including software, algorithms, knowledgebases) to assist designers in a more "intelligent" manner should be possible. That is, the theoretical foundation should provide the designer with both knowledge about the tasks to be done and his or her place in the design process and with knowledge about the importance, relevance, sources, and availability of information. Moreover, guidance to the designer and tools can then be matched to the current position of the designer within the design process. Also the design process, can be documented including alternatives, decisions, and products which are saved as they are created for future use. [3,4,6,13]

Implementation

In addition to these above theoretical issues, other areas exist which require more industry involvement in the development of knowledge. By looking at these areas and abstracting knowledge about them and organizing this in a systematic way, much experience and good practice can be transferred to other, possibly less experienced, designers.

Section 4 dealing with implementation issues is a case in point. This information was derived based on the experience of several industries in implementing axiomatic design—and complementary design theories—in their design processes. To further the development of this type of knowledge, more cooperation and communication between academia and industry is envisioned. An example of such communication is that provided within SINAD–the "Swedish Industry Network on Axiomatic Design". Each company within this network shares its experience and ideas about implementation of design theory with the others.

In addition to industrial communication, academia can contribute to developing knowledge by establishing cooperative research programs with industry to examine issues of change and implementation within organizations. These research programs would feed back learning and problems (for example, sample design problems on which to test theories) to the theory group, but an implementation group would primarily be concerned with the creation of technology transfer mechanisms, the transfer of the "technology" of design theory to industry. Industry benefits by acquiring information about implementation, and academia benefits by building a bigger knowledgebase of industrial cases from which to abstract further theoretical knowledge.

Dissemination and use

The last area of knowledge about design that will be discussed here concerns the dissemination and use of design theory by industry. This area is seen as more a consumer of knowledge from research in design theory than a producer of such knowledge. It would be built upon the theoretical foundations provided by the other two areas, but would be seen as a way to spread design theory by more directly providing value to industry.

Widespread use of design tools would be facilitated by the collection, abstraction, and distribution of experience between many companies. The development of standards for software, common databases, and CAD tools would help to minimize the risk to an individual company. Better solutions can be chosen because more concepts are considered, and developments (theory and tools) can be spread in a timely manner. Companies would have the assurance of an up-to-date resource to draw upon to provide suggestions and answers based on collected experience.

The development and distribution of software tools for industry would be an example of appropriate work. Other things would be training and the solution of specific company problems. Here the emphasis is on dissemination of fundamental knowledge, rather than its production. In so doing, value is created and as such should be capitalized upon. An industry group or industry-supported firm are two ways in which this value could be collected.

7. Conclusions

In this paper a number of industrial case studies of axiomatic design are presented. These are used to illustrate that axiomatic design can provide companies with several benefits: a more focused and disciplined design process, an ability to quickly identify problems in existing designs, a common framework for communication within design teams, and an improved decision making process.

Two generic models for the implementation of axiomatic design are introduced. Benefits, risks, and required infrastructure for each are presented. Then the strategic value of axiomatic design is discussed. It is shown that axiomatic design can provide a company with a sustainable competitive advantage. However, there is a risk investing in a method that commits the company to stay with the method for a long time before the investment can be recouped.

In order to reduce the risk, it is necessary for academia to educate more engineers in design methods and to implement the design methods in tools that are traded on the market. Such an effort is currently underway at MIT where a large effort to educate and to support education of students and professional engineers in axiomatic design is currently underway. Examples of course contents and teaching experience from MIT are presented. Furthermore, implementation of axiomatic design in computer software is underway at MIT. Two screens of this software are presented in figure 2 and figure 3; a more in-depth presentation of the software can be found in [3].

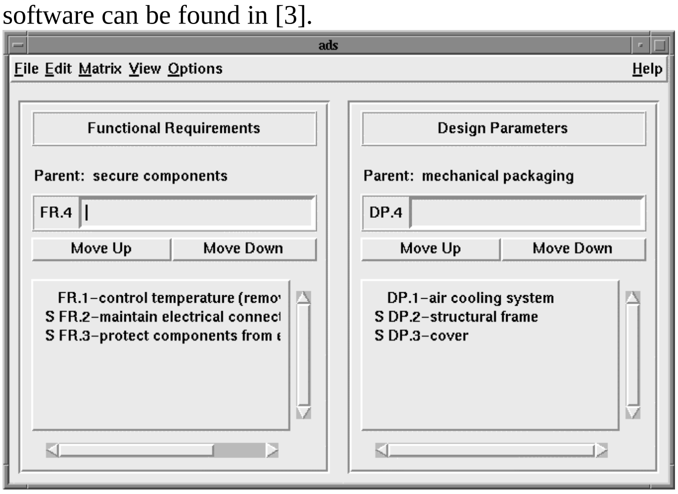

Figure 2. Functional and physical domains (screen from MIT's axiomatic design software)

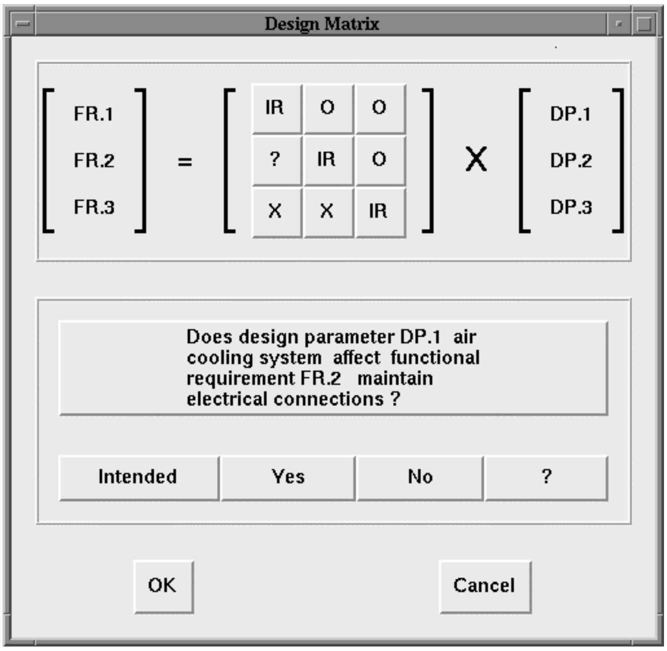

Figure 3. FR-DP design matrix (screen from MIT's axiomatic design software)

Finally, some issues for further research in theory development, implementation, and dissemination are reviewed.

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