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DECOMPOSITION AND PRIORITIZATION IN ENGINEERING DESIGN

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ABSTRACT

The objective of this work is to facilitate the use of axiomatic design in two ways. One is by improving the understanding of the process of decomposing with thematic characterization and design taxonomies. The other is through appropriate prioritization within decompositions. These are important because difficulties in developing a good decomposition, and appropriately prioritizing the elements, are common impediments to using axiomatic design effectively. Good hierarchical decompositions are essential for describing and developing the design. Appropriate prioritization can be important for applying the first axiom. In addition, thematic categorization and design taxonomies can expedite the development of new decompositions and facilitate the reuse of previous decompositions.

Keywords: thematic characterization, taxonomy, design decomposition.

1 INTRODUCTION

The general objective of this paper is to discuss ways to facilitate the use of axiomatic design and make it a more effective tool for a broader range of practitioners and design problems. The specific objectives are to address two common difficulties in using axiomatic design. One difficulty is addressed by methods that can be used to develop good hierarchical decompositions, which are effective for the application of the axioms. Another difficulty is addressed by a system for prioritization of functional requirements (FRs) that can be used in the upper levels of the top down decomposition process. This system will avoid erroneous assessment of upper level coupling in the design matrix thereby facilitating compliance with axiom one.

Philosophically and literally it is the application of the axioms during the process of finding a design solution that distinguishes axiomatic design from other design methods. The axioms can be most effectively applied when the design is structured in such a way that best accommodates that application. This structure can be developed through the process of creating a hierarchical decomposition. Practically, there is much value in a good hierarchical decomposition of a design, e.g., for organizing and communicating design concepts.

The ability to develop a good hierarchical decomposition is essential for the effective application of axiomatic design. Developing a good decomposition is often the first impediment designers perceive in attempting to use axiomatic design. This paper is intended to aid designers in developing methods for recognizing and developing good decompositions.

Appropriate prioritization of FRs at the highest levels can be important in developing good design solutions. The lack of appropriate prioritization can lead to the erroneous assignment of interactions at abstract levels, high in the design solution hierarchy. This causes problems in developing the lower levels of the decomposition. This problematic, erroneous assignment of coupling occurs in practice during attempts to apply axiomatic design.

Interactions that cause violations of axiom one often depend on the details of the design that are only evident when the lowest levels have been developed during the top-down decomposition process. At the highest, and more abstract, levels in the decomposition, interactions are often assigned based on some perception of possible or imagined couplings. This can lead to an assumption of coupling that appears to be irresolvable at the highest levels and inhibits further application of axiom one during the development of the design details.

1.1 STATE OF THE ART

Suh [1990] proposes that design solutions can be developed through hierarchical decompositions, which are developed through a process of zigzagging between the required functions of the design (FRs) and the physical aspects of the design solutions (design parameters, DPs). The design solution is developed top down through levels of abstraction from general aspects of the solution to more specific aspects until further decomposition is unnecessary because the rest of the solution is obvious. It can be said that Suh [1990] proposes two kinds of decompositions: lateral and vertical [Brown 2005]. Lateral decomposition is by domains, generally functional, physical and process, although more are possible. The lateral decomposition is not hierarchical. Vertical decompositions are hierarchical and decompose from abstract to detailed.

Hierarchical decompositions are used to solve all kinds of problems where the solutions are not immediately obvious because the problems are too large or complex to be solved as they are in their entirety. An example of a commonly used decomposition is in engineering mechanics where force balance is used and a force is decomposed into orthogonal components based on a Cartesian system [Hibler, 1998]. Another example of decomposition is to decompose the geometry of surface textures by scale, or wavelength, into form, waviness and roughness [ASME B46.1, 2011].

Set theory addresses decomposition in the context of partitioning a set. Grouping, concept mapping and hierarchical knowledge representation are included. The equivalence relation is based on a partitioning, which results in several disjoint subsets, or equivalence classes [Brualdi, 1999]. This partitioning in set theory and combinatorics results in a collectively exhaustive and mutually exclusive decomposition.

Mutually exclusive collectively exhaustive (MECE) is a decomposition rule used in decomposing problems in management consulting [Rasiel, 1999], which is consistent with the equivalence relation in set theory.

The creation of taxonomy systems, the science of classification according to a systematic arrangement of concepts or objects, has applications in design and understanding intricate digital systems [Bailey *et al.*, 2005]. The taxonomies discussed by Bailey et al. [2005] attempt to create a common language across different communities involved in the design of digital systems. The themes in the taxonomy also contain a definition of scale. In this taxonomy of digital systems there are several features potentially useful in all designs. These features include classification of the models used in design, implementation and verification, as well as system, architecture, hardware and software. The digital system taxonomies include hierarchies, arranged by type and sub type. The taxonomies become more specific, descending from generalities at the top to more details at the lower levels. The best know taxonomies are those of living things done by Linnaeus and Buffon in the 18th century. They sought classification systems that would advance the understanding of the systems they were studying [Farber, 2000], similar to what Bailey et al. [2005] sought for digital systems.

1.2 APPROACH

In this work the development of the decomposition method is based on examination of the decomposition processes and a discussion of case studies. A logical basis for the decomposition methods is attempted.

The examination of the processes for creating a hierarchical decomposition is directed primarily at developing the FRs. Because the design decomposition in the axiomatic design process is functionally driven, the FRs are developed first, then physical elements, DPs, are selected to satisfy the functions, FRs. However, the discussion on the hierarchical decomposition could apply to any domain, e.g., functional or physical.

2 HIERARCHICAL DECOMPOSITION

Hierarchical decomposition in developing a design solution involves partitioning parent FRs into two or more children, grandchildren and so on. The off-spring are essentially disjoint subsets, which decompose the parent. The decomposition process can be viewed as defining sub set boundaries for creating the modularity of the children.

2.1 COMBINATORICS IN DECOMPOSITIONS

In a good, hierarchical decomposition, the children must be *collectively exhaustive* with respect to the parent, and the children must be *mutually exclusive* with respect to each other (i.e., CEME). If the decomposition is not *collectively exhaustive*, some part of the solution will be missing. Therefore, only a collectively exhaustive decomposition can be a complete solution to the design problem defined by the parent FR. If the children are not *mutually exclusive* with respect to each other, then the children that lack mutual exclusivity will be coupled, thereby inhibiting compliance with the independence required to satisfy axiom one.

The accurate partitioning of a parent set into child subsets requires that the sum of the child subsets is equivalent to the parent (equation 1).

$$\sum \text{children} = \text{parent} \qquad (1)$$

Satisfying equation (1) guarantees that the decomposition is CEME. If the sum of the children is less than the parent, then the decomposition is not collectively exhaustive. If the sum of the children is greater than the parent then the children are either: A) not mutually exclusive or B) something outside of the parent is included. In the case of A, the same elements of the parent are appearing in more than one child and the design will be unnecessarily coupled, violating axiom one. The remedy is to redefine the children. In the case of B, extra elements have been added, so that the decomposition is no longer accurate. The unwanted result is that coupling could be introduced and the design could be redundant. The remedies can be to exclude the extra elements from the child subset under consideration, or to redefine levels and branches of the decomposition to include them appropriately.

Suh [1990] emphasizes that the elements in the decompositions should be minimum in number. This follows logically from equation (1). Anything more than the minimum number of children would be indicative of a redundant design, which would be suboptimal.

This concept of decomposition is elementary in combinatorics where the union of the child subsets is equal to the parent set and the intersection of the child subsets is zero [Brualdi, 1999]. Decomposition is nonetheless often an issue in the practice of design. The parent, S, is partitioned into some number of children, S_i. Subsequently each of the children could be further decomposed into the next generation of children $S_{i.j}$. This decomposition could continue until the most fundamental elements are reached. In design, the elemental level has been reached when the solution is obvious and has been called the nuts and bolts level of solution.

The elements that are found at the lowest level of the design, in any domain, are also present in the highest level. These elements are the children of the last partition in the decomposition. During the process of decomposing, it probably is not evident to the designer what all the fundamental elements are. The process of developing the decomposition hierarchy is one of grouping the fundamental elements into progressively smaller child subsets at each level.

In a hierarchical decomposition in design, each parent must have at least two children. If not, then nothing has been decomposed. There is no decomposition and there is no new grouping of the fundamental elements into subsets. If an attempt at decomposition appears to result in a single child, then the result should be examined. If the child is less than the parent, then some of the basic elements are missing and one or more children should be added to include them. If the single child equals parent, i.e., the child appears to contain all the basic elements that are in the parent, then the description of the child must be a restatement of the parent description. In this case the description of the parent might be modified to include those elements revealed in the attempted decomposition.

The practical product of the decomposition is the fundamental elementals of the physical domain, i.e., the DPs at the lowest level of the decomposition. The elemental DPs then need to be physically integrated into the final design. In composing the fully integrated design solution, having the optimal set of elemental physical components is essential. The specific course of the decomposition is not. The physical integration can follow other association schemes than those provided by the decomposition. Nonetheless, a good selection of the categorization schemes used during the decomposition process can facilitate verification of CEME and consensus building among the design stake holders.

2.2 Categorization in Decompositions

Different decompositions can lead to equivalent design solutions. Even though different decompositions could partition the fundamental elements of the design differently, at the lowest level of the decomposition the same fundamental elements should be present. The hypothesis that Suh [1990] presents is that there is one best design solution. The process of the decomposition and applying the axioms is the process of revealing that one best design solution.

When the practitioner develops a parent FR to be decomposed, the composition of the FR might be unknown. The working hypothesis is that is that there is a decomposition that will lead to a detailed design solution and that the designers are capable of developing that detailed solution. The process of decomposition attempts to provide the details of the design in the functional and physical spaces and thereby tests the hypothesis.

The description of the children indicates how the partitioning has been done. The descriptions are also important for building consensus among the design's stakeholders. Descriptions can also be useful in storage and retrieval for future use for knowledge management of design solutions [Brown, 2007]. The descriptions of the children need to be convincingly CEME partitioning of the parent. In this sense, it could be said that the decomposition is largely about semantics.

Semantics are important in design. Until a prototype is made, designs are primarily thoughts. The thoughts are expressed through drawings and words. The engineer's job is to produce designs, i.e., create value by thinking. Baum [2004, p.3] proposes that "thought is all about semantics", and that semantics is about discovering a fundamental descriptions or the universe. This is similar to developing details in a design.

The parent is partitioned in a certain way, along a certain thematic or taxonomic characterizations, by the decomposition. There may be several ways of partitioning the parent, several themes or taxonomies that could be used. Different themes or taxonomic categories group the fundamental elements of the design solutions differently. Each branch in a design composition is a kind of thematic or taxonomic characterization. Categorization is basic to the organization of knowledge as processed during thinking and can be localized in the brain, distinguishing between thematic and taxonomic categorization [Sass *et al.*, 2009]. A consistent categorization at each level assists in a decomposition that is convincingly CEME and in building consensus during design. Recognizing the distinction between thematic and taxonomic categorization in the design decomposition process can be important for building consensus and facilitating design reviews. In practice it appears that the categorization should be consistent at each level in a branch, but can change at different levels, as discussed in the examples below.

2.3 Examples

The term that was used above, "convincingly CEME," dodges the question about how to prove that the results of a particular decomposition are collectively exhaustive and mutually exclusive. It is imaginable that elements resulting from the decomposition process could be tested somehow for being mutually exclusive. Consider collectively exhaustive. It is not clear that the designer has thought of all the elements that should be included in the decomposition. The nature of top down decompositions in design is such that the full collection of fundamental elements will only become apparent at the end of the decomposition process. The proof that the fundamental elements resulting from decomposition are collectively exhaustive will be left for future work. It seems that the selection of some themes rather than others could facilitate assuring that the results of the decomposition are collectively exhaustive. The best themes should be specific to the application. Examples are considered below.

2.3.1 Interfaces for Transmitting Loads

Marques *et al.* [2009] discuss a contact and channel model that could be useful in decompositions of mechanical elements. Transmitting loads between two mechanical structures is a common function in mechanical systems. Mechanical contacts are common DPs for transmitting loads.

Some of the more interesting load transmission systems are those that transmit control loads from a person to a device and which have the additional functions of filtering potentially injurious loads. Examples of these systems are vehicle steering systems, hand power tools, seats in vehicles, and ski bindings. Consider the transmission branch of the decomposition. In the design of interfaces the FR to transmit loads might initially be decomposed into: transmit forces in three orthogonal directions, and transmit moments in three orthogonal directions

Table 1. Initial decomposition for load transmission.

FR0 transmit loads.	DP0 interfaces for transmission

FR1 transmit forces in the x direction.
FR2 transmit forces in the y direction.
FR3 transmit forces in the z direction.
FR4 transmit moments about x.
FR5 transmit moments about y.
FR6 transmit moments about z.

Of course an appropriate selection of the orientation of the axes will facilitate the solution.

The first thing to do after an initial decomposition attempt is to test to see if it satisfies CEME min. This system of decomposing a parent FR acting in space using Cartesian axes is convincingly collectively exhaustive. It could also initially appear to be mutually exclusive, since the axes are oriented orthogonally. This is a necessary but not sufficient condition for mutual exclusivity. The transmission of moments decomposes into:

FRn.1 transmit a force couple.
FRn.2 separate the force application locations.

Note that a force couple is two forces in opposite directions acting perpendicular to the moment axis separated by a moment arm. The decomposition is suggested by the expression for a moment, or torque, the vector product, rxF, where r is the moment arm, F is one of the forces in the couple and x is the vector cross product.

The children of the moment transmission FRs now can be seen to be containing fundamental elements that are also part of the force transmission FRs. DPs that satisfy the moment FRs will also satisfy the force FRs. Therefore DPs 1, 2 and 3 would be redundant. The decomposition in Table 1 is not mutually exclusive, nor is it the minimum number of FRs for decomposing the parent. Applying a criterion for minimum number would, in this case, appear to be redundant with applying that for mutual exclusivity. While that may be true in this case, it is not always true.

A second attempt at the decomposition would eliminate the force transmission FRs, 1, 2 &3 from Table 1. However, the tolerances on the force transmission children of the moment FRs should be checked to be sure that the DPs selected to satisfy them are sufficient to transmit the linear forces as well as the force couples for the moments.

At this point, the solution could appear to be obvious. And, as Suh points out [1990], the decomposition should continue until obviousness is achieved. However, if the DPs need to be modified to accommodate forces beyond those in the couple, then it would be appropriate to leave the corresponding FR for transmitting forces, as this clearly records the design intent and could be involved with some other aspect of the design contributing to coupling (axiom one) and information content (axiom two).

In the 1960s, Salomon, a major ski binding producer located in the heart of the French Alps, introduced a new step-in heel piece. The heel piece restrains the heel of the ski boot and transmits loads from the boot to the ski. In previous designs, the heel of the boot had been supported on either the ski itself, or a binding component that was about as wide as the heel of the boot. In the new binding, the boot sole at the heel was separated from the ski by a relatively narrow plastic component that was covering metal rails and screws that were used to attach the binding to the ski. The width of the plastic component was the DP that should have satisfied FRn.2 above, i.e., the moment arm, r. In defining the geometry of this plastic component the designers had apparently not considered its role in transmitting, roll, or edging, moments. Edging moments are the most important control load that needs to be transmitted in skiing. A teenager from central upstate New York pointed out the opportunity to improve the transmission of roll moments by increasing the width of the plastic component, and the company subsequently added a feature to do this [Howell, 2005].

2.3.2 Themes in the Design of Safety Systems

It is particularly important in design safety systems to assure that the design is collectively exhaustive. Shortly after the Columbia Space Shuttle disaster, Prof. Suh assembled a group to design crew survivability systems for an orbital space plane. This author was a member of that group. There was a meaningful discussion about the upper level decomposition. FR0 was to protect the crew. One proposal was to use a temporal theme which would lead to the following kinds of FRs:

FR1 Protect the crew prior to lift-off
FR2 Protect the crew during launch
FR3 Protect the crew during orbit
And so on…

Another proposal was to use a hazard based theme, which attempted to identify all the hazards, i.e, those things which could harm the crew. This resulted in the following kinds of FRs:

FR1 Protect the crew from thermal hazards
FR2 Protect the crew from acceleration hazards
FR3 Protect the crew from pressure hazards
And so on…

The solution that was ultimately used was to apply the temporal theme first, then to decompose the temporal FRs with the hazard FRs. The rationale for this approach was that not all the hazards are present all the time, therefore this decomposition resulted in fewer FRs. While either of the prioritization of the themes could have resulted in a CEME list, considering both levels, and putting the temporal decomposition first, resulted in a smaller number of FRs in the top two levels.

This example also speaks to the value of investing effort in the careful consideration of the high levels in the decomposition. This value is often not recognized in industry in the eagerness to produce drawings.

The temporal decomposition is obviously collectively exhaustive in time, because it covers the entire time span of concern. The hazard decomposition is less obvious. If it could be shown that all the hazards are associated with energy that has the potential to do injurious work on the people, and if all the sources of the energy could be identified, then the hazard theme could be convincingly collectively exhaustive.

2.3.3 THEMES IN DESIGN DECOMPOSITION IN PRODUCTION

Production implies transforming something to increase its value. Transformations imply doing work on something, and work requires energy. It is suggested that energy might be a good theme for decomposing manufacturing on the process level. Expanding this proposition is left to future work.

Consider producing versus providing. In production systems, the products are generally specified and FR0 is to produce the product. Product FRs are stated so that it is clear that they provide a user with something. Product FRs might begin with the active word "provide". The corresponding DP would be a product that would provide that something.

For example, if the task at hand is to design a bicycle then FR0 could be something like "provide personally powered transportation". DP0 could be a "personally powered transportation vehicle," e.g., a bicycle. In this case, the designer begins immediately to design a bicycle. FR0 might be decomposed into something like, provide an interface with the road, provide steering, provide for power conversion, and so on. If FR0 is "design a bicycle," then the active word is design and an appropriate DP0 could be "a system for designing a bicycle". The designer then does not immediately design the bicycle, but first figures out how to design a bicycle, which is a process design problem. The design process can have value and can have a customer and could be considered a product. However this product is not going to get anyone down the road. This product, a system to design a bicycle, could be thought of as an abstraction, and could be realized into the eventual design of a bicycle. The design of a bicycle also does not get anyone down the road. It is also an abstraction. The bicycle must be produced.

In the design of a production process, where distinct components that must be produced can be identified, an obvious decomposition is component by component and feature by feature on the component. Component by component as a theme for decomposition has been suggested as an approach to producing written works. Lamont [1994] describes the problem of writing as taking one topic at a time and rendering that on the page.

In assembling a bicycle frame from components, one decomposition theme could be joint by joint. The joint in this sense could also be considered as a component of the product. Producing the joint could be considered a component of the process. The process of producing a joint could be decomposed to include positioning the frame members and forming the joint. The joint is a way of preserving the position while resisting loads. The top level decomposition theme would be joint by joint, and then the theme for the decomposition of each joint would be position and joint.

The design of the tooling that is required for production can be considered as a separate design process, just at the process design is distinct from the product design and the tool design is distinct from the process design. The product drives, or suggests the FRs for, the process design. The process design in turn drives the tool design. Product, process and tool, are themes for a horizontal decomposition into domains.

There are valuable concepts that are not themes that are useful for design decompositions. Brown [2011] discusses two concepts in manufacturing, maximize value added and minimize cost. He proposes that these concepts can be exploited advantageously at every level in a design decomposition of a manufacturing process. These concepts are not intended to be themes to be used directly in the decomposition, although they could be. Concepts can be axioms or rules that are used to check decompositions. In lean thinking, manufacturing systems have been divided into value added and non-value adding activities [Womack and Jones, 1996]. This is a useful concept for analyzing manufacturing [Brown, 2011] but does not appear to be the basis for productive design decomposition.

2.3.5 OTHER THEMES IN DESIGN DECOMPOSITIONS

In selecting a theme for design decomposition, the issues of facilitating convincing arguments for being collectively exhaustive and mutually exclusive should be anticipated. Thus far, essentially three kinds of themes have been discussed: spatial, temporal and energetic. Force transmission could be considered to be a type of spatial decomposition.

Selecting a good theme for the decomposition of a design is not always obvious and could be part of the creative process. Some systematic approach to theme selection could help to assure that the CEME conditions are met. Capturing and reusing good themes for similar kinds of applications could be a useful part of a knowledge management process.

Just as in this case, in discussing themes, where the objective is to be collectively exhaustive, a category of "other" guarantees that a decomposition process has been collectively exhaustive at that level. This problem of being exhaustive is, however, merely displaced to the next lower level of abstraction as the elements of other are sought.

3 PRIORITIZATION IN ASSIGNING INTERACTIONS

When evaluating the design matrix [A] for compliance with axiom one, each FR is examined to see which DPs will influence it. The elements of [A] show how the DPs influence the FRs. The influence of the DP on the FR has to be large enough so that probable changes in the DP will have the possibility of taking the FR out of its functional tolerance.

Practically, DP columns in the design matrix are examined row by row systematically assessing the matrix element for each FR for its potential to be influenced by the DP. New designs are considered. This is also useful for reducing coupling in existing designs, identifying candidate DPs for modification.

The differential form of the matrix makes the influence more obvious as the elements become the partial derivatives, and if we just consider the off-diagonal terms in the matrix, such that $i \neq j$

$$dFRi = (\partial FRi/\partial DPj)*dDPj \qquad (3)$$

The primary assessment then is to determine if the partial derivative of an FR with respect to a DP is zero or nonzero.

In new designs, the details of the elements at the lower levels are not known, because they are still to be developed during the decomposition process. If the interactions are clearly unavoidable at the higher level, then the matrix element should be assessed to be non-zero and an X can be entered in the matrix. If the interaction is uncertain then matrix element should, to the extent possible, drive the detailed levels of the hierarchical decomposition.

In practice, designers sometimes decide that both the off-diagonal terms ∂FRi/∂DPj and ∂FRj/∂DPi are not zero and that portion of the matrix becomes fully coupled. When this happens in a new design, then one of the two elements can be deemed to be zero. Then the process of decomposition continues with the selection of the detailed elements, i.e., children at the lower level, driven by the constraint that they not interact in such a way that would cause their parents to be coupled. Alternatively, this problem can be addressed by the introduction of another FR.

In existing designs when both off-diagonal terms ∂FRi/∂DPj and ∂FRj/∂DPi are not zero, this is a candidate branch for re-design to reduce the coupling. This can be accomplished through the selection of DPs that do not interact in unwanted ways or finding new FRs and DPs, i.e., a new solution set for that branch.

3.1 EXAMPLES OF DECOUPLING BY PRIORITIZATION OF EXISTING FRS

The examples here are considering two FRs and their corresponding DPs. The examples are chosen to illustrate the case where one of the FRs is determined to be more important. The problems introduced by the coupling are that non-productive iterations could be required to reach a solution, or that that a solution might not exist, i.e., the iterations do not converge on a solution.

In the design of a car roof, the FR for protecting the passengers in a rollover can become coupled with the DPs for satisfying an FR for aesthetics. Batzer et al. [2007] show that it is possible to satisfy both FRs. The designers have the option to prioritize either the protection or the aesthetic FR.

In the design of a pleasure boat, the DPs to satisfy the FR for comfort can interact with the FR to provide seaworthiness. In this case, the matrix element showing the interaction of the DP for comfort with the FR for seaworthiness should be zero, i.e., seaworthiness trumps comfort. This is obvious because it does not matter how comfortable you make the boat, if it sinks, then the boat will become unacceptably uncomfortable.

In the design of systems that convert chemical energy to mechanical or electrical energy, there is an FR to convert the energy, and there can be another to control the environmental influences. Clearly, this is a candidate for the dual interactions described above. Conventional product design usually favors the conversion of energy over the environment, however government incentives, regulations, and public concern for the environment are driving the selection of DPs for power production that do not adversely influence the FR for controlling the potentially adverse environmental influences.

3.2 EXAMPLES OF DECOUPLING BY PRIORITIZATION OF AN ADDITIONAL FR

The examples here show how the addition of an FR can eliminate an unwanted influence, which result in a coupled design matrix.

In the design of the roof for a car, there are the posts, vertical members extending from the lower part of the body that have to be joined with the bows and the rails, horizontal members supporting the roof. The attachment points drive the design of one of the members to dominate the others. To resolve this, a gusset can be added that adapts to both the vertical and the horizontal members and eliminates the unwanted coupling [Batzer *et al.*, 2007].

In conventional ski bindings, the DPs include moving elements that allow for release, to avoid transmitting potentially injurious loads to the leg, also displace the mechanical elements that restrain the boot to the ski. It is this displacement that adsorbs shocks to avoid inadvertent release. The result of the coupling is an increased tendency for inadvertent release over a non-coupled design. An inadvertent release is said to occur when the boot detaches from the ski when the risk of injury is not imminent. As a consequence of an inadvertent release during skiing, the skier can lose control and serious injury can result. An FR can be added to adsorb energy, and the matrix element can be selected so that the corresponding DP does not alter the boot-binding interface while energy from shocks is being adsorbed. This way the full capacity for retention can be maintained until injury is truly imminent. Energy adsorption devices can be incorporated into the boot-binding systems, which can be designed to accomplish this. In one case, there are elements that restrain the boot mounted on a plate and the displacement takes place between the plate and the ski. The energy that might cause inadvertent release, is adsorbed in an interface that does not alter the retention of the boot. The plate and underlying energy adsorption mechanisms are the DPs that satisfy the new FR.

4 CONCLUSIONS

Decomposition rules, collectively exhaustive, mutually exclusive and minimum number (CEME-min), can be valuable for facilitating the developing of designs that are in compliance with axiom one. Thematic characterizations and taxonomies can facilitate the development of decompositions that are CEME-min. These include spatial, energetic and temporal. Appropriate prioritization and the addition of new FRs can help to resolve coupling in design matrices.

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