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Design Record Graph and Axiomatic Design for creative design education

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Abstract

The authors have been offering a graduate level design course at the University of Tokyo. The students form groups of about 5 members to identify their own design goals and construct creative solutions to meet the product functional requirements (FRs). The course teaches Design Record Graph (DRG), a network diagram that starts with the product FR that divides into a number of sub-functions. The division continues until all functional elements are identified, and when every element functional requirement maps to a single element design parameter (DP), the design meets the independence axiom. The projects often start with heavily coupled designs that gradually turn into clean solutions towards their finalized design. The graph expression is easier for design students to get started with functional decomposition without having to work with design matrices.

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1. Introduction

The authors teach a graduate level course at the University of Tokyo, School of Engineering. The course title is “The Practice of Machine Design.” It teaches mechanical design in the conceptual stage. Formal language of the class, including discussions and presentations, is English, and it attracts foreign students throughout the school.

The course objective is a group project to identify a problem to solve within the school-life and define a creative solution for it. From the nature of this assignment, the student groups often find improvements for solutions that are already in place but with existing inconveniences.

The course instructions are modeled after the practice at Stanford University d.school. To the 5 stages of conceptual design, Empathize, Define, Ideate, Build, and Test, the course additionally elaborates

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between the Ideate and Build stages. The students analyze their proposed solutions with Design Record Graphs (DRGs). The next section explains DRG and how it relates to the Design Matrix in Axiomatic Design [Suh, 2001]. Section 3 explains common pitfalls students often encounter when they draw DRGs for the first time.

The DRG representation gives an easy entrance to the concept of "divide and conquer" which is also the foundation of Axiomatic Design. The simple node and arc diagram allows breaking down a product functional requirement into sub-functions and eventually into functional elements. When the independence axiom is met, the DRG shows a ladder like set of arcs across the functional and structural spaces. DRG is especially useful in teaching functional analysis to students not well trained in linear algebra.

2. Design Record Graph and Design Matrix

Brown pointed out the advantage of Axiomatic Design for teaching traditional design [2]. Park reported applying Axiomatic Design in conceptual design education [11]. Liu and Lu reported challenges for students in learning Axiomatic Design [8].

The concept of DRG was earlier called function-structure diagram (F-S Diagram) [Iino *et al.*, 2014] following the Stanford naming of function and structure diagrams [Leung *et al.*, 2005, Ishii and Iino, 2008]. Hatamura and Nakao separately developed the same concept [Nakao, 2003, Hatamura, 2006]. Stone and Wood developed the functional model [Stone and Wood, 2000] which has input and output identified for each function. To avoid confusion with this functional model, the diagram is now called DRG because it is intended more for describing the designer's development of the design starting from the product functional requirement.

DRG is a directed graph with functional nodes in the left and structural nodes in the right. The two sides respectively show the hierarchy of functions and structures. The left-most functional node is the product functional requirement, also called the maximum functional requirement [Ishii and Iino, 2008]. The right end is the product. This graph representation, often used for mechanical design, is simple, easy to use and frequently used for other applications like service engineering, planning and software development.

The product functional requirement divides into sub-functions and continues dividing into smaller functions until they are divided into a set of Functional Elements (FEs). An FE maps across the border to the structure space to one or more Structural Elements (SEs). The SEs gather to form components and higher level assemblies until they all combine to define the right end product. Fig. 1 shows a typical DRG. This figure shows 4 layers of hierarchy in both the functional and structural spaces. There is, however, no set number of layers to draw in the graph. For conceptual design, 3 to 5 levels on each side are recommended.

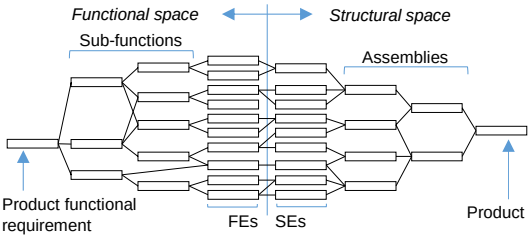

Fig. 1. Typical DRG

Axiomatic Design, on the other hand, relates Functional Requirements (FRs) to Design Parameters (DPs) in the formula Eq. 1 [Suh, 2001], where ***A*** is the design matrix. DRG relates to ***A***, such that FEs in DRG are the components of the FR vector, and SEs, those of the DP vector.

In constructing a DRG, students identify customer needs in the first decomposition level of subdividing the product functional requirement. Thompson pointed out that mixing customer needs with FRs can confuse the Axiomatic Design process [15]. Bragason *et al.* showed an example that had to map the customer needs first to FRs to complete the Axiomatic Design analysis [1].

DRG is not as rigorously defined as Axiomatic Design, e.g., the level of hierarchies in the functional and structural spaces do not have to match, and the designer is not concerned about correspondence of intermediate level nodes between the functional and structural spaces. The less structured nature of DRG may lead to confusion, but experienced designers can map customer needs in the first functional decomposition level to functional requirements in the second decomposition and repeat the subdivision to reach FEs. Well defined FEs state its requirement in the form of engineering metrics. DRG is easier for designers with less experience in linear algebra to start subdividing functional requirements.

The designer applying axiomatic design will strive to meet the independence axiom [Suh, 2001]. The goal