A Digital Ecosystem for Learning and Team Design

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Design is a human activity that encompasses a broad array of tasks. In engineering design, individual efforts can be aggregated into teams to maximize collective progress. Effective teamwork, however, requires extensive management, organization and communication. Furthermore, modern challenges encompass complicated multi-disciplinary problems with faster schedules, fewer resources, and greater demands.

Design, as a process, can be dissected into characteristic phases. Within each phase, design solutions are gradually developed. Technological tools have prioritized the structured analyses of the detail and final design phases and have proven to be incredibly powerful multipliers for effective design efforts. It has long been the case, however, that major commitments of intangible resources are made during efforts in the technologically abandoned earlier phases. These commitments and lack of modern toolsets for requirement development and conceptual design activities materialize as a major source of design pitfalls in industry today.

A digital ecosystem is introduced that integrates numerous features to provide a comprehensive framework throughout the design process. The Ecosystem for Learning and Team Design is proposed as a feasible technology to bolster student information management, teamwork, communication, and proficiency in fundamental design principles alleviating rework and process-related productivity interruptions.

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Introduction

Engineering design is a broad term describing the evolution of a product from need to manifestation. In a synergistic process, design involves aspects of organization, communication, creativity, and robust analysis. The framework that directs this spectrum of necessary and complementary activities can make or break the success of a design project. Then, it is highly advantageous to create a modern tool for a modern design task that can help designers navigate the landscape of engineering design and avoid common pitfalls, traps, and hopefully disasters[1].

This report describes the development and implementation of a digital ecosystem whereby these inevitable pitfalls can be avoided, managed, or overcome. This ecosystem is intended for commercial release to aid designers in efficient, comprehensive, and effective completion of their duties and responsibilities. Minimizing the impact of predictable issues and maximizing the quality of design efforts is a clear path to increasing productivity, compressing timelines, and easing strained budgets.

In general, design is an iterative decision-making process that produces plans by which resources are converted into products or systems that meet human needs and wants or solves problems[2]. This decision-making process is the foundational cornerstone upon which engineering design theory is built, and there are many recognizable and widely accepted process representations. The digital ecosystem described herein utilizes a four-phase model similar to the one proposed by Pugh[4].

Engineering design can be described as the systematic and creative application of scientific and mathematical principles to practical ends. The majority of research into creativity has taken the psychological-constructivist viewpoint, inferring that designers' knowledge and subsequent innovation are products of their environments, memories, and prior experiences[4]. It has understandably become standard practice within engineering to manage creative efforts without undue subversion or restraint but also without a substantial focus on promotion or inspiration. In the so-called Information Age, it is natural to expect an advancement in this shortfall.

The advancement proposed requires an integrated suite of requirement analysis and concept design tools – a “best of” collection from the numerous acclaimed and accepted design methodologies to guide and facilitate informed, purposeful early-process decisions. Through hierarchical functional modelling, physical solutions to complex problems can be assembled modularly. Utilities from morphological ideation techniques employed conjunctively with axiomatic methods effectively justify and correct problem statements, identify viable concept solutions, and optimize the solution path[2,4,5,6]. While morphological methods excel at generating plausible solution paths, axiomatic methods excel at evaluating the problem statement and guiding solution decisions. As a result, the integration of multiple methods can assist a designer with faster, more efficient progression through the design process and help to eliminate wasted effort and other major pitfalls[8].

The Digital Ecosystem

Concept

The aforementioned framework for modern design can be thought of as an ecosystem for design activity. A digital ecosystem describes a software system that exploits the properties of biological ecosystems, which are robust, scalable, and self-organizing[8]. The digital ecosystem in this report refers to technology specifically engineered to serve human purposes, developing to solve dynamic problems with high efficiency[9].

The framework constituting the environment and fitness landscape provide a sufficiently constrained, flexible design space for concept maturation and development. Consequently, the ecosystem can be leveraged in the realm of engineering design education, and specifically capstone-style experience-based courses. The results produced in the course of a capstone term can be described by a collection of evidence that demonstrates skills, achievements, learning or competencies[10].

For many students, the capstone project marks their first and only academic experience accommodating the full-spectrum of design, and also their first exposure to many modern engineering tools. For the experience to remain valuable for the student as a learning tool and the teaching staff for evaluation, the ecosystem must propagate an efficient, reliable, realistic, and compact experience. The framework automates administrative functions as well as taxonomic data input and management for maximum benefit for all stakeholders.

Design data materializes as distinct representations that transform throughout the design[11]. In each phase information is generated, collected, evaluated, and assessed to enable informed decision-making and to provide targeted feedback by faculty mentors to team members. The automated data management process formulated for use in the ecosystem has been defined by Imagars[12]. This study is not intended to outline proprietary software processes, but focuses largely on the implementation and results of automated assessment and the meaningful evaluation of design inputs.

System Characteristics and Use

The ecosystem has been developed for installation on a Windows-based tablet or convertible laptop. An available keyboard or touchscreen allow direct text and non-textual input and intuitive interaction within the ecosystem in a manner familiar to engineering students of the present generation[13] as depicted in Figure 1.

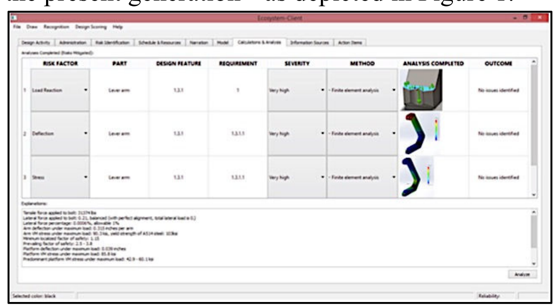

Figure 1: Application-based Windows interface.

In order to ensure the pedagogical utility of the ecosystem, several ABET-derived learning outcomes have been extracted that reflect the skills that student engineers are expected to demonstrate at the completion of a capstone project[13]:

1. The group demonstrates the ability to evaluate and incorporate information into the design;
2. Members function as part of a team;
3. The group communicates in the language of design; and
4. The group defines, performs, and manages the steps of the design process.

Information in each phase is mined to extract pertinent performance indicators respective of the pre-defined learning outcomes. Performance indicators for each outcome are collectively extracted from the Information Literacy Competency Standards for Higher Education and are compiled into phase-specific rubrics enabling the interpretation of the completeness and quality of design activity[14]. A spectrum of evaluable activity enables opportunities for timely automated prompts and targeted mentor feedback to upgrade deficient areas.

Requirements Gathering Phase

In the ecosystem, the bulk of external information input occurs within the boundaries of the requirements gathering phase, but is not strictly limited to assessment and evaluation there. It is presumed that a design problem has been provided from outside the ecosystem as a statement of need, and it is up to the designers to populate applicable elements of the product design specification (PDS) including the identification of all applicable customers and their collected influence on the problem. The PDS was proposed initially as the foundation of Total Design[4] and is adapted for comprehensive use in the Ecosystem as shown in Figure 1. It is naturally the prominent feature that initiates all concepts from the requirements phase.

The backbone of the PDS are the "foundational", i.e. common-core Functional Requirements (FRs) of the problem statement, corresponding Performance Requirements (PRs: the quantitative specifications of each FR; or UPRs: Unattached Performance Requirements which are necessary qualitative Constraints), Constraints (CONs: the binary boundary of the design solution domain), and Objectives (OBJs: or optimizable qualities of a design), as shown in Figure 2. Each FR, OBJ, and potentially UPR are formulated into a "fitness function" which algorithmically ranks design options according to the mission-statement of the PDS.

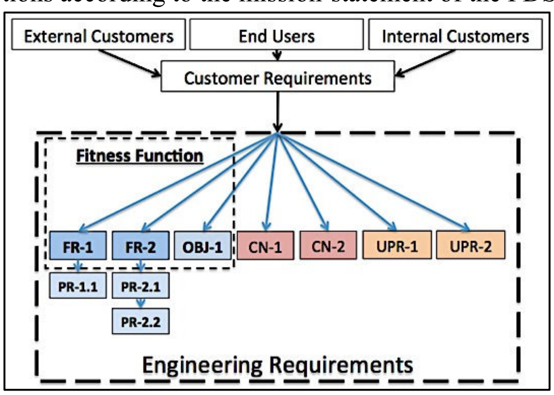

Figure 2: Ecosystem PDS feature architecture.

Concept Design Phase

Within the ecosystem, functional modeling decomposes a design problem into several lesser design problems. Concept-specific FRs, and the representative solution paths are outlined in the form of a design tree. The solution paths are formulated as Design Features (DFs) which act as macro-scale binders for the discrete design-point delineators: Design Parameters (DPs). The hierarchical decomposition of the functional model continues until parallel fundamental problems are determined which can be solved by basic solution principles.

Basic solution principles are drawn from Systematic Design. Axiomatic Design principles identify the relationship between parallel problems. Functional modeling is given high priority for the enforcement of rules in AD. To continue with appropriate context and allow future use of supporting AD principles, the terminology and procedure for functional decomposition is specific to this application, and is represented in Figure 3.

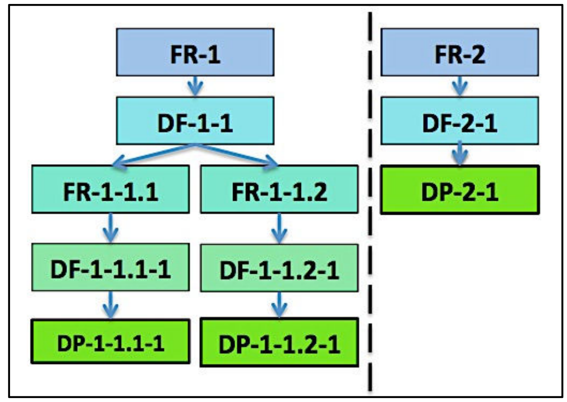

Figure 3: Functional decomposition for an uncoupled concept.

Pure AD is intended as a top-down approach. To some extent it is possible and beneficial to design in this manner. However, a hybrid approach can be used more effectively in most cases. The hybrid method proposed utilizes functional decomposition in a top-down manner but utilizes controlled convergence via design parameter optimization in a bottom-up manner in accordance with Total Design.

Detailed Design Phase

The concept that survives the fitness competition in conceptual design advances to detailed design. At this point, efforts to improve multiple species are redirected toward the evolution the overall winner. From the engineering requirements and functional decomposition, all PRs, CNs, and OBJs are specified by assessable quantities. It is imperative in this step to specify analyses to verify those requirements. While unlimited project time would yield unlimited analysis capability, limited resources typically require a degree of triage to determine the analyses that must be completed. The importance categorization associated with each applicable engineering requirement ensures designer efforts are appropriately guided. It should be the intent of a successful team to analyze all fitness parameters and verify at a minimum all requirements listed with very high, high and medium priorities. Proper consideration of each engineering requirement and applicable tolerances should be sufficient justification for the selection of the design point, defined as the vector of identified DP solutions characterizing the developed concept.

Final Design Phase

When a fully evolved design meets the engineering requirements, it is fit for advancement to final design. The final design phase is concerned primarily with the generation of production documentation and the creation of subsequent plans for manufacturing and testing. The user uploads pertinent part files, assembly files, and bill of material (BOM) files from the solid modeling package to ensure completeness. For parts purchased off-the-shelf commercially, detailed drawings can often be uploaded from the manufacturer and can therefore be specified as such for BOM accounting purposes. A feature envisioned for future development entails a continuation of the interface from detailed design, where solid model files are automatically collected and archived into a comprehensive bill of materials as attributes for each DF.

Conclusion

The Ecosystem for Learning and Team Design is an effective solution to design process issues identified by practitioners and researchers in the field. Industrial design challenges were established as the nexus for ecosystem development, but engineering institutions may reap maximum benefits from ecosystem implementation and participation. The Ecosystem is currently undergoing testing and development with significant favorable feedback in undergraduate capstone courses at Portland State University, the University of Nebraska – Lincoln, and the University of Minnesota – Twin Cities. Specifically, students have found the automation of administrative functions very useful, but have commented on limited team collaboration capability in the initial version (work-around now in place).

Implementing a synergistic collection of utilities from accepted design methods bridges the observable void for early-phase design tools. By rigidly supporting PDS development and functional modeling, additional formal and informal tools can be implemented to maximize the creative output and resulting available solution paths.

This report ascertains that the Information Literacy Competency Standards for higher education provide useful indicators for assessing the four ABET-derived learning outcomes identified for engineering graduates in the context of capstone courses. Meaningful evaluation of these indicators can enable rapid iterative design activity through automated prompts and targeted mentorship to increase overall design quality, maximize compliance with and comprehension of fundamental design principles, and increase individual teamwork skills.

Finally, the structured data input framework and intuitive interface are natural extensions of Information Age technology that allows limitless extensibility and tailoring for maximum effectiveness within academia, and industry at-large. It is predicted that these attributes collectively represent the “minimum viable product” for commercial development and institutional adoption.

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