THE ENGINEERING DESIGN GRAPHICS
Journal

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Online Distribution
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EDGD Calendar of Events

Future ASEE Engineering Design Graphics Division Mid-Year Conferences

70th Midyear Conference – January 24-26, 2016, Embry-Riddle Aeronautical University. Site Chairs - Heidi Steinhauer and Lulu Sun. Program Chair - Diarmaid Lane.

Future ASEE Annual Conferences

Year	Dates	Location	Program Chair
2015	June 14 - 17	Seattle, Washington	Ron Paré
2016	June 26 - 29	New Orleans, Louisiana	Heidi Steinhauer
2017	June 25 - 28	Columbus, Ohio	
2018	June 24 - 27	Salt Lake City, Utah	
2019	June 16 - 19	Tampa, Florida	
2020	June 21 - 24	Montréal, Québec, Canada	

If you're interested in serving as the Division's program chair for any of the future ASEE annual conferences, please make your interest known.

Election Results

According to the Division by-laws (see http://edgd.asee.org/aboutus/edgdbylaws.htm), the chair of the Elections Committee shall transmit the results of the election to the Chair of the Division. The Chair shall inform each candidate (including those not elected) of the results of the election for his office and shall transmit the names of the newly-elected officers to the Editor of the Journal for publication in the Spring issue of the Journal. The chair of the Elections Committee shall report the results of the election to the Division at the annual business meeting. The results for the most recent election are as follows:

For Vice-Chair: Norma L. Veurink

Norma L. Veurink is a Senior Lecturer in the Engineering Fundamentals Department at Michigan Technological University where she teaches introductory engineering courses which include engineering graphics. She teaches a spatial visualization course designed for engineering students with poor spatial visualization skills. Ms. Veurink manages several summer programs that introduce middle and high school students to engineering. She is active in the American Society for Engineering Education and the American Society of Civil Engineers. Her research interests include spatial visualization, engineering education and first-year programs.

For Secretary-Treasurer: Heidi Steinhauer

Dr. Steinhauer has taught at Embry-Riddle Aeronautical University since 1997. Currently, she is an Associate Professor and the Department Chair of the Engineering Fundamentals Department. She teaches: Introduction to Graphical Communication, Introduction to Engineering Design, Spatial Visualization Development, Advanced 3D Modeling, Additive Manufacturing, and Design for Manufacturing and Assembly.

Her research interests include the development of engineering curriculum that utilize the power of 3D modeling to foster deeper learning by providing students a scaffold to successfully implement an interdisciplinary approach, and the effect of engineering

design skills on student learning and academic success in the engineering field, specifically its impact on the recruitments, retention, and success of women.

Dr. Steinhauer has been integral in the development of several instrumental retention and outreach programs at Embry-Riddle. In 2006 she co-founded the ERAU Womens' Baja SAE Team and in 2007 she co-founded the College of Engineering's FIRAT Program, a coaching program geared toward the success of women in engineering. In 2009 and 2010 she was the co-director for the GEMS summer camp. She has also been the faculty advisor for Project Piquero, which developed an UAV to police for illegal shark finning in the Galapagos Islands.

She has authored over 20 journal and conference papers and has been funded as a PI on several NSF grants. Steinhauer, a three time recipient of Embry-Riddle Women's Vision award in 2007, 2009, and 2011 and also has received the ABET Diversity Award in 2010. She is an active member in the Society of Automotive Engineers, SAE, American Society for Engineering Education, ASEE, Women in Engineering Program Advocates Network, WEPAN, and the American Education Research Association, AERA.

Dr Steinhauer received her B.S. in Aircraft Engineering and her M.S in Systems Engineering, and her Ph.D. in Engineering Education from Virginia Tech.

For Director of Publications: AJ Hamlin

AJ Hamlin is a Senior Lecturer in the Department of Engineering Fundamentals at Michigan Technological University, where she has taught first-year engineering courses and a course to develop spatial skills since 2001. AJ received a BS in Environmental Engineering in 1993, a MS in Civil Engineering in 1995, and a PhD in Engineering, Environmental in 2002 from Michigan Tech. She also completed an NRC Post-Doctoral Fellowship at NASA Langley Research Center.

AJ's research interests include spatial visualization skills and engineering education. AJ has been an active member in ASEE since 2006, and has presented papers at annual conferences, EDGD midyear meetings, FIE, and the First Year Engineering Experience Conference. As a co-author, AJ is the recipient of the EDG Journal Editor's award. AJ has served as Site co-chair and Program co-chair for the 65th Midyear conference. AJ has been associate editor of the EDG Journal since 2011.

SAFAS: Unifying Form and Structure through Interactive 3D Simulation

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Abstract

There has been a significant gap between the tools used for the design of a building's architectural form and those that evaluate the structural physics of that form. Seeking to bring the perspectives of visual design and structural engineering closer together, we developed and evaluated a design tool for students and practitioners to explore the inter-relationships between the **form** and **structure** of long span structures*.* We have developed an interactive 3D design application for spatial structures that integrates with a web simulation service, enabling the iterative analytic comparison of designs by structural weight, force distribution, member deflection and stability. In this paper, we describe the design and development of this Structure And Form Analysis System (SAFAS) tool using the usability engineering methodology, presenting its evolution and evaluation though four semesters of use in undergraduate architecture classes. In this paper we present our summative results and lessons learned for the usability engineering of e-Learning systems, scientific visualization of structural dynamics, and user skill sets.

Introduction

The building industry has evolved with a division of labor that reflects two very different perspectives on the same coin. Architects, historically, are concerned with the form, perception and use of built spaces whereas structural engineers are concerned with the physics and forces at work in the spaces we build. There are, of course, rich and important relationships between these concerns of form and structure and these are naturally expressed in 3 Dimensions (3D). In this paper, we present the results of our work in the usability engineering of an interactive 3D design and analysis tool for long span, space frame structures.

The Structure And Form Analysis System (SAFAS) project is ultimately intended as pedagogical tool for undergraduate architecture education; however, its functionality is unique and significant enough for use by practitioners as well. The project is a collaboration between the Architecture, Education and Computer Science departments at Virginia Tech to develop and evaluate the use of simulation tools in design education. There are both explanatory and interactive resources for the structure and form curricula. The explanatory resources include an online website with extensive text, image, video and 3D resources on the origin, types and properties of space frame structures (Module 1). In this paper, we detail the evolution and design rationale behind the online interactive courseware, SAFAS Module 2 (see also: Bacim et al., 2010; Setareh et al., 2012; Polys et al., 2013; Jones et al., 2014).

We consider design as an iterative process of *generation* and *reduction*: designers generate multiple solutions to a problem and then reduce those alternatives to the most

feasible or functional or aesthetic solution. There may be several criteria or requirements for designers to balance in their solution. As both engineers and artists recognize, there is both science and art in tradeoff analysis: multiple local minima or maxima may exist and these are not likely the same as the global minima or maxima. In the exploration of the parameter space over several design iterations, a solution may converge slowly or it may appear unexpectedly in a flash of intuition. In order to reduce the design time to solution, we believe that digital design tools and simulation engines should be well integrated in order to tighten the design cycle between generation and reduction. This integration requires both a system with a flexible design interface that can execute simulations and a powerful analysis interface to explore and portray results.

SAFAS is such a system; it consists of a client and a server application that work together to support the convergence of architectural design and structural engineering activities. The client is a 3D space frame designer that includes several menus and modes with which to create expressive and realistic long span structures. Direct manipulation tools allow users to interactively deform the structures into novel shapes. Users submit their models to a structural simulator server over the web and receive the results back for analysis and comparison with other designs. Through this iterative, experimental process, SAFAS supports online inquiry-based learning (Furtak et al., 2012).

SAFAS was developed over several years with deployments in three universities over four semesters. We used Scholar/Sakai as our common course management system to deliver six different online lab assignments. As the tool evolved, we collected extensive feedback from the students about the performance and usability of SAFAS. This feedback guided our user interface and software improvements and provided empirical data on undergraduate student outcomes. In this paper, we detail the iterative usability evolution of SAFAS, presenting specific results bearing on the visualization of force, load, and deformation of steel structural members in 3D. We conclude with a discussion of how complex (spatial) concepts can be more clearly conveyed with interactive 3D simulation tools and the potential for future e-Learning systems.

Background

Interactive 3D Courseware

Online courseware and virtual 'lab-based' activities are gaining widespread adoption in K-12 and higher education. Many architectures and software have been deployed as educational applications and content have moved from server-based to client-based to client/server based and now back again to server-based (web/cloud). There are strong budget and mission pressures in education and therefore premium value is given to content accessibility, portability, durability and interoperability. As technology platforms evolve at a rapid pace, practitioner communities still face the challenges of digital content management and publishing in a world with a 3-5 year hardware lifecycle. Cooperative development and adoption of standards through International bodies such as

Web3D, ISO, W3C and IMS provides one essential strategy to balance innovation with sustainability.

Interactive 3D pedagogical content in domains from cell biology (Saini-Eidukat, 1999; White, 1999), astronomy and physics (Chakaveh et al., 1999) chemistry (Abdul-Kader, 2008) and optics (Thomas et al., 2008) has been demonstrated and evaluated with generally positive results. The successful cases are all a result of close collaboration between the teachers and software developers. Formal materials such as conceptual inventories, standards of learning, and rubrics all come from the teacher's expertise and the system is built to meet those requirements. However, there is an additional complication in the usability engineering of e-Learning systems - the teacher is not the end user (Bacim et al., 2010). We developed SAFAS through several rounds of both structured and open-ended student and teacher feedback.

The SAFAS client is a cross-platform *3D design and review application*; it provides expressive tools for creativity, and supports an industrial-strength structural simulation engine to evaluate the forces and deformations in the structure. The original Structure Analysis Program (SAP) was developed at Berkeley in the 1970s as a general-purpose Finite Element Analysis software. Its older open-source version (SAP-IV) was written in FORTAN and it is now offered as commercial software by CSI-Berkeley (SAP-2000). Being built for engineers, both present a steep learning curve. Our SAFAS server exposes both SAP simulation engines through a web service, providing a queue manager that processes SAFAS client simulation requests.

Virtual Environments for Structural Engineering Education

The use of Virtual Reality technology has been developed and evaluated for teaching structural concepts as related to the performance of typical steel structures subjected to seismic excitations (Setareh, Bowman, Kalita et al, 2005; Setareh, Bowman, and Kalita, 2005). Following up on those promising results, we decided to drive the development and impact of SAFAS by emphasizing the new requirements of Portability, Durability, and Interoperability:

Portability of interactive 3D content: the open-source Xj3D rendering library (Java, OpenGL) provides cross-platform client application to visualize models and structural simulation results from laptops to immersive displays.
Durability: 3D Models and lab scenarios need to be reproducible decades after their creation. Extensible 3D (X3D) is an open, royalty-free standard developed through the Web3D Consortium and ratified through the International Standards Organization (ISO).
Interoperability: X3D and VRML model import/export; Industry Foundation Classes (IFC) and CIMSteel Integration Standard (CIS/2) export through server simulation engine (CSI SAP 2000).

3D Modeling and Design

There is at least 30 years of history behind 3D computer graphics, content creation and interaction with 3D models. Indeed, numerous fields ranging from CAD/3D modeling to sketch-based modeling and interaction have tackled this problem of authoring solid geometry, meshes and textured photorealistic worlds. Our spatial structures are like a 3D mesh in one way: a network of linear members connected at nodes (vertices). However, there are some important differences: space frames are comprised of rigid-body members arranged in 3 layers (top, bottom and web), each of which may have different pattern of connectivity and physical properties (size and material) of members (edges). We adopted existing modeling metaphors, namely parameterized proxy 'deformer' geometry that allows users to manipulate and displace all nodes in a selection.

Perception in Scientific Visualization

In the early visualization literature, researchers evaluated and ranked visual mappings for different information types; Table 1 shows the pre-attentive ordering of visual markers per data type, as a result of meta analyses done by Mackinlay (1986) and Cleveland and McGill (1984). These rankings were focused on the legibility of a visual attribute as function of human visual perception. For example, color is very good for representing nominal/categorical variables, but very poor for representing quantitative variables.

Table 1

Pre-attentive Rankings of Visual Markers in the Information Visualization Literature

Data Type	Nominal / Categorical	Ordinal	Quantitative
Most pre-attentive	position color texture connection containment density	position density color texture connection containment	position length angle / slope area volume color / density
Graphical Representation	shape length angle slope area	length angle slope area volume	
Least pre-attentive	volume		
	(Mackinlay, 1986)	(Mackinlay, 1986)	(Cleveland & McGill, 1980)

While ability to extract a specific value (search) and pre-attentively order it along a dimension (comparison) is crucial for SAFAS users, we are also interested in the next higher level of abstraction – pattern recognition – at local and global scales. For scientific visualizations like scalar quantities over a regular structural network, this means portraying the distribution of these values throughout the network. In this way, SAFAS enabled us to probe the value of several glyph representations and examine how their

combinations of visual properties can support users' recognition of patterns in the distribution of forces.

SAFAS Design and Development

To build a usable 3D design tool for space frame structures, we adopted the Usability Engineering methodology (Rosson & Carroll, 2002). Usability Engineering refers to the process of setting operational definitions of user performance, executing a task analysis and then iteratively prototyping and evaluating the user interface features to meet those requirements. In this section we report the results of this design and development process for the Structure and Form Analysis System (SAFAS), a cross-platform, open-source, Web3D tool for architecture and structural engineering.

Activity Design

SAFAS is a free, online educational tool for architecture students, engineering students, architects, engineers, and anyone interested in structural dynamics. The primary purpose of SAFAS is to help individuals better understand the relationships between structure and form by building spatial structures, subjecting them to environmental loading conditions and observing the results. There are two principal activities supported as: Structural Design Mode and Structural Analysis Mode.

Models can be built, saved, loaded and exported for virtual reality walk-through and web publication. Most importantly for the iterative exploration of 'authentic' structures, models can be submitted online to a structural simulation engine, which computes the deformations and internal forces based on the structural configuration, properties and the applied loads and returns these values to the client for visualization and analysis. Users' models are managed through SAFAS and submitted to the CSI SAP-2000 simulation engine running on the same server. The simulation results can then be visualized on the client where further revisions can be made, submission and comparison with other designs.

Structural Design Mode

Information Design

When users create a new building design, a dialogue window opens with a menu of established base unit types and a screen image with text boxes in it, locating each parameter in the context of the structure (see Figure 1). The eleven fundamental types of space frame units fall into four families: Rectangular Grids, Diagonal Grids, Rectangular/ Diagonal Grids, and Three-way Grids. These 3D base units, which repeat in two dimensions to create the space frame, are displayed at left. The set of unit types covers the base configurations available in industry practice today. Users can specify the dimensions of the structure, the number of units in the length and width dimensions, the depth dimension, the height, the dead load and the snow load (in pounds per square

foot) and choose among a set of column types (Post, Tree, Pyramid) and their distribution (edge, corner) as well as settings (blank, trees, and a 3D Virginia Tech campus model).

All parts of the structure are referenced to a database of standard steel members with actual geometric properties and weights. Upon parameter selection, SAFAS generates the space frame, evaluates the base loads and sets the steel size of all each member in the top, web and bottom layer members. Users can change the size of selected members at any later time in Design Mode.
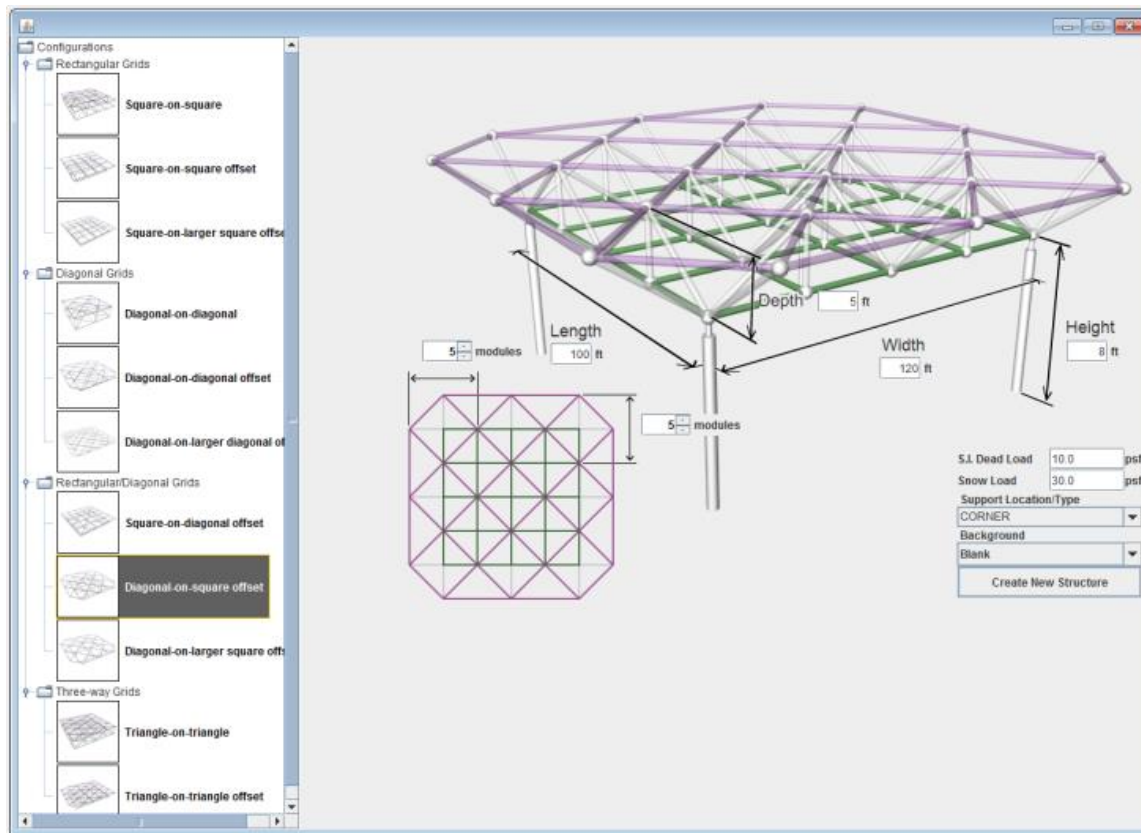
Figure 1. Specifying a space frame structure in SAFAS.

The generated structure is then displayed in the 3D panel with a categorical color coding by layer (green = bottom, white = web and purple = top layer). At the top of the SAFAS screen is a menu panel including six system and task-related pull-downs and then below them, shortcut buttons for common functions (with mouse-over tooltips) running from left to right. Down the right hand side of the SAFAS interface is a set of 2D control panels that are used to set parameters for Loading, Viewing, Comparing and Morphing. The color bar at the bottom of the screen indicates what mode the SAFAS is in: green for editing the structure (design mode), yellow for morphing the structure and red for inspecting the structure (analysis mode).

The newly created structure is shown in an interactive 3D window. The loads at each node in the structure can be rendered as arrow glyphs and/or with a color coding (white to red). As users mouse-over the nodes and members of the 3D structure, the elements highlight to yellow showing they are selectable. For members, their size, area and length is shown in the upper right in a Heads-Up-Display (HUD); for nodes, the x, y and z position as well as load are displayed. The 3D Axes included in the lower left of the HUD shows the user's orientation relative to the model (see Figure 2).

Interaction Design

To navigate in SAFAS, users orbit the structure by clicking and dragging the right mouse button. The position of the virtual camera is constrained to stay above ground-level. The mouse scroll-wheel zooms in and out of the scene toward the current cursor position (target-based zoom). Users can also use a pull-down menu in the right 'View Control' panel to jump to specific viewpoints.
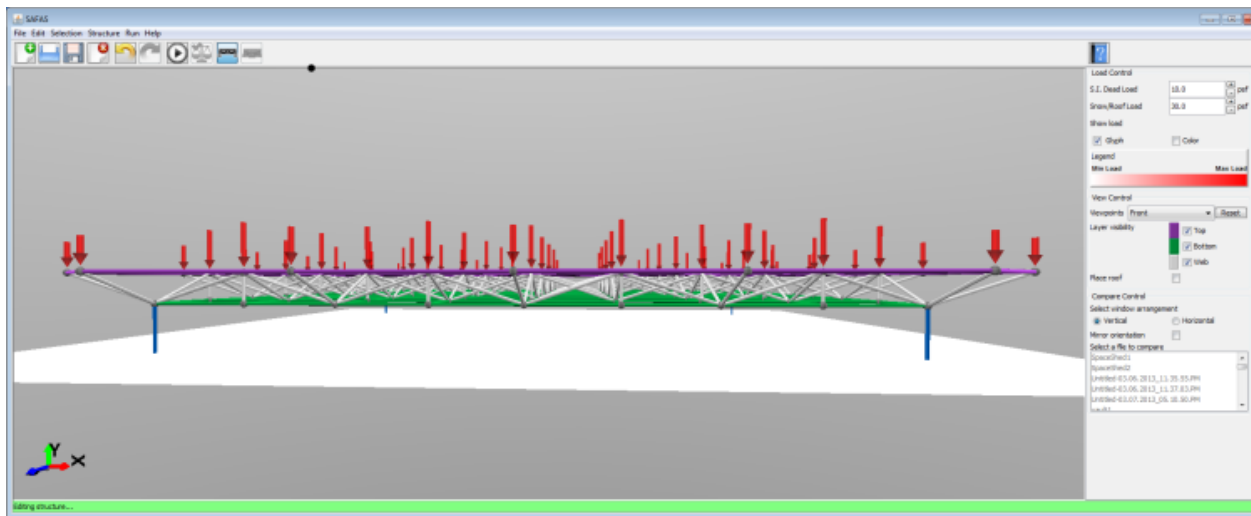

Figure 2. A newly-created structure showing node load as a glyphs.

The design interactions for the creation of architectural forms in SAFAS are driven by a rich set of functions. In the content-sensitive Morph Control panel at right, users can specify the properties of the deformer geometry that is used to shape the structure. The deformer geometry (a sphere or a cylinder) may be sized by radius and, in the case of the cylinder, aligned to any angle in the horizontal plane. We integrated a useful student suggestion for a shortcut button to size the deformer geometry to be the maximum di-mension of the current structure.

A morph action can also be customized with regards to the effect of the deformation of selected nodes within the proxy geometry. Through a pull-down menu, users can choose from a set of functions that determine the deformer's effect from the center of the selection to its radius; for example, the displacement of the nodes can follow a

smooth bell curve, a linear function, an elliptic or a uniform function. Through a 2D graph panel at bottom right, users can further customize the profile of the effect function by directly manipulating control points on the curve (see Figure 3).
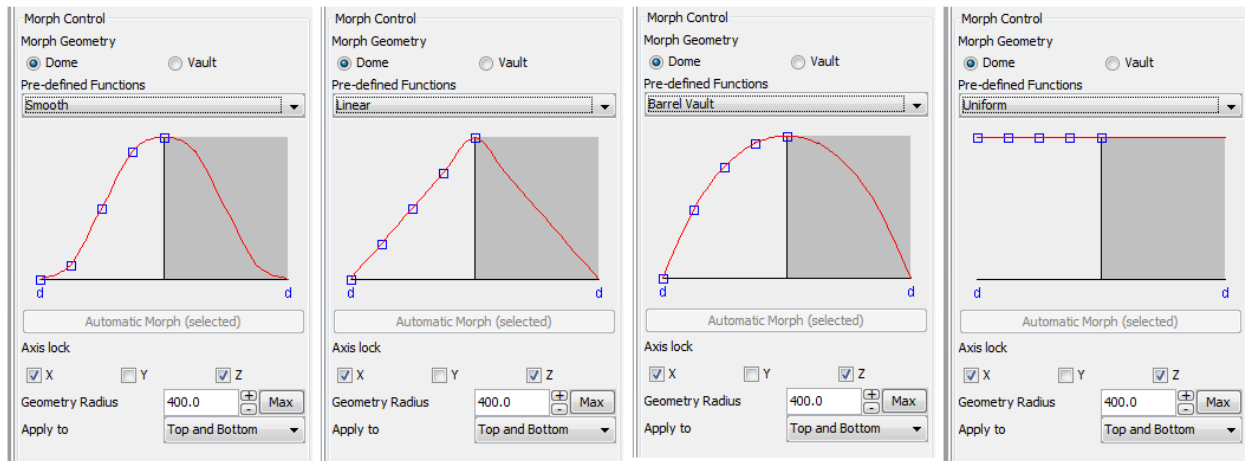

Figure 3. Close up of curve functions driving the SAFAS soft-selection design deformers.

The shape deformation of the structural network can be further specified to effect by layer or be independently constrained along any of the three axes. The selection of nodes within the deformer geometry is color coded to show the degree of effect a morph action will have on that node. Ultimately, a morph action can be executed with a direct manipulation (mouse click and drag) or by entering in displacement numbers (in inches) along any of three axes. The result is a built shape or form that is a structure specifying real steel members and under specific loading conditions (see Figure 4).
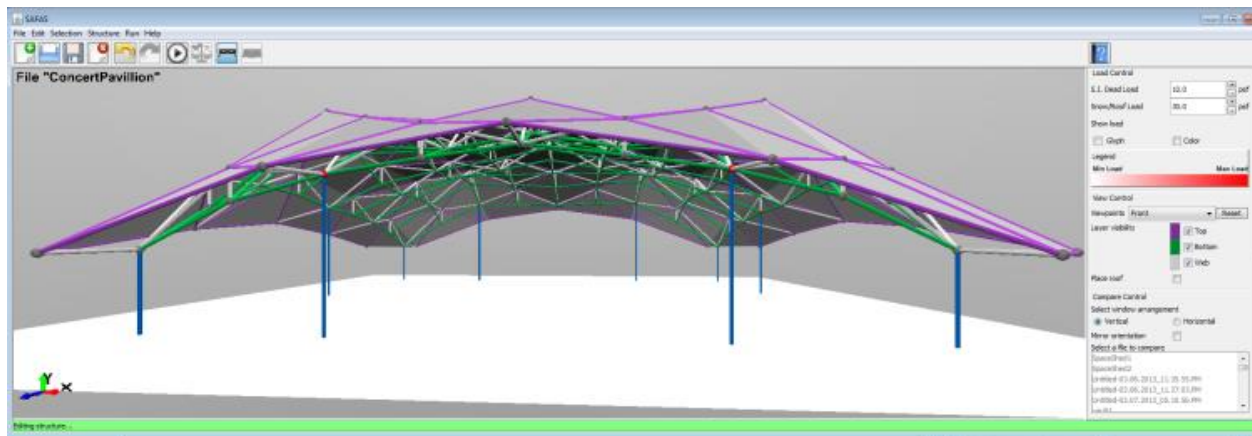

Figure 4. Example structural form designed in SAFAS.

To submit a structure design to the SAFAS server for simulation, users can use the 'Run' menu or the shortcut button at top. Users can specify their own name for the design, which is saved and submitted to the SAFAS server. An alert box shows the sub-

mission, processing and reception stages of communication with the server.

Structural Analysis Mode

Information Design.

After a structure has been evaluated on the server and the results retuned to the design client, users have a number of options for visualization and analysis of the simulation results. In the 3D window, users can query specific nodes and members to view numeric results with a mouse-over. By mousing-over a node, the upper right of the HUD shows a numeric readout of their x, y and z position as well as the directional load; mousing-over a member shows its forces numerically in the HUD.

The challenges of visualizing continuous data on a spatially-discrete network are significant. For example, there are several values of interest to represent in the context of occlusion and repetition in the structure of the network itself. In order to understand the relationship between structure and form, users must be able to find 'hot spots' as well as recognize patterns in the force distribution. To visually communicate the structural properties of a space frame form, we devised three visualization mappings of data values to visual values and one time series mapping (displacement animation) described below.

Table 2

Visual Mappings Used to Portray Force in a SAFAS Structural Network

Visual Mapping	Description	Categorical variable (+/-)	Quantitative variable
Color	Members' material properties are changed to show a diverging color scale going through white at 0 where tension is blue and compression is red; the member keeps its realistic size.	Hue	Luminance
Cone glyph	The member keeps its realistic size. Two yellow cones are shown at each member's midpoint; the cone's orientation shows direction of force, cone radius shows magnitude of force;	Orientation	Size
Cylinder glyph	A cylinder at each member's location is colored red or blue for direction to type of force and the cylinder's radius shows magnitude of force	Hue	Size

The distribution of tensile (+) and compressive (-) forces in the structural members can be portrayed through any of the three available visualization mappings. Table 2 summarizes the visual mappings used in the SAFAS structural analysis mode; Figure 5 shows an example of each. Checkboxes in the View Control panel at right enable the 'Highlight Max' and 'Highlight Min' buttons, which provide a quick assessment of extreme forces in the structure (with the active visualization mapping).
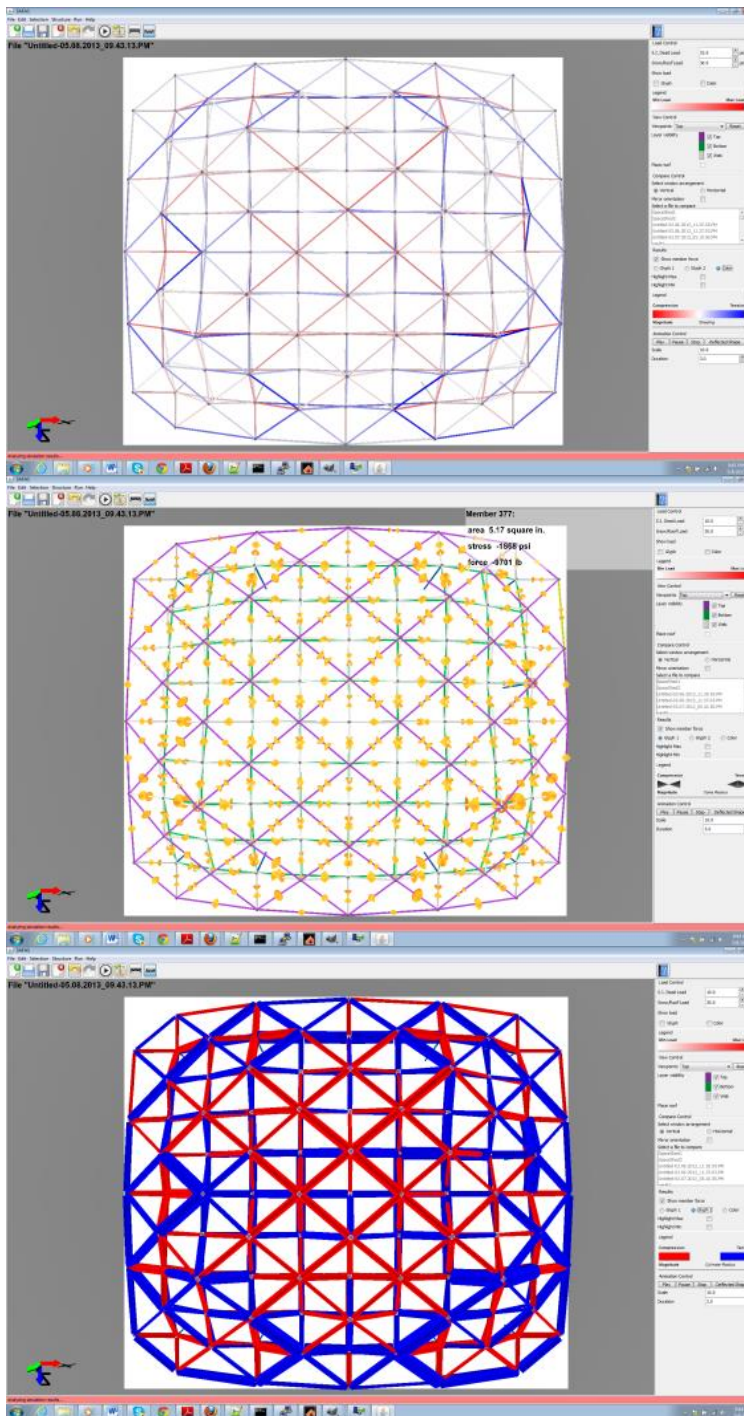
Figure 5. Visual Mappings of forces in discrete members.

There are a variety of color maps discussed in the literature and deployed in scientific visualization, depending on the distribution of data values to be mapped. Considering that force is a range on both sides of zero, we can say we need to represent the quantity of force magnitude in two different categories (positive or negative). We followed Mo-

reland (2009), adopting a linear diverging scale from blue to red for our first mapping. In the second mapping, we also preserve the structural members' actual size, but add an additional shape whose orientation and size portray the force in the member (cone glyph). The third mapping replaces the members' geometry with either a solid red or solid blue cylinder; where the size of the cylinder is proportional to the force magnitude.

Interaction Design

The calculations done by SAP on the SAFAS server return the internal forces in the structural members as well as the physical displacement of the nodes. The SAFAS client can display this information by mouse-over of a node or a member (numbers appear in the HUD) or with a 3D animation. The Animation Control panel at bottom right provides buttons to Play, Pause or Stop the animation as well as to snap to the final loaded shape. Users can enter their own values to uniformly scale the displacement animation or to adjust the playback speed of the animation.

In the design of an architectural form and the optimization of a structure's integrity, several versions of the model may be built. SAFAS allows for the side-by-side comparison of two different structures and their simulation results. In Compare Mode, users can select any prior models to load in an adjacent window (see Figure 6). 2D user interface elements in the Compare Control at right allow the windows to be tiled horizontally or vertically as well as for navigation to be synchronized between windows (mirror orientation).

SAFAS Implemtation

SAFAS 3D design client is built on Java, Extensible 3D (X3D) and OpenGL. NetBeans and SVN was used as the project development platform. We exposed the Structure Analysis Program (SAP) simulator programs through a custom-built web-service and queue manager, which tracks users and their job submissions on a Windows Apache server. Structures with thousands of elements are easily evaluated and returned in a few seconds. Online video tutorials were developed showing each of the features and processes of SAFAS necessary for the assignments. The software engineering aspects of our Web3D User Interface can be found in Polys et al. (2013).

Using our SAFAS 3D design application (Java client) and the online resources, students were asked to construct building structures with specific properties and to critically review the structural behavior. Each semester, we released a new version of the tool for use by the students. The development of the graphical user interface was a main focus as we iteratively improved the features based on the feedback of students from the online assignment questionnaire.
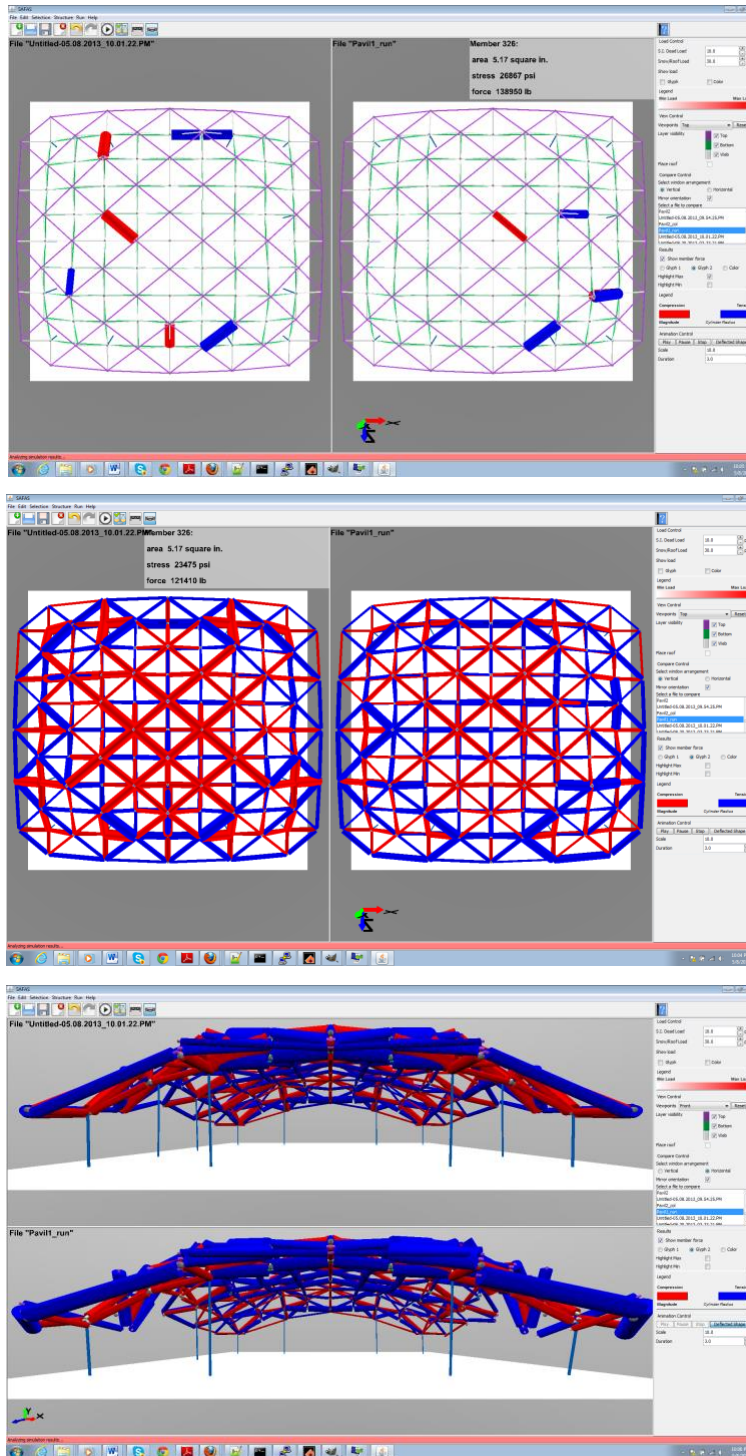
Figure 6. Comparing the two structures in SAFAS Analysis Mode with the Cylider glyph after adding two columns to keep the structure from collapsing; the top and middle plan views show the new structure design at left, original at right; the bottom screenshot shows the deflected shapes with the new design at top of 'landscape' compare mode.

The server-side system (web simulation service, queuing manager and file management) was integrated and tested with the open-source SAP IV as well as the commercial SAP 2000 structural simulator software. The design client was compiled and packaged for several platforms so that students could run it on their laptops or home machines. Finally, we implemented stereo rendering for the SAFAS 3D component and installed a version on the large passive stereo (circular polarized) projection wall in the Virginia Tech Center for Advanced Visual Media (CAVM) lab (see Figure 7).
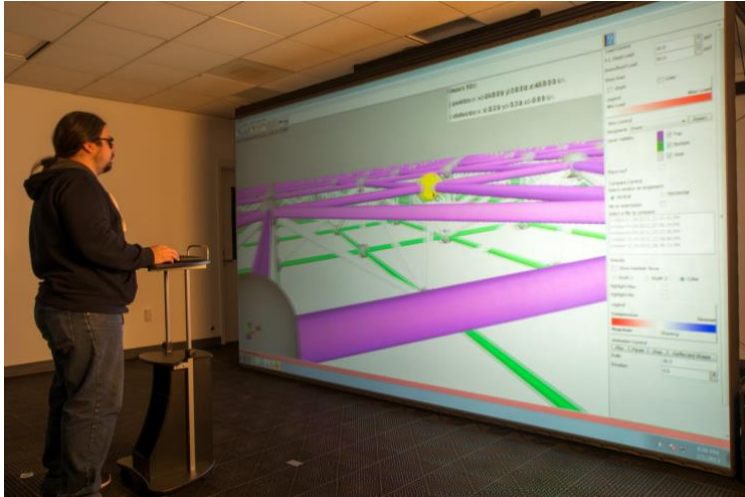
Figure 7. SAFAS designer on our Stereo wall.

The online assignments were designed so that, through their completion, students would learn the key structural concepts for their class level (see Table 3). To better understand the effects of form on structural behavior, the assignments required students to design both flat and barrel vault double-layer grid spatial structures. Typically, the procedure was to: log into the courseware website (Scholar/Sakai) and begin an assignment. Assignments were not timed and students could stop and resume any number of times before the deadline.

Table 3

Assignment topics used in SAFAS evaluation

Assignment	Key Structural Concept
1	the effects of the number of supports on structural behavior
2	the effects of support number and location on structural behavior
3	the effects of span-to-depth ratio on structural behavior
4	the effects of overhang length on structural behavior
5	the effects of different support types on structural behavior
6	the effects of different grid configurations on structural behavior

The assignments consisted of a set of instructions such as *'build a structure with the following dimensions and properties ...',* which students built with the SAFAS designer. Once students had built and analyzed the structure, there were a series of tables/ forms in the Scholar assignment to fill out; for example: questions about the various forces (min/max) and their distributions. Students had to extract the values from the SAFAS interface and enter them into the online assignment forms for grading. Each assignment included a section with reflective questions about the tool, including its features and ease of use (see next section). Each assignment took on average about 1.5 – 2.0 hours to complete and students were offered extra credit for their participation.

SAFAS Evaluation & Evolution

Over the course of this project, we iterated the SAFAS development through four semesters of formative evaluations. Each semester, students downloaded the client and installed it on their personal computer, completing the assignments and feedback questionnaires through Scholar. Our iterative tool development relied on structured and open-ended feedback questions from the users, yielding actionable results throughout the evolution of SAFAS.

Versions 1 and 2

The first two semesters were primarily spent developing the SAFAS tool's functionality, its user interface and the first 3 assignments. In Fall 2010 and Spring 2011, N = 11 and N = 35 respectively. At this early stage of development, the open-ended questions were a potent source from which to gather feature suggestions and improvements from the students. A majority of these suggestions were integrated into subsequent versions of the tool. After consideration from the team, several important features as varied as pull-down menus to automatic morphing dialogue parameters to 3D navigation and coupled views between compare windows, were implemented as the direct result of this user feedback.

The structured questions asked students to respond with a subjective rating (Likert scale: 1 (*strongly disagree*), 2 (*disagree*), 3 (*neutral*), 4 (*agree*), and 5 (*strongly agree*). These types of questions were designed to assess students' perceptions of the various functions of the SAFAS, as well as to assess students' beliefs about their abilities and motivation related to the SAFAS. They also helped us in identifying problem spots and prioritizing our work items. After reviewing the Fall 2011 results (reported in Setareh, Bacim, et al., 2012), we were confident we had a reasonable framework and tool that could be further developed to meet our research and pedagogical goals.

Version 3

We continued to develop the SAFAS as well as the protocols to assess it with (i.e. Assignments 1 through 3). In the Fall semester of 2011, we included students in another undergraduate architecture course at a different university for N = 78. In this iteration,

we focus on assessing the relationships between users' skills, their tasks, and how the different representations presented in the 3D tool support the conceptualization of structural dynamics.

Each student completed the Purdue Spatial Visualization test (Guay, 1976; Bodner & Guay, 1997) at the beginning of the semester, delivered through our online Scholar (Sakai) system. We conducted several statistical analyses on the results of the spatial visualization test and student scores. Over all three assignments (1-3), there was a strongly-significant correlation between their spatial visualization skill and their final scores (Pearson R = .341; p = .002). The student scores on the Purdue visualization test were positively correlated with their performance on specific assignments, notably, Assignment 1 and Assignment 2. On Assignment 1 (the effects of the *number* of supports on structural behavior), the correlation with Spatial Visualization was .304 with a p = .007 (n=78). On Assignment 2 (the effects of support *number and location* on structural behavior), the correlation was R = .275 with p = .016 and n=76.

At the beginning of Assignment 1, we had a set of ten questions that explicitly asked users to find the minimum and maximum loads on a structure with each of two visualization mapping (color and glyph). In Structural Design Mode, users can select to see the environmental load magnitude on nodes as either a color map (white to red) or as a vertical arrow's length (e.g. Figure 3). Users were asked to do this for both an edge-supported structure and a corner-supported structure. After the four questions regarding the load in each structure, users were asked *"After trying the "Glyph" and "Color" Visualization options, which one helps you better understand the properties of the structure?"*

Examining the responses of users by their spatial visualization score, we determined that a higher proportion of those on the lower end found the Color Map helpful. This difference was not significant by logistic fit or contingency analysis, but worth noting the trend that if we consider 'Low spatial visualizers' as scoring a 17 or below (out of 30), 55% of their choices were for the Color Map and 45% were for the Arrow Glyph. In contrast, 'High spatial visualizers' chose the Arrow Glyph 60% of the time.

At several points in each assignment, students were asked to record the visualization mapping that most helped them complete that analysis task (color map, cone glyph, or cylinder glyph). This allowed us to collect data regarding the perceived utility of the representations of force values in the structural members. Overall for three assignments (1-3) and semesters, the Cylinder glyph was strongly preferred to the Cone Glyph and Color for the visual mapping of tensile (+) versus compressive (-) forces. Out of the 684 total responses, 429 of those selected the Cylinder Glyph (62.7%), 175 selected the Color Map (25.8%), 80 selected the Cone Glyph (11.7%).

The Cylinder Glyph was clearly the most useful to students in completing their tasks overall. A one-way ANOVA showed this difference as significant both overall (F = 56.90; p = .017) and per assignment (for Assignment 1, F = 34.58 and p = .028; for Assignment 2, F = 260.46 and p = .004; for Assignment 3, F = 76.91 and p = .0128). Follow-up t-

tests of the Color versus Cone Glyph responses showed that although Color was pre-
ferred, overall the difference was not significant (t = -4.037 and p = .060). For Assign-
ment 2 (the effects of support *number and location* on structural behavior), the differ-
ence between Color and Cone preference was significant (t = -8.94 and p = .0198) with
users preferring the Color Map over the Cone.

Finally, we examined the role of spatial visualization skill on visual mapping preference.
We did two post-hoc analyses, dividing the population into 'High' and 'Low' spatial visu-
alizers. The cutoff value for these categories significantly affected these results, yet the
threshold is rather small based on 30 questions. When we used a score of 18 and over
(60%+) as the categorical cutoff value, there were 68 students in the High spatial visual-
ization category and 10 in the Low category; when we made the cutoff at 20 and over
(66.6%+), we had 55 in the High and 23 in the Low categories.
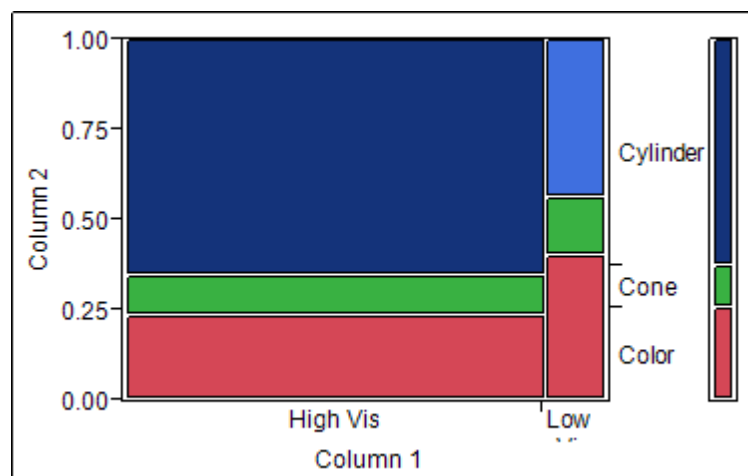
Figure 8. Color Preference per group: p = .0004.

A Contingency Analysis of user's preference for Color Map, Cone Glyph or Cylinder
Glyph show that 'Low spatial visualizers' had a greater preference for the Color Map
over Glyphs than 'High spatial visualizers' did. If we consider 'Low spatial visualizers' as
scoring a 17 or below, we see a significant result overall: Pearson Chi-square = 15.474
and p = .0004 (see Figure 8). However, when we used 19 and below as the cutoff score
for grouping, this difference was not significant (Pearson Chi-square = 4.558 and p =
.1024 at n = 684).

Version 4

In the Spring semester of 2012, we developed and deployed the remaining assignments
(4-6) and N = 89. Over all three of these assignments, again there was a strongly-
significant correlation between good spatial visualization skill and good final scores (R =
.291, p = .007, where n = 86). The students' scores on the Purdue visualization test
were correlated with their performance on specific assignments, notably Assignment 4

and Assignment 6. On Assignment 4 (the effects of *overhang length* on structural be-havior), the correlation with Spatial Visualization was R = .428, p < .001, n = 86. On As-signment 6 (the effects of *different grid configurations* on structural behavior), R = .433, p < .001, n = 82.

Across all of our evaluations of each Assignment 1-3 (SAFAS Version 3) and Assign-ments 4-6 (SAFAS Version 4), we asked students to rate their level of agreement with several "Ease of use" questions on a 5-point Likert scale. These subjective ratings showed that students generally agreed that the SAFAS features were easy to use, as evidenced by the fact that the mean values were about "4" for the ten specific questions presented (see Table 4).

The items with the highest ratings were those that related to the ease of placing the col-umns and the ease of understanding the definitions. All of the items were rated higher than "neutral" (on the "agree" side of the 5-point scale); however, the items with the low-est ratings were those that related to the ease of morphing the structural form, the ease of understanding the morphing options, and the ease of using the "Compare" window. The responses are generally on the positive side and even though Assignments 4, 5 and 6 were more challenging in demonstrating advanced concepts, we see a consisten-cy across the SAFAS versions. We conclude that form and structure activities are well-supported overall by our interface features.

In the open-ended feedback section for each SAFAS Version 3 and Version 4, we asked: "What did you like least about using SAFAS?" We coded students' responses and compared Version 3 and Version 4. Some of the responses provided by students were similar across time points, but others were quite different. One difference was that students reported much less "crashing" or "freezing" of the SAFAS with Version 4 (2.2%) than with Version 3 (32.9%). Students also reported fewer "bugs" or "glitches" with Ver-sion 4 (11.0%) than with Version 3 (22.4%), as well as less trouble downloading the SA-FAS Version 4 (1.1%) than Version 3 (7.9%).

These findings indicate that the modifications made by the SAFAS project team be-tween Version 3 and 4 were successful in helping the SAFAS to run more robustly and efficiently. Other comments, however, showed that there was still room for improvement with about 10% to 15% of students reporting that the SAFAS runs slowly, was not user friendly, or had to be closed and re-started with a new structure if a mistake was made or if a re-analysis needed to be completed. Comments made by fewer than 7% of stu-dents with either version were that: SAFAS was hard to learn to use, the tutorials were boring, and that it was hard to select nodes or members. Additional details and data from an pedagogical perspective can be found in (Setareh, Bacim et al., 2012).

Discussion

Usability Engineering

When we first set out to build an accessible, free software system to tighten the architectural design loop in long span space frame structures, we faced several challenges. Our goal was to construct a user interface and system to support constructivist and experiential learning for architects. Therefore, it had to be an authentic tool that realized the actual complex physics involved in real structural frames. Second, it had to be an expressive design tool, capable of generating a wide variety of building forms. Third, it had to be usable by novices on a variety of client platforms – this includes ease of installation and execution and user interface.

Table 4

Students' Perceptions of the Ease of Use and the Helpfulness of the Features of Module 2

Questionnaire Items	Version 3 a: M (SD)	Version 4 b: M (SD)
Ease of use (1 – 5)		
1. It was easy for me to visualize the various configurations of spatial structures presented when I created a new model.	3.94 (0.90)	3.68 (0.81)
2. It was easy for me to note the differences between the various configurations.	3.86 (0.85)	3.73 (0.79)
3. Selecting members and assigning sizes to the structure was easy.	4.05 (0.99)	3.86 (1.07)
4. Morphing the structural form was easy.	3.45 (1.18)	3.28 (1.00)
5. It was easy to understand the different morphing options.	3.58 (1.09)	3.32 (1.03)
6. Placing columns was easy to do.	4.23 (1.04)	4.29 (0.94)
7. The "Compare" window was easy to use.	3.41 (1.37)	3.62 (1.13)
8. The following definitions were easy to understand: S. I. Dead Load; Snow/Roof Load; Glyph; Viewpoint; and Layer Visibility.	4.25 (0.86)	4.31 (0.81)
9. The definitions for structure, length, width, depth, height, module size, and number were understandable.	4.30 (0.96)	4.28 (0.87)
10. The SAFAS interface button icons (the shortcut menu buttons) were appropriate.	4.04 (0.99)	3.80 (0.91)
Helpfulness of features (1 – 5)		
1. The "Module 1 Topics" were helpful to me.	3.30 (1.01)	n/a
2. The materials in Module 1 helped me to note the differences between the various configurations.	3.48 (0.95)	n/a
3. The "Compare" window was useful to me to better understand differences between the performances of structures under loads.	3.91 (1.27)	3.75 (1.11)
4. The "color coding" of the structure helped me to understand the action of loads and distribution of forces within the structure.	4.03 (1.11)	4.08 (1.16)
5. The "Highlight Max" option helped me to understand structural behavior.	4.82 (0.62)	4.72 (0.74)
6. The "Help" topics were helpful to me.	2.94 (1.01)	2.94 (0.91)

Note: Response options included 1 (*strongly disagree*), 2 (*disagree*), 3 (*neutral*), 4 (*agree*), and 5 (*strongly agree*). [a] n = 78; [b] n = 89

Reflecting on the four (now five) iterations of the SAFAS, we can say that our original approach of adding an analytic 'Cognitive Scaffolding' step to the typical usability engineering process (Bacim et al., 2010) has guided our design and born fruit in a usable tool (i.e. Table 4). However, we can note a few qualifications that temper our original claims. First, despite frameworks for formal cognitive-task analysis and reductionism (Payne, 1986; Diaper, 1989; Schraagen et al., 2000), we still lack a complete picture of task and cognitive taxonomies across domains. Therefore, future research in applied HCI and 3DUI, especially e-Learning, should include deliberate efforts to identify and qualify the knowledge and cognitive operations required for a task in a given context.

The second observation worthy of noting is that for the SAFAS project, the Cognitive Scaffolding approach followed the law of diminishing returns. Specifically, it was the principle guide in developing the first and second versions of the software. However as the iterations progressed, the value of empirical evaluation increased. As the project progressed, many of the features were identified and validated by explicit user comments. In retrospect, this dynamic makes sense as the development effort shifted from the fundamental functionality to the usability of the client interface in supporting the specific activities and detailed work flows of the undergraduate assignments.

Scientific Visualization

The SAFAS project enabled us to explore some fundamental challenges of scientific visualization. Specifically, we evaluated the ranking of visual properties for the visualization of scalar values on (discrete) structural networks. We found that the Cylinder glyph (solid color hue for representing the categorical variable and size for representing quantitative variable) was the clear winner among the visual mappings tested. The results are generally in line with the information visualization literature where color is stronger than shape or angle for categorical data and area / volume is stronger than color for quantitative data. A caveat to this result is that for these tasks, there is no need to maintain the structure's real size when comparing the sizes of the force within the member - we can sacrifice realism and use the virtual environment graphics to accentuate the properties of the structure (distribution of force magnitudes) for easy, pre-attentive comprehension.

In addition, we observed a trend that High and Low Visualizers preferred different visualization mappings. For the questions about load in Assignment 1, we saw Low spatial visualizers relying on the Color Map more than the Arrow glyph, whereas for High spatial visualizers, the Arrow Glyph was chosen the majority of the time. In the case of Assignments 1-3 and questions about force, this preference was significant with a larger proportion of Low spatial visualizers (vs. High spatial visualizers) choosing the Color Map. We believe this result makes sense that users without strong spatial visualization skill are compensating by focusing on cues in the scene that are not geometric, specifically the hue and luminance values of members.

The Role of Spatial Visualization Skill

The finding that student performance on several of these assignments depends on spatial visualization skills is not surprising in itself, but more interesting is to consider the reasons why this correlation was not uniform across assignments. The Purdue Spatial Visualization Test significantly correlated with performance on assignments 1, 2, 4, and 6 but not 3 and 5. These results suggest that tasks which require the processing of three dimensional locations and configuration information are particularly demanding for students with 'low' spatial skills. Conversely, we may conclude that the tasks involving the span-to-depth ratio and column categories do not significantly require the spatial visualization skill measured by the Purdue test.

These results confirm other studies in engineering education that found that spatial visualization skill is predictive of success in engineering undergraduates (Sorby et al., 2003; Branoff, 2009). This is good news, since spatial visualization skills can be learned through training and practice (Sorby et al., 2003; Sorby, 2009a; Sorby, 2009b). At Virginia Tech for example, incoming freshman to the College of Engineering take the test and those with a score of 17 and below are enrolled in a special (intervention) class that demonstrably improves their spatial visualization skill and their chances of success in the program. We consider this evidence as a strong mandate to work with more student populations, such as architecture students, on developing these skills early in their career. One set of activities is already available, although expensive (Sorby et al., 2003), and could be updated to use real interactive 3D models online instead of pre-packaged 2D animations from a CD-ROM.

Future Work

SAFAS provides a robust platform for designing space frame forms and evaluating their structural feasibility through simulation. The process of development has given us a richer understanding of the factors in building successful e-Learning systems and scientific visualizations. The SAFAS tool installer and curriculum will continue to be deployed for undergraduates at Virginia Tech. Interested parties should visit the website to request accounts for themselves and their class. We believe SAFAS can be a robust platform for further user studies on visual mappings, the benefits of immersion, and interactive techniques for shape deformation.

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An Introduction to the Development of a Product Brand: An Evidence-Based Template for Use with First Year Undergraduate Industrial Designers

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Introduction

Successful industrial design activity has been shown to persistently improve corporate financial performance across a number of manufacturing industries (Hertenstein et al., 2005). Product aesthetics have been shown to positively influence consumers' responses and alter perceptions of brand quality (Page, 2002). This development of product aesthetics through the manipulation of color, form and texture within a commercial design activity is a core competency for an industrial designer and a significant factor in the potential success of commercial products. However, from nearly 50 years of combined academic experience, it is the authors' opinion that this key component of professional knowledge and skill is difficult to isolate within a design process. This may be due to the complexity of interactions that deliver both physical and social functionality. This area, which may be considered 'soft design engineering', is often overlooked within a purely physical functional approach to a new product design development. Social functionality is in this paper considered to be the value or values placed upon an object or service by an individual, group or society. The social function of a product is a core deliverable of an Industrial Designer, but still important to an Engineering Designer. To ensure a successful return on a new product, the physical and social functionality must be satisfied.

Social functionality may often be most easily seen through the delivery of brand. Brand may be considered to be a relationship between individuals within a market and a product, group of products and or product service. An important quality of a strong brand is the presence of a clear, well-defined brand identity. The identity is the set of desired associations with the brand that strategists working with the brand wish to establish and maintain (Aaker, 2000). Creating and maintaining a stable brand statement is an important aspect when developing a successful product in all industries. However, sustaining that statement is challenging due to the frequent misunderstanding of the associations behind the brand by industrial designers, marketing and engineering. Engineers need to explain manufacturing constraints to the designers; designers need a

rational framework in which to describe form in a manner that is comfortable for engineering, while marketing needs to understand the emotional impact of forms that compose the brand.

The job of the Industrial Designer is to use color, form, texture, temperature and movement to deliver a sensory experience that evokes a desired response. It is critical for a designer to understand the mechanism of human perception, along with the associated response that may result from the physical stimuli generated from a design intervention. The understanding of the mechanisms enables an industrial designer to employ an evidence-based approach to a user-centered process. The paradigm of evidence-based decision-making and putting the user at the center of a design process is core to the principles being taught by the authors and demonstrated through supporting professional practice in industry. This approach has also been developed and applied by the authors; and, subsequently documented through a number of case studies in different product fields (Torrens & Black, 2011; Torrens, 2012; Torrens et al., 2012).

The aim of this paper is to provide education practitioners with a template to facilitate the introduction of brand construction to first year undergraduate industrial design students through the visual and physical embodiment of a product. The ongoing pedagogic development has been refined over the last fifteen years alongside research into the professional practice of Industrial Design (ID). The objectives of this paper are to: provide signposting to the underpinning theories of the template; describe the template; show an example of student work that demonstrate the outcomes of template application; and, highlight where students have used the template within a brand related design competition to produce a successful design outcome.

Brand and Product Semantics

Brand may be considered the relationship between the product or service and the target consumer. The objective in this case is to deconstruct or reverse engineer a Brand. Dittmar (1992) provides a good discussion of the social value of things that are the drivers behind brand. As mentioned earlier, social value placed on the brand is important to try and measure the effectiveness of brand enhancement. Bloom (2010) provides a more generic social psychology viewpoint of the same drivers. A wider understanding of the social context of value and associated principles may be considered useful for academic staff to ensure they can answer student questions outside the focus of the given exercise.

Delivery of meaning, product semantics, is an important theoretical component of brand. Crilly (2008) has demonstrated some links between designed interventions within product artefacts and their deliberate manipulation of meaning through visual semantics. However, when considering the introduction of young designers to these concepts we should start with more fundamental explanations upon which to build to the complexity of a professional level of product semantics. Leborg (2004) provides an

accessible introduction to definitions of visual grammar, such as describing what is a point, line or curve. Building on this understanding of visual grammar, 'The Semantic turn' provides a comprehensive discussion of more sophisticated elements of visual meaning linked with user experience that may be incrementally introduced to students of industrial design (Krippendorf, 2006). In order to deliver product semantics of form, color and texture, we need to understand the mechanisms of perception.

Manipulation of Perception by Industrial Design

Although there is still much debate about the cognitive processes of human beings, there are some elements of consensus regarding perception. In this paper perception will be considered a biological process. The text 'Perception' (Sekuler & Blake, 2002) is a comprehensive and detailed reference that describes all aspects of perception. We perceive our world through a series of sensory organs that convert the physical stimulus from our world into electrochemical impulses or signals. The conversion from physical stimulus, such as light waves, vibration or energy (heat) is called transduction. The signals delivered from one's eyes, ears, nose, tongue, skin and underlying tissues produce patterns within the different sections of the brain to which they are delivered. These patterns are processed as symbols within the brain.

There is so much signal information being delivered that the brain filters the information which it processes. The brain chooses only useful aspects of the physical world on which to focus. The way in which the brain chooses what to sample is driven by the needs defined by primates from whom we are evolved. Gestalt is a term covering a series of principles associated with fixed gaze, which is how we add detail to an object of interest on which we focus.

The theories behind some of the practical manipulation of an individual's emotional, behavioral and reflective response (user experience) through color, form, texture, movement, heat or vibration are documented. A possible reason for this is that much of the data now collected is for commercial use and not published. Hekkert and Shiverstien have discussed a 'Unified method of aesthetics' (UMA), (Sheiverstien & Hekkert, 2008, Hekkert & van Dijk, 2011) within the context of design and emotion; however, the text 'Universal principles of design' (Lidwell, Holden, & Butler, 2003) is an accessible reference that provides a compendium of both mechanisms of perception and how designers can manipulate them. Lidwell et al (2003), linked with a subsequent publication 'Universal methods of design' (Martin & Hanington, 2012) provides a similar compendium of applied research based methods through which some of the principles may be evaluated. Key activities within the template based on this body of knowledge were to:

1. Identify keyword adjectives that define the current brand;
2. Deconstruct aspects of the real world that match the current brand and additional keyword;

3. Define visual graphemes (building blocks) based on a keyword and original brand 'form DNA'; and,
4. Construct a new artefact that communicated the novel meaning of a given brand.

Pedagogic Template

The module described here provides first year students with an introduction to brand and a process through which an existing brand may be analyzed and an associated product may be designed with an enhanced form of the existing brand. This process was meant to offer a simplified version of brand development that might be requested of a design consultancy. An analogy used during the explanation of this process to students was that it would be equivalent of making a perfect doughnut and then adding an unexpected, additional, flavor to it. The new blend of flavors is equivalent of what a consultancy would bring to the user experience of an existing brand, enhancing and renewing novelty in the relationship. Undertaking the task of blending new experiences into a brand, finding those which detract as well as enhance, is an important aspect of an Industrial Designer's learning experience. Dissecting the qualitative nature of brand development into a series of design decision-making elements provided an opportunity for more considered evaluation of the evidence used to make those decisions. The 'chunking' of information also enabled a clearer presentation of the pathway to brand development.

The module, within which the template was introduced and applied, accounted for 100 hours and delivered over 20 of the 30 weeks of a semester; around eight percent of the total within the first year of the 'Industrial Design and Technology' program. A much larger module, 'Design Practice', provided the main component of conventional industrial design process and practice, based around an evidence-based, user centered design approach. The module provided specialist knowledge and skills for those intending to follow more marketing-driven professional practice (Storer & Campbell, 2012).

The module was divided between a series of 11 one-hour lectures in the first Semester, which introduced brand, mechanisms of perception, and the ethical issues for designers associated with the development of brand and manipulation of consumer behavior. The knowledge examined via a multiple choice test was then applied through a project brief. The project followed a simplified professional process through an intensive day of activities, followed by five hours of project work per week for eight weeks to develop and communicate the final design. The brief was to develop and enhance a given automotive brand through an associated one litre oil bottle. The suggested theories applied through this section of the design process were:

1. Deriving keywords from the car brand description and Company 'mission statement', predominantly adjectives (describing words);
2. Brainstorming keywords, adjectives, associated with the brand;

3. Reviewing current forms and details from the cars produced within the current brand;
4. Choosing a keyword from those generated that would enhance the brand;
5. Taking pictures of forms, predominantly, that visually describe the chosen keyword;
6. Choosing ten images from those taken and using part of the student cohort (15 students) to rank them in order of which images most described the given keyword;
7. Deconstructing the outer form, graphic part lines, points of interest and surface finishes into a series of lines, simple shapes and textures of both current brand and the highest ranked images by the student cohort;
8. Reconstructing the identified lines, shapes and textures (graphemes) within the constraints of a one litre volume;
9. Validating the final design outcome using a peer review rating method against a given set of assessment criteria; and,
10. Presenting and edited version of the outcome and process within two presentation boards.

The main focus of exploration of form was related to the outline, which was considered to be a primary visual element reviewed by an individual. This is associated with a number of the principles highlighted in Table 1, particularly, figure-ground relationship, law of Pragnanz, top down lighting bias and threat detection. Color was not a primary consideration in this exercise.

Activities 1, 2, 3 & 4 involved the brainstorming of keyword adjectives the student felt described the cars produced under a given automotive manufacturer and product brand. The exercise included words taken from additional online documents associated with the brand and brand owner's 'mission statement'. Students were placed in groups and were encouraged to discuss their analysis, undertake group brainstorming and constructively critique ideas. The images had been visually grouped using a mind-map format, with annotation over the product images collected online.

Activities 5, 6 & 7 used a given ranking template to show the photographs taken for each reviewing student to complete. The given template, which was on an A3 size sheet, was compiled using photographs taken by the student designer, labelled A, B, C, D, and so on, for 10 images. The given feedback sheet had enough rows for 15 student reviewers and two academic staff to rank the images, where rank 10 was most evocative and rank 1 least evocative. An average was used to order the images by each student, using a majorities rule if there was a tie between any two images.

Once ranked, the student designer reviewed the order to evaluate why one image and form had been chosen over another. Each student designer annotated their images and attempted to derive lines and forms, visual graphemes, which most evocatively matched their keyword adjective.

Table 1

Summary of Principles from Lidwell et al (2003); Grey Sections are Directly Applied Within the Case Study Described in Table 2

Principle	Description	Application in ID
Affordance	Physical characteristics of an object influence its function	Relating semantics of components to function or controls
Alignment	Alignment of edges along common rows or columns or their bodies along a common center	Leading focus of attention along a series of elements or lists
Closure	Perception of individual elements as a single pattern	Making a common whole from parts, making objects appear complete
Color	Attract attention, group elements, suggest meaning and enhance aesthetics	Influencing emotion (unproven), highlighting objects and semantics of objects and controls
Common fate	Elements appearing to move in the same direction are perceived to be more related	Defining meaning through texture, differentiating components
Consistency	Similar parts expressed in a similar way	Emphasizing Brand and social groups
Constancy	A tendency to perceive objects as unchanging despite changes in sensory input	Combination of color, visual, haptic and sound changing over time to deliver meaning
Figure-ground relationship (gestalt principle)	Defining an object of focus or the rest of the field of perception	Defining primary form, semantic meaning, highlighting components
Good continuation	Elements arranged in a straight line or smooth curve are perceived as a group	Camouflage, combining individual objects into a whole
Law of pragnanz (gestalt principle)	A tendency to interpret ambiguous images as simple and complete	Camouflage, heuristic to reduce complexity
Gutenberg diagram	The general pattern followed by eyes when looking at evenly distributed homogeneous information	Order of review of elements, emphasize review of controls and information
Iconography	Use of pictorial images to improve recognition and recall	Controls, signals, semantics
Interference effects	Mental processes made slower or less accurate	Adding confusion to controls or products, puzzles, security, heuristic to reduce complexity
Layering	Managing complexity through organizing related groupings and reinforce relationships	Information, controls, heuristic to reduce complexity
Mapping	Relationships between controls and effects	Heuristic to enhance usability, alongside iconography, affordance and color
Orientation sensitivity	Certain line orientations more easily and quickly processed	Control interfaces, heuristic to reduce complexity
Proximity (gestalt principle)	Elements close together perceived to be more related	Control interface, heuristic to enhance usability
Signal to noise ratio	Ratio of relevant to non-relevant information in a display	Heuristic to enhance control usability
Threat detection	Ability to detect threatening stimuli more effectively than non-threatening stimuli	Semantics of objects, heuristic to enhance user experience

(continue)

Three dimensional projection	A tendency to see objects and patterns as three-dimensional when certain visual cues are present	Virtual environments viewed through a two-dimensional screen
Top-down lighting bias	A tendency to interpret shaded or dark areas of an object as shadows	Orientation of an object, enhance natural familiarity of an object
Uniform connectedness (gestalt principle)	Elements connected by uniform visual properties, such as color, perceived as more related	Control interfaces, heuristic to enhance usability

In activity 8 the student designers attempted to combine the graphemes from the ranked images with those derived from the forms of the branded products. The students used annotation to act as an 'aide memoir' and externalize their understanding of the relationship between different forms.

In activities 9 and 10, students peer-reviewed draft versions of the two A3 presentation boards. The boards were used to present the process and evidence of insights gained; and, descriptive illustrations of refined product designs into an evocative representation of the given brand and blended keyword adjective.

Students had discussed with staff the assessment criteria during the briefing at the start and at regular intervals during the course of the project. Students had been shown examples of good practice and process, quality of visual communication and effectiveness of brand delivery and enhancement from previous years student work. Students were also shown industry standard equivalents of the elements expected. The students were asked to peer-review the presentation boards of student designers in other groups with this common understanding of expected standards. Each given aspect of the assessed criteria was rated by reviewing students in each column. The rating was from 1-6, where 1 was very poor and 6 was excellent. As with the previous ranking document, there were 15 rows for student reviewers and two rows for staff.

Once the reviews were complete, each designer averaged the results in each column and plotted them onto a web diagram. This enabled each student to visually see strengths and weaknesses in their presentation, as identified by their peers and staff. Students were able to refine their work from activity 9 before submitting their finished presentation, as part of activity 10.
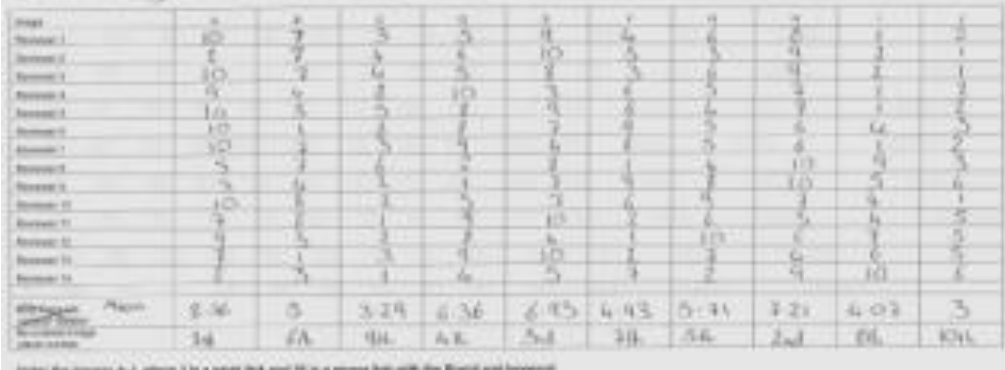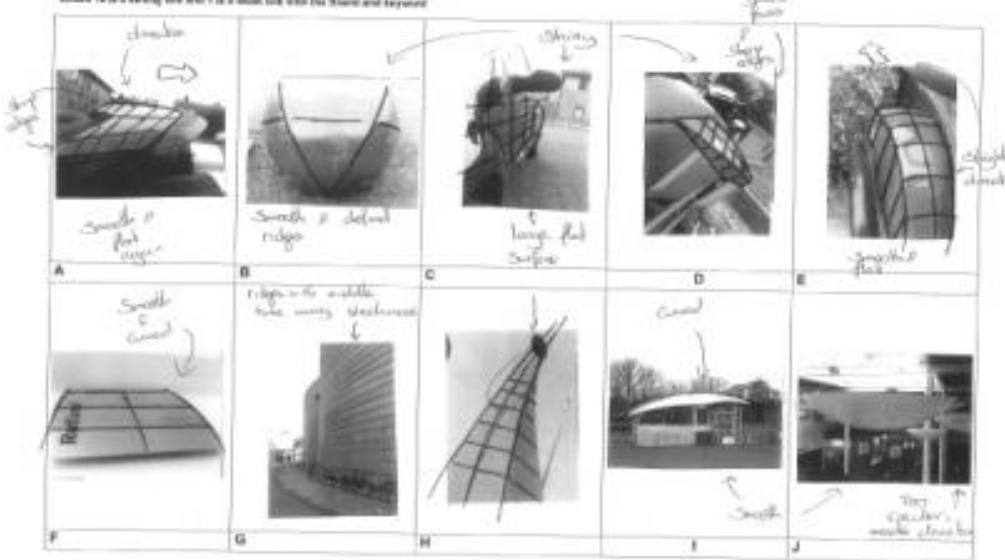
Outcomes

The images in Table 2 show different stages of the prescribed process. It can be seen that iterative cycles of individual and group discussion were undertaken during the activity.

The two images under activity 1, 2, 3 & 4 show the brainstorming of keyword adjectives taken from the cars produced under the Citroen brand, as well as a those taken from additional online documents associated with the brand, and brand owner's 'mission statement'.

Table 2

Student Project Example, Designer: Callum Tongue

Activity	Student outcome
1, 2, 3 & 4	Deriving keyword, brainstorming

The three images under activity 5, 6 & 7 show the format of the template to show the photographs taken, the ranking form for each individual reviewing student to complete and the images with annotations by the student designer who took them. When considering the student cohort, staff noted during the exercise that in some cases the averages produced very clear polarization of ranking; however, in some the averages were close together making clear rankings more difficult.

Activity	Student outcome
1, 2, 3 & 4	

Activity	Student outcome
5, 6 & 7	Images of keyword, ranked and analysis

Activity	Student outcome
5, 6 & 7	

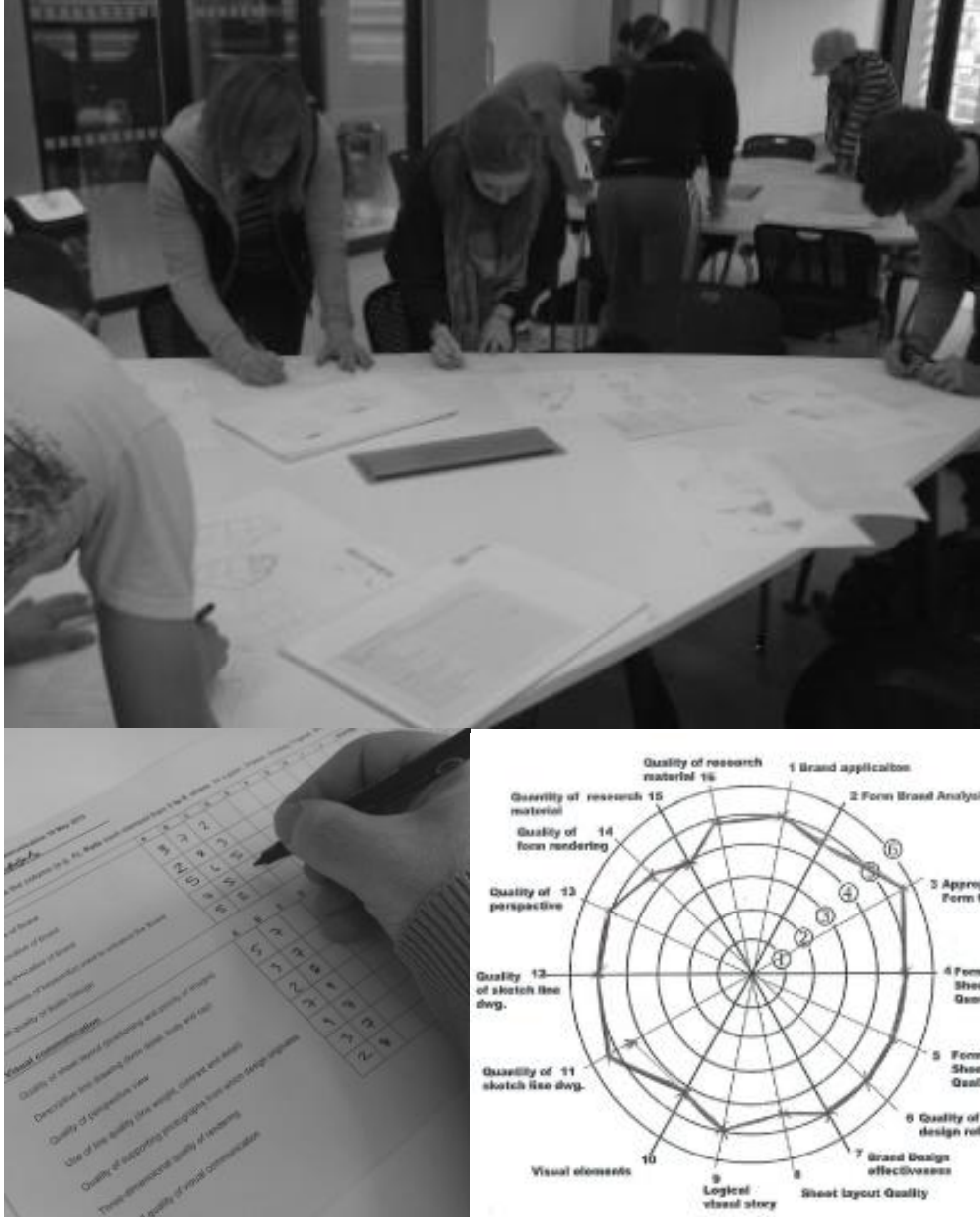| Activity	Student outcome
5, 6 & 7	

The design pages in activity 8 show how the designer attempted to combine the
graphemes from the ranked images with those derived from the forms of the branded
products, in this case Citroen cars.

Activity	Student outcome
8	Reconstructing using graphemes

(continue)

In activity 9 and 10, the images and documents shown are from the final weeks of the project, where students had peer-reviewed the draft versions of the two A3 presentation boards. The boards presented the process and evidence of insights gained and

descriptive illustrations of refined their designs into an evocative representation of the car brand and blended keyword adjective, which was 'Sleek' in the given example.

Activity	Student outcome
9	Validating design outcome through peer review rating

(continue)

Activity	Student outcome
10	Editing and presenting process alongside design solution

A tacit observation by staff of the applied process was that student designers did not undertake enough iterative cycles of exploration and refinement in each of the activity stages. This may be due to a lack of effective time management of multiple deadlines

associated with this and other modules; leaving less time of what may have been considered a less valuable module. Mark or grade watching is discouraged, but staff had found some students take time to become refocused on a more professional viewpoint of their studies.

Evidence of the same or similar process being applied may be seen in student success in design and brand competitions. Ms Chloe Tuck used the principles and process taught and practiced in the module to win a UK National packaging competition. See Figure 1. The winning entry has the same elements within it as the submission of the
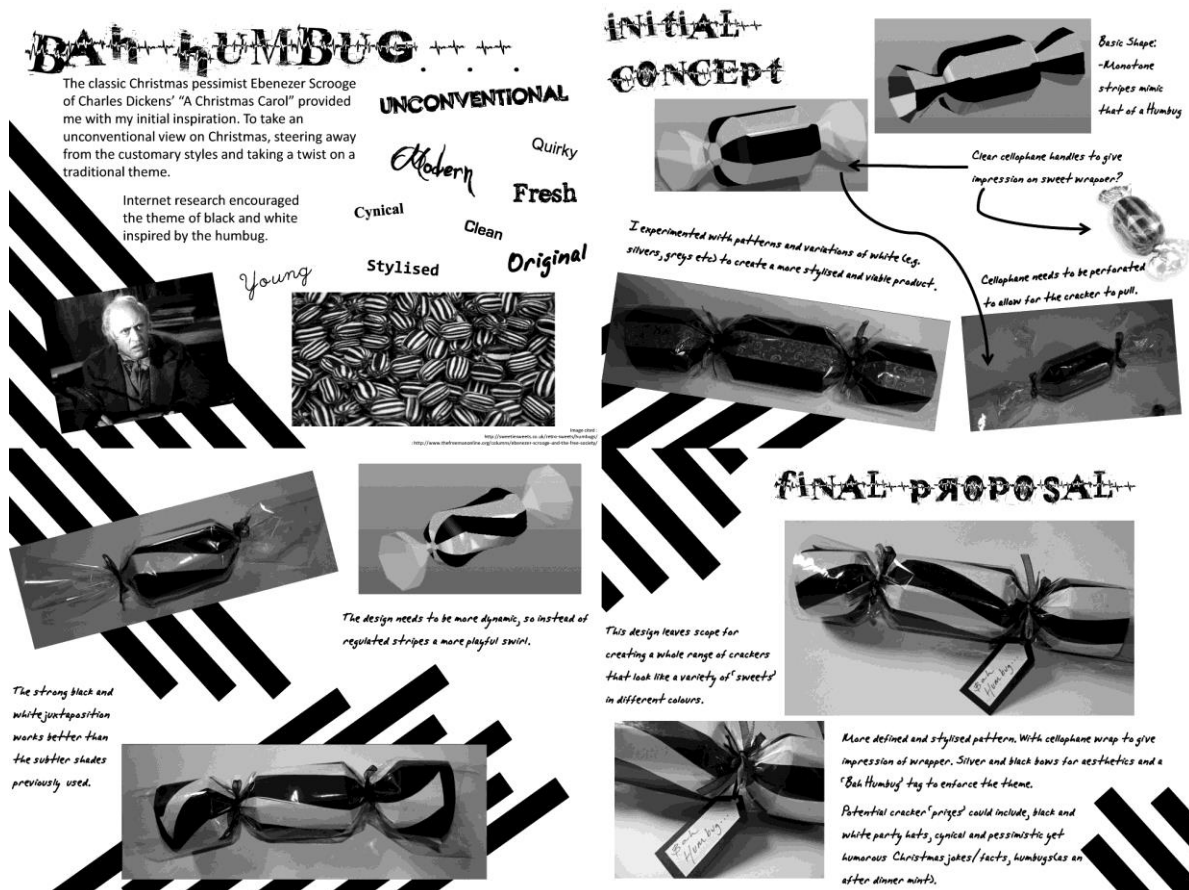
Figure 1. Winning Entry for the Tigerprint 'Gifted' Christmas Cracker Competition 2012, Designer: Chloe Tuck (Loughborough University 2015).

academic module. The designer has added words from the competition requirements. Ms Tuck has derived keywords from the new source; in this case, the Charles Dickens' novel 'A Christmas Carol'. She has deconstructed visual elements, graphemes, from a humbug sweet and wrapper, a type of traditional confectionary in the UK. Ms Tuck had brought together these graphemes into a packaging design that emphasized the keyword 'humbug' and visual association with the traditional confectionary. The designer has also highlighted visually the links between the different elements. In doing

so, she had demonstrated a visual audit trial to the viewer of her design process and decision-making. The presentation provides evidence of an evidence-based approach to a design process.

A more detailed example of the application of the template was seen in the next example. In 2014 sixteen students entered the 2014 student 'Starpack' awards for packaging design. (Starpack, 2015). One of those who entered was commended. What may be more enlightening is some of the feedback from judges to the students who entered the competition. The Starpack competition organizers and judges have kindly allowed their comments to be published (See Table 3.). The judges had a five point scoring system with an overall mark out of twenty. Half of those who entered obtained an overall score of nine, with one commended student receiving 11. An important element to pick out from the judges' comments was about the quality of the development boards. This element was specifically noted in four of the entries. From the comments made, most judges were critical of the practical application of technology and model-making.

Figures 2-4 show the commended competition boards from Ms Helen Couper. The three presentation boards provided research and development; the final design, linked to key brand elements; and, a scenario of use.

The key stages shown in the earlier car brand exercise are clearly visible in this presentation. Brand analysis, keyword generation are seen in the top sections of the board. Validation of keywords used to define the visual graphemes through ranking and peer review, are shown in the lower section.

The hand-drawn illustrations, brought together using Photoshop software, provide an explicit link between brand analysis, key images and the final design. Minimal annotation is needed to support the evidence for design decision-making and systematic approach to the concept development. However, the layered approach (foreground to background) provided a good example of a designer leading the viewer through levels of importance of the visual elements.

A scenario of use delivers an explicit realization of individual and social interaction, ergonomic usability and brand delivery.

Nineteen students for the academic year 2014-2015 had entered the competition, following on from those who entered in the academic year 2013-2014. In this second year of students entering from the program, eight students achieved awards: five were awarded 'Bronze' status and another three were commended. Two of those who achieved a 'Bronze' award were second year students entering without tutorial support, but who applied the same template and process. The designs of the 'Bronze' award winners for 2015 can be seen on the 'Starpack' competition website.

Table 3

| Scoring system is 10-11 commended award, 12-14 bronze award, 15-17 silver award and 18-20 gold award.	Answers the brief	The concept	Model	Development Boards	Points to consider (see the brief)	Points to consider (see the brief)	Score		Result
C: Packaging as a marketing tool	3	1.5	2.5	3	1	1	11	Well researched and development boards give lots of detail. Would like to have seen how you would have marketed this.	COM-MEND-ED
G: Norwegian fishcakes jump off the shelves	2	1	2	3	1	1	9	Would stand out on shelf and is innovative. However, not practical. Can't read the brand - too stranded!! Can't stack them. Good development boards presentation - very clear.	
F: The perfect package - designing for brands	2	2.5	2	2	0.5	0.5	9	Ergonomic, playful, stands out but rationale perhaps not fully formed. Obviously the student has a passion for structure. No link back to why decisions were made e.g. why olive oil? There's a lot more that could have been explored there. There was also no Webb deVlam branding or any real relevance to our company. We liked the idea of an everyday product becoming a design piece.	
F: The perfect package - designing for brands	2	2	1	3	1	1	9	The boards demonstrated a more progressive and creative idea than the model resulted in. The idea has potential but was not executed well at all. We would have loved to have seen some of the sketches on the boards which were more brand brought to life.	
E: Heinz miniature "trio-pack" for convenience sauces	2	2	2	2	1	1	9	Rather novel idea for stackable sauces by squeezing on to trays. Contamination concerns? Product waste? No mention of supply chain, nice mood boards.	
E: Heinz miniature "trio-pack" for convenience sauces	2	2	1	2	2	2	9	Good idea to hinge/attach the pouches would not work in blow molded PP, PET with molded cups. Good reference to the natural 'plant bottle' material.	
E: Heinz miniature "trio-pack" for convenience sauces	2	2	2	2	1	1	9	As a trio pack it works OK! Stackable blow molding would be complex as would filling. Shelf appeal unsure against existing market. Nice mood boards and consideration of design brief innovations.	
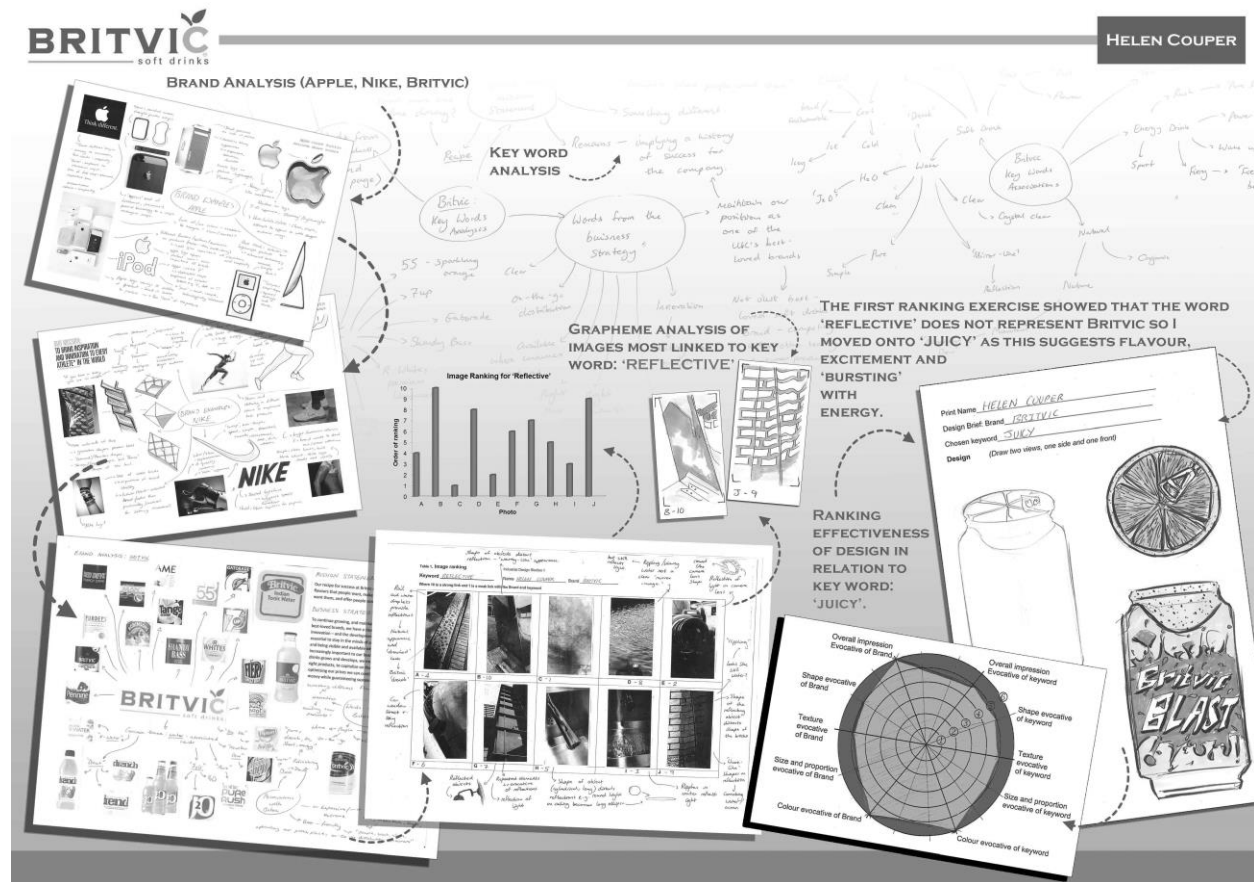
Figure 2. Research Board Shows Brand Analysis, Deconstruction and Validation of Concept Design (Designer: Helen Couper).

Conclusion

The template may go some way to providing insights into what is often considered the 'applied art' of brand design. The template can help designers, marketing and engineering to communicate brand design by supporting communication understood by each discipline. Examples of the template presented in this paper enable other educators and practicing designers or engineers to apply this way of working to their own needs. Through the template, marketing and engineering can understand brand based on a logical framework that breaks down the brand into sub-elements, making it more accessible and comprehensible to those not trained in aesthetics. The defined elements within the template may now be more effectively evaluated using a 'mixed methods' approach of qualitative and quantitative research methods.

Figure 3. Final Design Board Shows the Link Between Brand and Concept Design (Designer: Helen Couper).

Taking images from the real world provided students with an opportunity to practice identifying suitable visual elements to collect towards their goal. Their goal was to build a novel version of their given brand. The two check points in the prescribed design process enabled students to gain timely feedback on the real-world images they collected and their final design. The rating of their final design by 15 individual students from their cohort gave students some indication of how effectively they had communicated their design interventions. It also gave an indication of the effectiveness of communication of the reasons behind the final design solution. The metrics for the rating were the same as used by academic staff to assess their outcomes. It also enabled the reviewing students to experience critically reviewing design work in a constructive way.
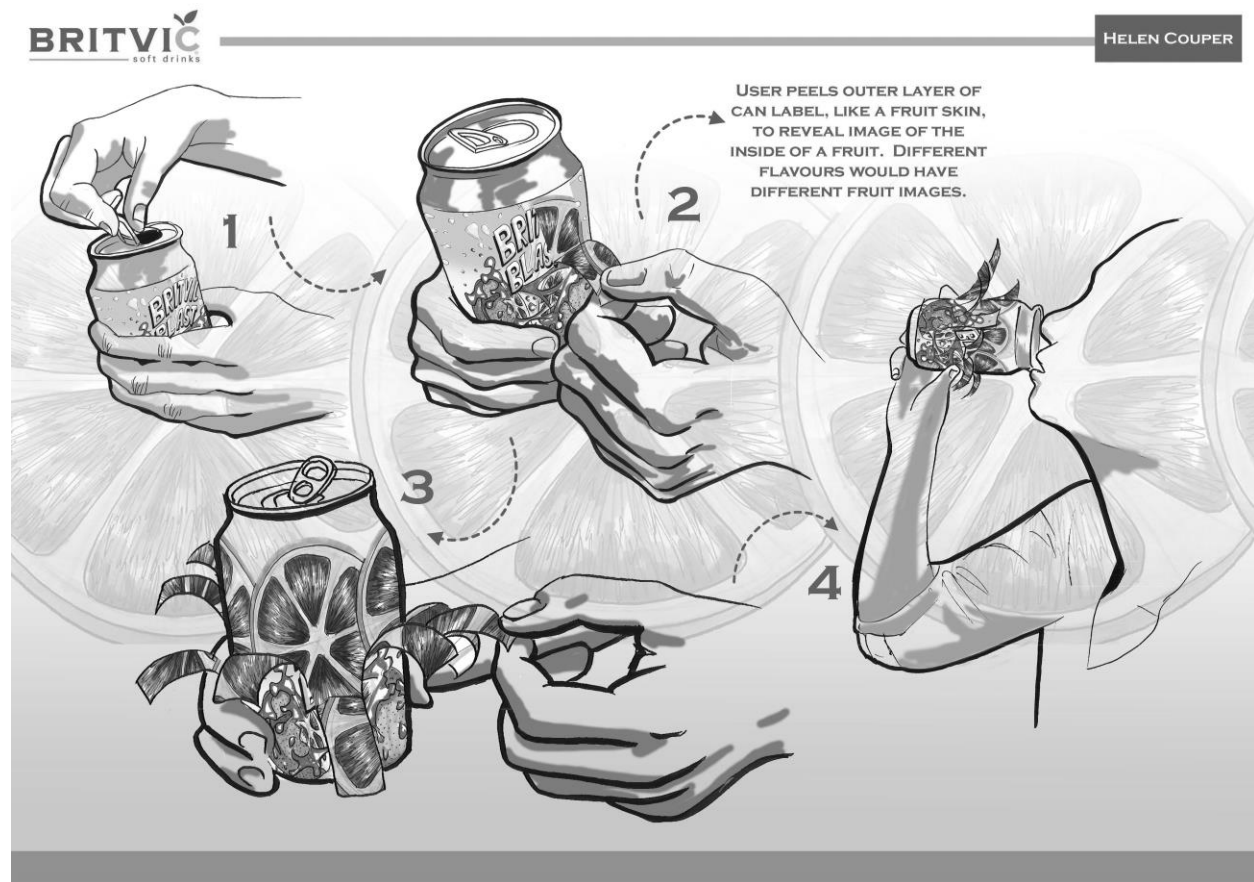
Figure 4. Shows the Scenario of Use Presentation Board (Designer: Helen Couper).

The prescribed process appeared to be effective for students, who went on to build the level of complexity of their meaning with a product design. Tacit feedback to the authors from students who had undertaken the module in previous years indicated it provided individuals with a simple framework within which they could identify and view marketing strategies, social value and brand communication in a wider society. It enabled them to see the patterns and coding embedded in advertising and associated Branded products.

The design competition winners showed that the generic understanding of brand and product semantics enabled these students to compete at a higher level of sophistication against more experienced design students and even design professionals. In the case of first year students competing in the student 'Starpack' packaging competition they received only basic advice relating to packaging technology before submission. They had to build their models in their own time, as it was not timetabled within the program at that time. This may account for the critical comments made by the 'Starpack' Judges.

Future developments will be to research and develop validation methods aligned with the principles shown in Table 1 and compiled by Martin and Hanington (2012) that are accessible for student designers and integrate them within a pedagogic program. The

authors would welcome further discussion of the template presented in this paper with colleagues from design and engineering disciplines to further these objectives.

Acknowledgements

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