ViSA: A Parametric Design Modeling Method to Enhance Visual Sensitivity Control and Analysis

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Abstract
The ability of parametric computer-aided design systems to generate models rapidly enables designers to explore the downstream impacts of changes to key design parameters. However, the typical modeling functions provided in the parametric systems can become insufficient when such exploration is needed for increasingly complex parametric design models. Main challenges for exploration that we observed are control and analysis of changes on the design model and in particular, when they are introduced continuously. The system interfaces and the human-visual perception system alleviate these challenges. In this study, we demonstrate ViSA, a Visual Sensitivity Analysis method that aims to make the effects of change within a parametric model controllable, measurable and apparent for designers. The approach aims to improve visually analyzing the sensitivity of a design model to planned parametric changes. The method proposes customizable control and visualization features in the model that are decoupled from each other at the design level, while providing interfaces between them through parametric associations. We present findings from our case studies in addition to the results of a user study demonstrating the applicability and limitations of the proposed method.
I. Parametric Modeling and Systems in Design

Parametric CAD systems provide powerful modelling functions that are more flexible than their predecessors. They can reduce, if not eliminate, much of the effort required to regenerate design models during design exploration or when changes to design are desired. The system can quickly generate variations of the model by responding to parametric changes through propagating them to the associated elements in the model. Models can incorporate parametric dependencies on data such as design requirements that are not even part of the design solution but can be used to derive the design. These systems provide multi-level interaction with design models: in addition to direct-manipulation, designers can build and change the models using transaction sequences, scripting, and custom features [1]. Today's competitive design world leads designers to enhance their design ability [2]; and use of parametric systems is an important advantage for designers.

Although parametric systems have distinct potentials, they pose a number of challenges in the practice such as complexity of computational geometry, human-system interaction methods, and increasing scale in design models [3]. A related bottleneck caused by these challenges is observed during design that entails complex model building, analysis and evaluation. Complexity increases rapidly as the interdependencies between design elements grow. This may cause designers to not always be aware of the impact of changes introduced on one part of a design model to other parts of the model. Designers typically adjust a model, observe the effects of the change by switching between different views, and then assess the consequences of that change before selecting the next action. A decision to alter a parameter results in a change to the model, which in turn may lead to other decisions in changing other parameters or returning to an earlier state. Current parametric CAD systems fail to facilitate this process. This process is intense, tool-specific, and hinders particularly analysis-based decision-making.

At the task level, making changes to a model and observing the effects of those changes is hard to perform. Interaction with a design model in these systems is not tailored to aid the designer in controlling and perceiving the effects of change made to the model at the design-level. Comparison of design variations is discrete and manual: it requires the designers to manipulate models frequently while relying heavily on their memory to make comparison-based assessments. Functions provided in parametric CAD system can support change-control and visualization of change-effects to a limited degree and mainly through and on the original model. This is an inefficient approach for exploration as the original model is lost in the process that makes comparing current to previous states almost impossible.
There are various potential solutions for dealing with these challenges, one of which is increasing already complex functionality of these systems (the tool level); another one is to handle design-related changes in the human computer interface (the model-level), making the functions transparent. Both have justifiable reasons. In this study, we choose to work on developing a method that aims at enhancing the design modelling and analysis as design progresses at the model level. This is mainly because, every design model is unique and standard functions particularly for analysis can be limited in meeting unique analysis needs. Flexibility and custom control and visualization features are needed. By developing Visual Sensitivity Analysis method, called ViSA, we aim to formalize parametric model exploration by using such features independent from design and parametric system. The study uses visual analytics and sensitivity analysis approaches for achieving the following objectives:

- To augment designer’s control on changing parameters while maintaining a parametric design-model’s integrity
- To provide interactive visualization means that can focus on different aspects (perspectives) of the model under change for insight gaining.
- To provide continuous feedback to support a change-analyze cycle and to enhance design cognition, visual search, and decision-making.

The approach in ViSA differs from the conventional use of mathematical or statistical sensitivity analysis methods. It rather falls in the visual (or graphical) sensitivity methods category such that the sensitivity of the model is controlled and displayed visually to the designer through interactive representations, which could be of same or different type than the model itself. The designer can interact with the visualization and control parametric variations of the model simultaneously. The method adapts the Model-View-Controller paradigm from software engineering to decouple customizable control and visualization features in the design model, while providing interfaces between them through parametric associations.

The next section briefly presents the relevant research. Section 3 introduces the method from designer’s perspective. Section 4 presents a case study to demonstrate the structural and procedural aspects of the method. The conclusion section discusses the outcome of this study with our comments based on a qualitative user study and suggests future work.

2. Research in Parametric Modeling Systems and Design Exploration

We aim to enhance parametric CAD systems abilities in interactive change-control process in parametric CAD-based sensitivity analysis. Thus, this study spans in three major areas: parametric modeling, sensitivity analysis and visual analytics focusing on human-perception and interactive systems (Figure 1). The following discusses salient conceptual issues discussed in the literature that are relevant to our study.
2.1. Parametric Modelling, Design, and Visualization

Design Exploration Using Parametric Models

Research on design exploration has gained attention in recent years following the emergence of advanced parametric and constraint-based computational design systems [1, 4, 5]. Parametric design systems that support design generation are becoming a “source of inspiration” for designers [6] and are considered as tools for variable design representations [7]. These systems support creativity [8] by enabling designers in generating, managing, and organizing highly complex design models, particularly when the “beauty” and “efficiency” of the model is also desirable [6] (Figure 2). The forms created are technical solutions requiring using complex geometry solvers.

Katz [9] identifies the difference between non-parametric and parametric systems based on how they treat design rules and geometry. Parametric modelling systems are explicit in terms of the rules and constraints between components, while they are implicit in terms of the resultant model geometry. In non-parametric CAD systems, the designer must re-establish the design every time a change is made to the input variables. Parametric systems have behaviors that distinguish them from conventional design systems. Kolatan [6] lists these characteristics as “diversity”, “adaptability”, and “responsiveness”.

The behavior of models in such systems is analogous to the ‘rubber-band effect’: if the band is stretched from two ends, all the points on the band will respond to change, and as long as it is stretched, the band will keep its form. The geometric parameters on the model either trigger change, or are
modified to follow other dependency changes such that the model in its entirety is kept as a coherent structure by not losing its defined characteristics [10]. They allow creating a range of possible sketches of a single design model without the need to set up the models again from zero [4]. They also provide designers with the opportunity to model, generate and modify the dependence and variations of design solutions rapidly [1]; and to integrate phases of a design process. [11, 12]. In parametric design systems such as GenerativeComponents [10], the system is not only responsive but also adaptive to applied changes in real time.

Design Information, Geometries and Parametric Models

Designers make decisions using different types of information at each phase of the design. In the early design phases, decisions are often based on higher-level, abstract information as design requirements [13]. During solution generation, lower-level and spatial information is structured and used. Spatial information is represented in visual forms such as CAD models that describe and communicate design geometries. These are also means of exploring design alternatives.

It has become more common to use complex and irregular design geometries for creating objects in different design domains, such as architecture, aerospace, automotive, industrial product design, etc. [14] (Figures 3). There are various motivations for using such geometries; sometimes aesthetic and sometimes functional justifications can be stated. As the complexity of design solutions increases, the cost and time required to evaluate them becomes more pronounced. Designers may need to make different versions of the model several times, potentially from scratch, in order to compare one solution to another. Regardless of the motivation, designing objects with complex geometries requires computational support such as parametric modeling.

In parametric design systems, objects are ‘intelligent’. The ‘design intent’ captured in parametric associations helps designers explore, revisit...
earlier decisions and improve the relationships in every stage of design process [1]. Design models may help the designer to reveal and to compare the different design models in order to devise an improved design solution [7].

Although parametric models are one of the obvious solutions, the systems for creating parametric models are not currently equipped with necessary tools to directly support design-decision making. For example, comparison of design variations is modal and requires switching between views numerous times to observe and assess the effect of changes, which consequently imposes extra cognitive load on the designer. Given the complexity of design geometries, controlling the switch-observe-assess cycle hinders design exploration. The complexity of design model representation in this cycle should be reduced to set of less complex representations, which also results in reduction of the cognitive load [15]. Designers hence are in need of methods that enhance their perception in predicting the effects of alterations in the design model without changing the reference design model itself. This suggests that we need to add sensitivity analysis as a visual overlay to parametric modelling systems.

2.2. Sensitivity Analysis in Design

Sensitivity analysis is the process of measuring the effect of changing input variable values on the output of a [design] model [16, 17]. The term sensitivity in this study adapts Frey and Patil’s [18] definition: it is taken as the measure of change in one or more values of a parametric design model when any change is applied to its input parameters. Sensitivity analysis methods have been applied in a variety of different domains, e.g. in economics, engineering, physics, sociology, and medical decision-making [18]. Sensitivity analysis can be performed during any stage of design development [16] and can identify [17]:

- Significant parameters that contribute the most output variability.
- Insignificant parameters that can be held constant or eliminated during evaluation of a design model,
- Whether or not there is any interaction between parameters of a design model; and if so, which group of parameters interacts?

Parametric design models are typically complex. Small changes to the input parameters of a design model may result in hidden or unanticipated changes to other components of the design that may not be obvious at the outset. Sensitivity analysis in may help the designer “to perceive the behaviour of the design model, the coherence between parameters in the design model as well as interaction between them” [17]. It may also help them make design decisions, which are not only “the most important” task for designers, but also the most “difficult” ones [19].
Sensitivity Analysis Methods

Sensitivity analysis methods are studied from related perspectives: (a) based on application purpose and scope and (b) based on methodology used (Figure 4). The first classifies the purpose of screening, local and global effects. These methods are distinguished with the scope in which they focus on, i.e. applying change at either one input at a time or applying change to a number of inputs. They can methodologically adapt mathematical, statistical and graphical methods \[16, 17, 20\].

Sensitivity analysis methods are commonly selected with respect to different factors such as model characteristics, the computational time needed to evaluate the model, available resources and the objective of sensitivity analysis \[20\]. Screening is a useful qualitative sensitivity analysis method that is generally used in early stages of modelling when a large set of data must be examined. It is used when the number of important independent parameters—that have the potential in influencing the results of the analysis—is large \[16\]. The qualitative nature of this method is its disadvantage since this method cannot quantitatively list the significant inputs. The local sensitivity analysis intends to show the amount of effect that a relatively small change has on other parts of a model. In design, this means studying the rate of change in the model output by varying input variables one at a time. Unlike local methods that are commonly carried out by individually varying only one of the model inputs at a time, input parameters in the global models can be selected either individually or in a group with other input parameters. Global sensitivity is measured for the entire range of each input variable.

Mathematical methods analyze the sensitivity of model output for a few values of an input in its possible range or for a small perturbation. Although this method is a helpful means of screening the significant inputs in the models, it does not address the variance in the output due to the variance in the inputs. In mathematical sensitivity analysis, a model is expressed through a mathematical equation; this causes the analysis to be usually an expensive and time-consuming process \[16–19\]. Statistical methods are used to identify the effects of real-time interaction among several inputs in the model. One or more inputs can be varied at a time in.
the statistical method. Although, this method is widely used in engineering design it has some issues regarding applying it to the complex design models due to “computational and organizational” problems [21]. A graphical method uses graphs, charts or surfaces due to a change in the model input individually or as a supplementary method on top of the statistical and mathematical methods. An advantage of graphical methods for sensitivity analysis is its generality of application to a wide range of complex models [18]. However, in design interactive control the effects of input on the design model is needed; hence the approach to sensitivity analysis in this study differs from the conventional use of mathematical or statistical methods where the sensitivity is controlled and displayed by means of interactive visualizations.

**CAD-Based Sensitivity Analysis**

In parametric design, the parameterization incorporates geometric control points that are also used to create the design model as well as other input variables deriving design [22]. In sensitivity analysis, control point to apply change is selected if it controls the part of geometry that designer intended to change. Analysis generally computes the vector field resulting from a change on any of the control points or variables. The vector field determines the significance of the change, its location, magnitude, and direction.

In earlier CAD-based sensitivity analysis, CAD tools represented only the surface geometry and analysis included several steps. First, the sensitivity vector fields of points on the surface are calculated and then sensitivity vectors of interior points computed mathematically [21]. Visualization is an additional step usually performed outside of the model. However, new systems are capable of integrating routines such that, when changes occur they can perform complex sensitivity calculations and visualize changes hence support analysis. This feature enables designers to interactively apply changes and observe change effects as part of the design process.

A case study by Katz [9] shows how this can be achieved using different parameterization techniques. This study calculates the sensitivity of a building’s skin to the change in solar incidence angle. Parameters are defined in the program such that they iteratively control dia-grid proportions with regard to several aspects such as structural performance, area inside the building and desired aesthetical features (Figure 5).

In the systems such as GC, SolidWorks, Solid Edge and CATIA, designers are able to move control points and visualize changes in a real-time basis. However, implementing a desired sensitivity analysis scheme is not trivial. For example, although some CAD applications allow what-if scenarios to be embedded in the model, the original model is changed during the course of design and therefore the designer is unable to track the change effects. Additionally, they are weak in supporting, facilitating and visualizing sensitivity analysis directly. The bottlenecks are principally the result of
system functionality, complexity and uniqueness of designs, and the limitation of human visual cognitive systems. These bottlenecks include:

- No direct function for controlling change and change history.
- Altered original design model during analysis hence loss of reference data.
- Increasing complexity of local design decisions.
- Scale and resolution management task and limited screen space.
- Frequent shift in locus of attention on model and system (including UI).

This list is not exhaustive and among these, the most challenging are those related to human cognitive and perceptual abilities.

2.3. Visual Cognition and Visual Analytics

Visualization, Cognition and Design

Visual information augments human cognition and supports understanding of the model, to enhance the comprehension of the complex relation between model components and the effects of change on them [23, 24]. Visualization provides representations for concepts, and reveals relationships between concepts as spatial structures in design [25, 26]. During the interaction between (design) visualization and the user, three main loops occur (Figure 6) [27]. At the “low-level loop”, the designer interacts with objects by selecting and moving them using “eye-hand” coordination. At the “intermediate level loop, the exploration, navigation, and view refinement”,

![Figure 5. Façade of a building design analyzed comparing sun angle and surface normal as inputs and their effect on energy performance. The result visualized by color changes. Source: www.aecbytes.com/viewpoint/2007/issue_32.html; Accessed on: 18 October 2009](image)

![Figure 6. The navigation control loop; Source: Ware, 2004](image)
take place. The "higher-level loop" includes problem solving, where the observer forms hypotheses about (design) data and refines them through augmented visualization processes. These cycles are revised and replaced accordingly as new data are added.

In parametric-CAD, interaction adds a heavy load to the (visual) cognition when the intensity and frequency of the input-process-react cycle increases. For designers, complexity in the CAD system and design model can quickly cause this to happen, thereby hindering comparison-based decision making and sensitivity analysis during design. Design requires constant attention to the model while changing and observing the effects of a change. Analysis also entails frequent switches of attention from one representation to another, and navigation of the model following the change-observe-manipulate cycle.

**Limitations of Visual Cognitive Systems**

Literature reveals a number of limitations of the human-visual system that are relevant to our work. First, change blindness, which Rensink [28] describes as “the inability to notice changes that occur in clear view of the observer, even when these changes are large and the observer knows they will occur.” This limitation is highly probable in parametric design that consequently a designer may be unable to perceive global or local change effects. Second, visual-spatial working memory is limited [29]. When external visualization of a model is not capable of representing the difference between pre- and post-change information clearly, designers make use of their internal cognitive representations. However, these are not accurate due to limited visual-spatial working memory. In visual sensitivity analysis, change occurs dynamically and may or may not result in a directly observable outcome due to the magnitude or location of the change or the magnification of the view. Observing a dynamic change, as opposed to ‘intermittent’ changes [27], is restricted by the visual working memory’s capacity of tracking 4 to 5 objects at a time [30]. This impedes the recognition of important changes in a large model. Designers need to maintain perceptual continuity in the location and time of the elements being changed.

Because design models are typically complex, designers frequently manipulate the view, rotating, panning, filtering, and zooming the view camera to analyze where and what changed. At the task level, this manipulation of the view creates a challenge for the visual system in that it involves a rapid shift in the locus of attention and intensive visual scan and search to gain insight about the model’s behavior [31].

**Visual Analytics Approach**

The challenges can be addressed by employing visual analytics approach. Visual analytics provides methods that leverage human visual cognition by using “human-centered interactive” systems to support the process of decision-making [32]. Visual analytics methods define the process of task
performance by visualization means that their visual design principle can help
design models ("windows" in Ware’s terms) to reduce visual complexity by
limiting zooming and view manipulation [27]. We propose an approach that
utilizes multiple visualizations for parametric controls and views along the
parametric model, to be interacted with while analyzing sensitivity. Our
approach draws on visual analytics to provide guidance to the development
of these visualizations with the aim of improving task performance.


We propose a prototyping method to improve design decision-making
during sensitivity analysis of design and by utilizing visualization and control
support adapting visual analytics techniques. The goal of the method is
to enhance control of parameter on the design model when applying
parametric changes and enable analysis of the effect of changes focusing on
a particular aspect of the design. The method addresses how designers can
control the design during sensitivity analysis and improve the representation
of the design model under change. We first introduce the structural
organization of design models to which we apply the method followed
by our scheme for capturing design model preparation-change-evaluation
activities. We then describe in a set of activity diagrams to show the
activities in each of these phases.

3.1. Structural Composition for Change Analysis

In most parametric systems, ‘features’ are composed of geometric objects.
The parameters of these objects can be linked to existing objects to receive
input; or they can derive values of other parameters in other objects, which
can be called as ‘feature parameterization’. This capability enables creation
of reusable features that can interface with each other through their
constituent objects. The ViSA method we propose adapts a structural model
inspired from the Model-View-Controller (MVC) framework in software
design [33] and utilize ‘feature parameterization’. The intent of this approach
is to increase cohesion and decoupling of visualizations and controllers from
design model to be used during visual analysis such that the model contains
only design-relevant information while leaving control and visualization
independent (Figure 7). This enables the controllers and the change-effect
visualization to be modular and exchangeable.

![Figure 7. Structural model decouples model from view and controllers]
A controller is a geometric feature or graphical component that is not a part of the design model per se and may directly link with different parameters in the model. Controllers provide means to controlling precision, range, direction etc. Visualization features like controllers are geometric features or graphical components; their role here is to show changes by comparing the reference and target models, to filter and format change data as desired, and to make the effect of change visually determinable. The term ‘reference model’ in ViSA refers to the original design model in which sensitivity of some of its input(s) is of our main interests; and ‘target model’ refers to a clone of the reference model to which changes are applied. Examples of the structural components in ViSA is shown in a simple B-Spline curve model (Figure 8).

3.2. Process in ViSA for Change Analysis: Designer’s Perspective

ViSA comprises three distinct and iterative phases: model-controller preparation; visualization selection and setup; and analysis (Figure 9). According to the goals in the sensitivity analysis, in the first phase, the designer selects or creates control features, which are linked with the target model. A goal of creating target models is to keep the reference model intact during change and sensitivity analysis, and compare its changes to the reference model. The target model is created using the same input.
(e.g. geometric control points) as those of the reference model with the exception that their corresponding perturbed points in the control feature have replaced the original control points. Figure 10 shows a suggested activity sequence for accomplishing the first phase. Change in input(s) to the target model is controlled through a control feature. Applying change on a design model indents to simplify the interaction task and to increase the precision.

![Figure 10. Preparation phase activity diagrams with inputs and outputs from each activity](image)

In the second phase, visualization features are associated with associated with both reference and target models. Visualization features visually show the effects of applied change on the model and their selection depends on the designers' intent in representing the effects of change on the design (Figure 11). Visualization features can be used individually—as separate models—or located on the design model view. Their role is to continuously...
calculate the changes and visually inform the designer of sensitivity of the model to changes, i.e. display output from the model. The structure may include one or many control or visualization feature.

The analysis of a model is conducted through a change-analyze cycle comprising four distinct tasks: introduction of a change to the design model through the control feature, switching focus between interaction and visualization, observing, and assessing change effects (Figure 9). Through manipulating the controller, new changes are applied to the model. Simultaneously, the effects of these changes appear in the visualization features. Switching focus between control and visualization features enables the designers to observe and consequently assess the effects of the applied changes on the design model in a real time basis. ViSA suggests using various visualization and control features (Figure 12). These features can be selected from a precompiled set of features or can be defined by the designers. They can be defined geometrically or using routines that can generate them. The change-observe-assess cycle in analysis phase continues until insight gained about how the design model reacts to parametric changes.

4. Case Study: Elongation Control in the Components of a Meshed Surface

We experiment with how ViSA by working on case several studies including different design geometries at varying levels of complexity such as modular
area change on free-form structures, linear member changes in space frames, block shadow studies in planning, curve extraction from intersecting planes etc. The following case study demonstrates structural and procedural aspects of ViSA on a design of a quadrangular mesh surface for structures similar to shown in Figure 13a. The model quadrangular meshed nets is built on a B-Spline surface constructed using six poles (points $P_{01}$-$P_{06}$) then the surface used to create on its $uv$ space (Figure 13b). The goal here is to experiment with the sensitivity of the elongation of edges of the meshed net to the changes on the poles.

### 4.1. Control Feature: Angle-Length Control Feature

The goal is to move three of the control points of the surface and control and analyze the effect of the elongation changes on each of the linear members on the meshed net. Three Angle-Length controllers are attached to the poles defining the B-Spline surface (Figure 14a). An Angle-Length control feature consists of a circle $C$ and three points: the reference control point $P$, the perturbed point $TP$ and length controller point on circle $PL$ (Figure 14b). The reference control point is the centre of circle $C$ and
perturbed point is orbiting on this circle. Length controller point in this feature controls the radius of circle $C$. The perturbed point is used to control $T$ parameter along the circle in the domain $T \in [0, 1]$ and it refers to the proportional distance along the curve between the starting point and end point. The radius is in the domain $R \in [0, 1]$. It controls the unit displacement of the perturbed point.

Target Model as the clone of this surface replaces its poles with the perturbed points on the controllers. A target surface is implemented through applying individual deltas as well as $T$-values to change the position.

Figure 13. (a) Benjamin Schneider-TU-Wein; Quad Meshes in Architecture; Source: www.bentley.com. Accessed on: 14 November 2009; (b) the top view of model used in the case study

Figure 14. (a) Three control feature attached on the model (b) Angle-Length controller
of the perturbed points. Different target models are generated by changing delta and T-value of perturbed points.

4.2. Visualizing Sensitivity: Circular Indicators on Edges

The changes on the model are visualized using Circular-Indicator that shows the change of length of a linear object using circle on the object changed. The center of the circle is located at the middle of each line (Figure 15). The radius of the circle is calculated to incorporate scale or zoom factor in the view and calculated using the Eqn 1.

\[
r = k|l_0 - l_1|/10
\]

(Equation 1)

where \(l_0\) refers to the reference length for the component and \(l_1\) refers to the corresponding component length after change in target model. \(k\) is an externally chosen scale factor. Red color in the circle shows an increase in length and blue color decreased length.

4.3. Sensitivity Analysis as Control Points Change

The sensitivity of quadrangular meshes to changes in delta and T-value of incorporated three Angle-Length controllers is examined under various conditions. Figure 16 shows the effect of changing parameters T-value and delta of perturb points \(TP_{03}, TP_{04}\) and \(TP_{06}\). The color coded visualization aims to recognize which parts of the meshed model experiences more decrease or increase, instantly and continuously.

However, design models are complex in real life. The case studies we conducted included several more realistic design models, such as a model using similar 3D surface to this case study on which a feature of folded-planes in UV space is array-mapped (Figure 17). The folded-plane consists of a base polygon and six other polygons that are parametrically associated with the base polygon. The folded plane is arrayed on the surface following...
5. Summary and Conclusions

Switching to new generation of parametric CAD systems from traditional non-parametric CAD tools gives designers an opportunity to explore design

the method described in 'place holder design pattern' (Woodbury, 2007). The resulting model is similar to space-frame structures covering large spaces like stadiums, museums, and train stations. The analysis enabled using a complex visualization feature as frequency distribution of a series of range of element lengths on a histogram and as a separate view from the model.
variation without the need to rebuild the design model every time from scratch. When the complexity of the design models increases, the dependencies between components of model also become complicated. Although the new generation of parametric CAD system can improve designers’ performance, these systems create new challenges. The unclear relation between components of parametric design models, which requires frequently switching and manipulating the views to discover these relations while changing the components of the design model, makes for some difficulties in using these tools. In this study, we introduced ViSA as a complete farming for computing sensitivity analysis and applied cognitive techniques to answer designers’ need for a successful design. The method emphasizes visually analyses of the sensitivity of parametric design models by combining visual analytics techniques and sensitivity analysis methods. The method intends to formalize the change-control process on parametric design models with the main focus on how to augment designers’ cognition during sensitivity analysis of design models.

In addition to the case studies presented in this paper, we also conducted a qualitative study testing the methods structural, procedural,
and usefulness issues with real users, which details can be found in (Nahal 2010). The findings reveal that ViSA provides a logical means of interactively demonstrating the consequences of change on parametric design models. It represents an informative method, which can support designers in change-perception and insight gaining during investigating behaviour of the parametric design models. Utilizing ViSA can reduce designers' need to use external tools for analyzing sensitivity of the design model. Our findings have also shown that ViSA has the potential to be useful in controlling and predicting the behaviour of complex parametric design model. The structure of ViSA consists of intuitive and straightforward steps in creating both control and visualization features, as well as building target model during preparation, visualization and analysis phases. While ViSA method facilitates focusing on the behaviour of design models during change control and “what-if” scenarios, there are some concerns regarding the creation of the target model in the preparation phase. These concerns are compounded by the increasing complexity of the design model. As a partial solution to cloning the reference model, a deep-copy feature, which requires application-level programming, can be developed. Most of the parametric CAD tools come with an application programming interfaces (APIs) that enables such extension. Further study is needed to find a better solution in cloning the reference model. Another enhancement needed is improving the design of visualization and control features. As visual objects on design environment, they may be confusing or difficult to utilize. It also seems difficult to implement ViSA in complex design models, especially complex geometries that need occasional scripting and different mode of thinking. With regard to this problem, more research is needed to create “re-useable” and “modular” ViSA elements, which expected to reduce the difficulty. Therefore, more research and formal investigation needs to be carrying out to reveal the other aspects for improving the introduced ViSA method.

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