DISTRIBUTED AND COLLABORATIVE PRODUCT DESIGN CONCEPTS EVALUATION BY USING HETEROGENEOUS TERMINAL DEVICES

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ABSTRACT

It is common in engineering design practice for designers and engineers to evaluate design concepts to determine if the design solutions meet requirements. The common practice has been to use virtual models on visual display terminals and/or physical models to evaluate design concepts. The emerging heterogeneous terminal devices – including mobile terminal devices with miniature displays such as smartphones and tablet PCs - offer alternative ways of visualizing design concepts and of performing the evaluation tasks. In the work presented in this paper, we attempted to address the challenge of using handheld terminal devices with limited computational resources and miniature displays in design concepts evaluation. We propose a new distributed and collaborative product design concepts evaluation scheme in which the evaluation is performed based on virtual models and product data displayed on heterogeneous terminal devices, including handheld devices. This scheme consists of methods and mechanisms that help to sync the needs of the evaluation task at hand with the available computational resources and display specifications. A practical example is used to demonstrate the applicability of the proposed product design concept evaluation scheme and how it can be used in practice. The major contribution of the reported work was creation of novel high-level model pre-processing algorithmic procedures for adapting product models to meet the evaluation task requirements and terminal device resource constraints.

INTRODUCTION

Computing surrounds us: in our homes, in our workplaces, and almost everywhere. Today, heterogeneous terminal devices (such as desktop computers, laptop computers, smartphones and tablet PCs) provide platforms and means of communication, offer means of accessing healthcare services, serve as way-finding tools, provide important information for daily life (such as travel information, weather information and news) and are even used as tools in performing certain professional activities. Engineers and designers working from distant geographical locations can take advantage of the capabilities provided by the emerging heterogeneous terminal devices and use these technologies in performing some of the product development activities (such as design concept evaluation) collaboratively. Today, handheld terminal devices are typically equipped with multiple input means (such as touch screen, touchpad, stylus, microphone for voice input, and keyboard), which allow users to interact with product data and virtual objects. These devices also have built in memory and powerful-enough CPUs/GPUs capable of handling complex computations and the amounts of product data needed in certain product development tasks. One of the product development activities that can successfully be conducted collaboratively even from remote distant locations by using heterogeneous terminal devices and networks is design concepts evaluation. Interactive product data visualization is central for the success of the design concepts evaluation processes.

Evaluation is defined as systematic determination of merit, worth, and significance of something against a set of rules or formally defined criteria - see e.g., [1]. In this article, the term ‘design concept evaluation’ refers to a complex multi-criteria decision-making process which determines whether or not the requirements are being met as the design process progresses. Design concept evaluation provides feedback to the sub processes of the design process and therefore contributes greatly to quality assurance of the in-process deliverables of the design processes and sub-processes - ranging from initial customer needs to the final product design concepts. It relies on a wide variety of information (which is typically derived from
large amounts of data) and it also depends on the expert judgments, which may sometimes be imprecise, uncertain and subjective – see e.g., [2-4]. Design concepts evaluation is often conducted continuously within the design interval and each evaluation is considered to be an important milestone and decision point in the product development process – see e.g., [2]. In many design concepts evaluation undertakings, subjects are often required to respond to several questions that help in exploring whether or not the design aspects have been addressed sufficiently. These include questions that; explore the correctness of materials choice (e.g., Has the designer been satisfied with the choice of materials? Would it be necessary to make further adjustments next time?); investigate the aesthetics aspects (such as: Is the color scheme set as was expected? What alterations could be made? Does the solution have the right shape and appearance?); explore manufacturing and manufacturability aspect (such as: Are the techniques to be used to make the solution available or would it be possible to use a different range of manufacturing techniques? Would it be easy to set up a production line for the manufacture of the eventual product? To what extent this would influence the cost of manufacture? Can the specified surface quality and tolerances be realized? Would the project take too long to make?); investigate safety aspects (such as: Is the proposed design solution safe? Could it be made even safer?), explore the ergonomics of the design (e.g., Does the design solution have the right dimensions? Can it still be made even more ergonomically friendlier?, evaluate functionality (e.g., Would the design solution function? What changes are required for the solution to function better?), and seek general opinions on the overall design (such as: What does the subject think of the overall design? What further changes could be made?)

Just as physical prototypes (produced by using techniques such as Laminated Object Manufacturing, 3D Printing, Selective laser sintering, Fused Deposition Modeling and Stereolithography) are used in the evaluation of design concepts or use processes, virtual objects (displayed either on computer screens such as flat panel displays or through special stereoscopic displays such as head mounted displays) can also be used in the evaluation of concepts or use processes. For instance, virtual objects can be replicated or learned from, and can play central role in design evaluation. Virtual prototypes can also capture the intended design aesthetics and simulate the appearance, color and surface textures of the envisioned product. And apart from design concept evaluation, virtual models can also be used in other applications such as in market research and executive reviews.

Several design evaluation frameworks have been proposed in the literature. These include the distributed object-based modeling and evaluation (DOME) framework [5] proposed for modeling and evaluation of product design problems in a computer network-oriented design environment and provides the ability to rapidly construct integrated design problem models; and the design decision making framework proposed in [6], which provides a theoretical evaluation framework that allows users to make sense of past research and consequently give shape and structure to future developments. Furthermore, Geng et al. [2] proposed an integrated design concept evaluation approach based on vague sets, in which design concept evaluation problem is solved from customer-requirement and design requirement perspective. Yoon et al., [7] proposed an evaluation method and a model for designing product-service systems, which considers several subjects (i.e., providers or customers) related aspects such as the macro effect, economic feasibility, technological feasibility, political and legal feasibility, relationship to other service providers or customers, the expected value, possibility of acceptance and preferred applications of service or product. In addition, there are also some design concept evaluation frameworks that have been created specifically for evaluation of certain specific aspects of design. These include, for instance, frameworks for evaluating: behavioral performances - e.g., [8]; perceived value of products from emotional perspectives – [1]; disassemblability [9]; product form design [10]; assembly plans [11] and for evaluating usability [12].

We argue that heterogeneous terminal devices (including handheld terminal devices) and networks can also play central roles in supporting collaborative design concept evaluation. There are, however, several challenges that must be addressed, including the operability challenges. To this end, product information contents must be adapted to simultaneously meet heterogeneous terminal device and network constraints, user preferences, and the design evaluation task requirements. This paper concentrates on the investigation of the possibility of using heterogeneous terminal devices and networks in collaborative design concept evaluation. The focus is specifically on content adaptation across terminal devices. It explores how the adaptation mechanism should be like and what new features would be needed in adapting product information content for sharing across heterogeneous terminal devices (including handheld terminal devices) and for use in the evaluation of product design concepts. It also proposes measures that should be taken to effectively take advantage of the capabilities provided by these devices to enhance collaborative product development. We first briefly review and analyze relevant technologies and approaches, and describes the research problem in the following section.

A CONCISE REVIEW AND ANALYSIS

The ability to access and to share product information content across heterogeneous terminal devices is an important aspect in communicating product information and in collaborative evaluation of design concepts remotely by using these devices. Internet is arguably the widely used communication and information sharing means. Accessibility of information within the Internet – including, e.g., visual information content - requires that the content must be
represented in a certain form or must be transformed into a form acceptable to all terminal devices in a network. Most of the existing web-based tools have been developed using Java script while in the past two decades, most user interfaces have been developed by using various programming environments such as HTML, Java Applets, ActiveX, VRML; Prolog and Common Lisp. And the commonly used formats for online information contents are HTML, XML and SGML. As for product data handling and remote use of applications via heterogeneous networked terminal devices, one of the key challenges that have been dealt with in many publications is how to adapt content to meet both the device constraints and user preferences.

Content, which in some instances can often be in various modalities (such as images, audio and text), may not always be in the forms acceptable for sharing via the Internet or readily suitable for visualization by using all heterogeneous computing and communication devices. Various techniques for adapting content (e.g., image features, sizes, etc.) by, for instance, prioritizing features, manipulating dimensions or dimensionality (e.g., reducing, embedding, or sub-setting), representing model in different resolution levels, or by getting rid of unnecessary model details, are available. Overall, there are already several experimental and commercial implementations of content adaptation algorithms used in various applications such as in converting audio or graphic images. Some of these conversion algorithms can be adopted and used in adapting product information content for product design evaluation tasks. However, challenges such exchanging complex product data generated by dissimilar systems, handling of context of content across heterogeneous terminal devices, dealing with varying requirements of organizations, dealing with restrictions on access to proprietary database information, and visualizing information across dissimilar hardware and platforms are still out there and need to be addressed.

Various techniques are presently used in sharing and exchanging contents remotely. With constantly improving mobile communication handheld hardware devices, operating systems and networking technologies; one can claim that the infrastructure and means of sharing and exchanging product information contents across heterogeneous terminal devices (including handheld devices) for use in applications such as design concept evaluation are virtually already in place. These include several IP-based tools such as web browsers and file transfer applications widely used for accessing data remotely. Most of the existing IP-based tools widely used for information exchange use techniques such as JDBC, JSQL and ODBC in sharing information over the web and for integrating databases - see e.g., [13-14].

Downsizing the amounts of data to meet terminal device and network constraints is an important consideration in adapting product information content. Data can be reduced in several different ways such as through abstraction [15]; clustering [15-16]; summarization [17]; vector quantization [18]; and axis reconfiguration [19]. Additionally, concepts and approaches such as image pyramids representation [20-21]; simplification envelopes [22]; vertex decimation [23]; and wavelet surface [24] can also be applied in reducing the amount of data. However, one of the main problems with most of existing model data downsizing methods is that they sometimes fail to copy, represent or reflect the real nature of the data and context of information.

In light of the above discussion, it can be said that, with the availability of a wide spectrum of improved mobile/wireless networking technologies – coupled with increased network bandwidth and enhanced software for mobile data-communication, most of the key infrastructural resources needed in building an early prototype (e.g., for validating the idea of using heterogeneous devices and networks in product design concepts evaluation) are available, literally. The main challenge we faced and dealt with in this work, however, was that of developing suitable mechanisms for assuring that product information is communicated and shared across heterogeneous terminal devices in the context of the evaluation task at hand.

NEEDS ANALYSIS AND A POSSIBLE WAY FORWARD

The emerging heterogeneous terminal devices and networks can greatly influence and may even change the way design concepts evaluation is conducted. The needs and some basic requirements to formulate a generic scheme for using heterogeneous terminal devices (including handheld terminal devices) and networks in design concepts evaluation can be identified through traditional techniques such as needs analysis and brainstorming. The most important ones include the need for mechanisms for: (a) selecting appropriate way of representation or the right modality; (b) assessing resource requirements; (c) reducing the amounts of data to meet resource limitations; and for (d) handling various aspects of content adaptation (such as context and meaning).

Handling of large amounts of product data in particular is a mammoth challenge. Various terminal devices and networks often have limited capabilities. Content containing large amounts of data cannot readily be handled e.g., by terminal devices with inferior computational capabilities or transmitted across networks. In order to come up with a comprehensive adaptation technique, several other challenges also need to be addressed, including the challenge of sensibly managing the reduction of data or image details in the product model while ensuring that the reduction of the amounts product data or image details do not change the meaning or context of the content. There is also always the chance that adaptation approaches such as those involving changing layout, summarization of information content or removal of geometry or features in the product model may sometimes seriously distort the meaning of the content. Furthermore, design concept evaluation is a complex task in which designers and engineers typically use various kinds of data and represent the product data differently (e.g., as hand sketches, 3D CAD models, orthographic CAD models, etc.) within the design interval. Therefore, apart from standard multimedia contents (such as
graphic images, audio etc.), various genres of engineering design visual representations such as 3D CAD product models, orthographic CAD models, hand sketches, tables and charts. would also need to be adapted. The envisioned content adaptation technique should be able to support adaption all these kinds of visual representations of product data to meet the design concept evaluation process needs, should allow sharing and transmission across heterogeneous terminal devices, and should ensure homogeneity of the meaning and of the context of content across various terminal devices.

THE PROPOSED CONTENT ADAPTATION SCHEME FOR DESIGN CONCEPTS EVALUATION

We propose a new content adaptation scheme (depicted in Fig. 1) for supporting designers and engineers in performing design evaluation tasks by using heterogeneous terminal devices and networks in this Section. The scheme is based on the observation that various types of product data can typically be represented in different ways (e.g., in text form, as a 2D model, 2.5D model, 3D wireframe model, 3D surface model, 3D solid product model, 3D tessellated model, 3D tessellated animation or as a 2D vector representation) and used differently as the basis for evaluation of different design aspects (such as ergonomics, aesthetics, functionality, manufacturability, usability and cost). The scheme also hinges on the observation and the understanding that certain forms of content representations may be more suitable for evaluation of certain design aspects, and may at the same time be unsuitable for evaluation of other aspects. Furthermore, there is also a perception that a product model can be scaled down (e.g., resolution reduced, some features removed, reduced in size, etc.) or represented differently (e.g., with less number of polygons), and still adequately represent the product (i.e., in a way suitable for evaluation of design aspects such as ergonomics, aesthetics, etc.).

The starting point in using the proposed scheme is a fully developed design concept. The design concept has to be fully developed and has to be translated into a digital representation (e.g., in the form of 2D or 3D sketch, 2D, 2.5D or 3D CAD model, text, video image, etc.). The proposed design concept evaluation scheme also calls for design aspects to be dealt with one at a time. Therefore, the design aspect in question (i.e., under evaluation) must be specified first. Then, two analyses need to be carried out, namely (a) the product data must be analyzed to determine the best way to represent the product and the amount of data the representation will contain; and (b) terminal device and network resources must be analyzed to determine their capabilities. The analysis results are then evaluated to determine if the constructed product model representation meet terminal device and network resource constraints. If it meets the constraints, then the content (i.e., 3D product model, text, etc.) can then be processed (i.e., by using the terminal device in question, e.g., a tablet PC, smartphone, desktop PC, etc.) and transmitted or shared (across heterogeneous terminal devices) and subsequently applied in the evaluation processes.

![Figure 1. THE PROPOSED CONTENT ADAPTATION SCHEME FOR DESIGN CONCEPT EVALUATION.](image-url)
Otherwise, a different way of representing product concept can be selected and the above mentioned steps repeated. If the overall evaluation results are unsatisfactory in the opinion of the designers or engineers, then the feedback loop – see Fig. 1 (which entails redesigning of the product to ensure that the requirements that describe the aspect in question are fulfilled) can be pursued to help improve the product concept. As for choosing the way to represent the product data, advances in

### (a) Choosing the best way to represent product data

- **Initialize-Representation**
  - Call a full model representation
- **Compile components breakdown**
  - Set geometric-data <- Product Description (3D, 2.5D, orthogonal views, etc.)
  - Set non-geometric-data <- Non-geometric-Data (materials, surface finish, manufacturing constraints, etc.)
  - Determine the amounts of data in the model
    - AmountOfData = (Geometric data) + (Non-geometric-data)
- **Return results**
  - Return, geometric-data, non-geometric-data, AmountOfData

### (b) Device and network resource assessment

- **Initialize-ResourceAssessment**
  - Call device and network type
  - Identify device and network resources
  - Terminal-device-resources <- Terminal-Device-Limitations = {memory, CPU, display size, etc.}
  - Network-resources <- Network-Resources = {bandwidth, bitrates, etc.}
- **Compile resource limitations**
  - resource-limitations <- {terminal-device-resources, Non-Network-Resources}
- **Return results**
  - Return, resource-limitations

### (c) Decision making

- **Initialize-Decision**
  - Set user-preferences <- {modality, format, interaction, personal characteristics, etc.}
  - Set resource-limitations
  - Determine the amounts of data in the model
    - AmountOfData = resource limitations
- **Proceed with the product model as it is?**
  - If (AmountOfData > resource limitations ) then Adapt (i.e. No)
  - If AmountOfData < resource limitations then Proceed (i.e. Yes)
- **Return results**
  - Return decision

### (d) Adaptation

- **Initialize-Adjust**
  - Set user-preferences <- {modality, format, interaction, personal characteristics, etc.}
  - Set resource-limitations
  - Determine the amounts of data in the model
    - AmountOfData = resource limitations
- **Maximize** (AmountOfData, user-preferences) Subject to (resource-limitations)
- **Adaptation-recommendation <- max-possible-data&preferences**
  - {NewAmountOfData, Selected-user-preferences}
- **Return results**
  - Return, Adaptation-recommendation

### (e) Evaluation product model construction

- **Initialize-Construct**
  - Set relevant-geometric-data
  - Set relevant-non-geometric-data
  - Set selected-user-preferences
  - Set resource-limitations
- **Build the evaluation model**
  - Maximize selected-(geometric-data, non-geometric-data, user-preferences) Subject to (resource-limitations)
  - Evaluation-model <- {selected-geometric-data U selected-non-geometric-data U selected-user-preferences}
- **Return results**
  - Return, Evaluation-model

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Figure 2. VISUAL PRODUCT INFORMATION CONTENT PRE-PROCESSING
computing have enabled objects to be represented in a variety of ways. Common representations used in design engineering practices include: (a) two dimensional (2D) representation (or planar representation), (b) two and half (2.5 D) representation (or planar with depth or thickness information), and; (c) three-dimensional (3D) representations. The process of choosing the best way to represent product data – see Fig. 2 (a) - involves carrying out an inventory of the components in the product model and compiling a full components breakdown showing the components and the amounts of data arising from them. It should be noted here that a representation of a product in any form is in some sense a product model in that it contains product data. An engineering product representation typically consists of: (a) geometric data, e.g., 3D CAD models or product definition in terms of orthogonal views according to some conventions, etc., and (b) non-geometric data, which for instance includes materials, surface finish and production process information.

The resources assessment algorithmic procedure (Fig. 2 b) analyses terminal device and network resources and inspects if the terminal device in question can handle (i.e., process and display) the amount of data in the product model. This is done with the view to uncover in advance if the terminal devices would actually perform satisfactorily, e.g., process product data fast enough, etc. The resource requirements, which essentially describe whether or not the terminal device can handle product data, should be known before the decision on whether or not to adapt a product model is made. The resources in question include memory, CPU capability and display size while the most important network resource is bandwidth. The algorithmic procedure shown in Fig. 2 (b) returns the terminal device and network capabilities. Having chosen the best way to represent product data (Fig. 2 a) and determined terminal device and network resource requirements (Fig. 2 b), the decision making process on whether or not to adapt the model (e.g., change modality, change format, etc.) follows (Fig. 2 c). Then the adaptation algorithmic procedure shown in Fig. 2 (d) follows, and as indicated; and user preferences such as modality preferences, format preferences and personal characteristics (e.g., vision limitations, etc.) are then taken into consideration as well. This adaptation algorithm is essentially an institutionalization of a multi-objective problem formulation with the view to accommodate both the product data and the terminal device and network resource constraints whilst fulfilling user preferences. As indicated, the outputs of the previously described algorithms – along with user preferences, are the inputs to this algorithm. It returns some adaptation recommendations, which if implemented, would help, e.g., reduce the amounts of model data to the acceptable levels, adapt model representation modality, or reduce image dimensions or details whilst meeting user preferences and maximizing quality of service offered.

A product model representation that would be used in the evaluation of the design aspect in question (e.g., ergonomics, aesthetics, manufacturability, functionality, etc.) can then be built based on the outcomes of the previously described algorithms. As shown in Fig. 2 (e), the evaluation model construction algorithm uses only the relevant geometric data (i.e., data contained in assemblies, subassemblies or parts required in the evaluation of the aspect at hand) and non-geometric data (e.g., surface finish, color, form, materials information, etc.) needed in performing the evaluation of a particular aspect; and take into consideration only the identified user preferences in model building.

**ILLUSTRATION**

In this section, we illustrate, by using practical examples; how the proposed heterogeneous terminal devices-based design concepts evaluation scheme (shown in Fig. 1) works in practice. Figure 3 shows the products we selected and used to demonstrate the applicability of our working theory and of the proposed solutions. Virtual models of these selected products can be represented in different ways (e.g., in different presentation styles or layouts, with or without colors, etc.) and in different modality (e.g., as a full product model – such as a SolidWorks model, as a video images, etc.). Each of these ways of representing product data uses certain specific mechanisms in them that allow data to be processed and stored differently.

<table>
<thead>
<tr>
<th>Modality</th>
<th>Description</th>
<th>Product 1 (Knife) [Memory in MB]</th>
<th>Product 2 (Boring machine) [Memory in MB]</th>
<th>Product 3 (Electric mixer) [Memory in MB]</th>
<th>Product 4 (Office Chair) [Memory in MB]</th>
<th>Potential applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAD (SolidWorks) Model</td>
<td>Complete description of the product. Include both geometric and non-geometric data.</td>
<td>17.7</td>
<td>40.7</td>
<td>21.2</td>
<td>3.46</td>
<td>All design engineering tasks</td>
</tr>
<tr>
<td>Picture JPEG</td>
<td>Pixelized images. Good quality images. Could be attached to emails on the web. Include neither geometric nor non-geometric data.</td>
<td>0.0155</td>
<td>0.0257</td>
<td>0.0338</td>
<td>0.0167</td>
<td>Evaluation of aesthetics, components layout; concepts evaluation and selection</td>
</tr>
<tr>
<td>Picture GIF</td>
<td>Pixelized images. Relatively low quality images. Could be attached to emails and on the web. Include neither geometric nor non-geometric data.</td>
<td>0.0099</td>
<td>0.0163</td>
<td>0.0421</td>
<td>0.0151</td>
<td>Evaluation of aesthetics, components layout; concepts evaluation and selection</td>
</tr>
</tbody>
</table>
The proposed algorithmic procedures aim to pre-process the product data in advance and to generate product models that meet both different terminal device constraints and task requirements. The idea is to have the product information content prepared beforehand in different ways of representation that satisfy various device specifications as well as the evaluation task requirements. And for a given evaluation task, only the portion of the product data required in constructing a suitable product model needed to support the designers and engineers in performing the task at hand would be delivered (and the client terminal device would subsequently render that product model based on this data).

To illustrate that the resource requirements for various representations (that may be used, e.g., to serve the same purpose) differ significantly, the designs of the four selected products (see Fig. 3) were represented in three different ways; namely as: full product models (i.e., as SolidWorks models), as JPEG pictures (which are good quality images that could be used on PCs, e.g., as email attachments or on the web), and as GIF pictures (which are essentially simpler images with relatively lower quality, which however could also be used on PCs, e.g., as email attachments or on the web). The resource requirements for these different modalities of product representations were recorded as shown in Tab.1, and the values were plotted and compared as shown in Fig. 4.

In general terms, it can be seen that there were significant reductions in terminal device resource requirements for various modalities. Although the memory resource requirements in all cases decreased by over 99% by changing modalities (i.e., by transforming SolidWorks models into GIF or JPEG image coding formats), these representations were still good enough for use in the evaluation of certain aspects of the product design such as aesthetics, layout or assemblability of components. In all cases, the actual memory resource requirements dropped significantly to the levels that met even the resource constraints of some of the low performance handheld terminal devices such as smartphones and tablet PCs. Some of these representations could therefore be exchanged electronically - e.g., as email attachments, published on the Web, or kept in a server and downloaded fast enough even by using terminal devices with inferior computational capabilities.

DISCUSSION

Many content adaptation techniques have been proposed in the literature. Most of the existing techniques focus more on adaptation of web page contents (with texts, audio, pictures and/or video images) represented by using techniques such as HTML and WML - see e.g., [25]. These methods can be applied in adapting contents rendered by various web-browser applications including e-entertainment and e-business/e-commerce applications. The techniques used in content adaptation often involve, for instance, changing layout of contents, changing formats of contents to satisfying different device specifications or detecting the device and adapting the content by, e.g., reducing the amounts of data to meet device requirements.
constraints. These techniques may sometimes alter the contexts of the contents. Also, strategies such as summarization and geometry culling may sometimes generate content that might not be suitable for supporting designers and engineers in performing certain design concept evaluation tasks. Performing engineering design tasks such as design concept evaluation collaboratively from remote distant locations by using heterogeneous terminal devices requires that the context of the product information content must be the same across all terminal devices used by the members of the design team. A content adaptation procedure that meets these sorts of design concept evaluation needs has therefore been proposed. It is based on a simple principle that only the product data needed in a particular design evaluation task should be included in the product model.

It has been demonstrated that product models can be adapted to meet certain specific needs and the amount of data can also be reduced to meet certain device constraints such as memory requirements. The proposed heterogeneous terminal device-based design evaluation scheme allows users to represent product data in a way that would facilitate the evaluation of various design aspects such as aesthetics, manufacturability and ergonomics. The principal idea is to lower the amount of data in the product model to meet terminal device constraints while keeping the model suitable for the design concept evaluation task at hand. It is essential to mention that in practice, apart from 3D or 2D virtual CAD models, designers often use product data represented in other different ways, e.g., as pictures or video images, unstructured data, and structured data (such as tables & charts) in performing design tasks. Special representations such as 3D tessellated models, 3D tessellated animations and 2D vector representations are also used in some instances. Furthermore, the proposed approach also attempts to address other challenges faced in design concept evaluation such as the challenge of preserving the meaning of content and handling of large amounts of data. The later challenge is important because most product information contents typically consist of large amounts of data that may not readily be handled by certain terminal devices, e.g., those with limited computational capabilities. It should be noted, however, that any adaptation that involves reduction of data in the product model can change the meaning of the content and may also make the content not able to meet certain user preferences (e.g., personal characteristics, modality preferences, etc.).

It is also important to recognize that different types of terminal devices are often equipped with different kinds of input means. Therefore, apart from adaptation of product data, there may also be the need to adapt input means to meet various terminal device constraints or user preferences (e.g., interaction preferences during design concept evaluation). These issues are the subjects of the ongoing and future research.

CONCLUSIONS AND FUTURE WORKS

The possibility of using heterogeneous terminal devices (including handheld terminal devices) in design concepts evaluation has been investigated. The challenges faced in using these technologies in supporting designers and engineers in performing design concept evaluation tasks remotely have been identified and a scheme for evaluation of design concepts that takes into consideration the needs of the evaluation process and the constraints imposed by terminal device and network has been proposed. The main contribution in this work was creation of new formal algorithmic procedures for model and product data pre-processing. These includes algorithmic procedures for selecting ways of representing the product model, inspecting terminal device and network resources in advance, supporting decision making, tailoring and adapting the product model based on specific user-defined choices and preferences, and for constructing appropriate product model for the evaluation task at hand. The applicability of these procedures in real-world has been illustrated by using a practical application example. The proposed solutions contribute to addressing the problem of adapting product information content (e.g., product models in the form of CAD models) to meet certain specific device constraints and the needs of the design concept evaluation process. The proposed scheme allows transmission of the relevant product data only (e.g., product data needed in performing certain particular design concept evaluation task such as ergonomics or aesthetics review) across heterogeneous devices (including handheld terminal devices with inferior capabilities). This helps to reduce the resource requirements, allows sharing of product data across heterogeneous terminal devices, and facilitates remote design concepts evaluation and collaboration in design teams. Future work includes (i) implementation of the developed algorithms in the form of a suite of integrated software tools, and (ii) real-world validation of the applicability of the proposed algorithmic procedures.

REFERENCES


