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The challenges in computer supported conceptual engineering design

Tijana Vuletic[a,*], Alex Duffy[a], Laura Hay[a], Chris McTeague[a], Laura Pidgeon[b], Madeleine Grealy[b]

[a] Department of Design Manufacture Engineering Management, University of Strathclyde, Level 7, James Weir Building, 75 Montrose Street, G1 1XJ, United Kingdom
[b] Glasgow School of Psychological Sciences & Health, University of Strathclyde, 6th floor, Graham Hills Building, 40 George Street, Glasgow, G1 1QE, United Kingdom

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ABSTRACT

Computer Aided Engineering Design (CAED) supports the engineering design process during the detail design, but it is not commonly used in the conceptual design stage. This article explores through literature why this is and how the engineering design research community is responding through the development of new conceptual CAED systems and HCI (Human Computer Interface) prototypes. First the requirements and challenges for future conceptual CAED and HCI solutions to better support conceptual design are explored and categorised. Then the prototypes developed in both areas, since 2000, are discussed. Characteristics already considered and those required for future development of CAED systems and HCIs are proposed and discussed, one of the key ones being experience. The prototypes reviewed offer innovative solutions, but only address selected requirements of conceptual design, and are thus unlikely to not provide a solution which would fit the wider needs of the engineering design industry. More importantly, while the majority of prototypes show promising results they are of low maturity and require further development.

Contents

* Corresponding author.
E-mail address: tijana.vuletic@strath.ac.uk (T. Vuletic).

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1. Introduction

Current Computer Aided Engineering Design (CAED) tools are continually improving and those widely used for engineering design and manufacture in industry now successfully support and interlink detailed design, analysis, simulation and manufacturing [20,21]. Conceptual design is not typically performed in industry using CAED systems, and it is often claimed that this is due to a lack of support for conceptual design built into commercially used CAED systems [75]. Horváth [29] finds that academic research on conceptual CAED has not been adopted by the industry, which is still happier to pay a designer to perform a conceptual design the way they find the most appropriate, than to invest in adoption of a more systemic solution. This paper reports a literature review exploring the reasons behind why current CAED systems are not used for conceptual design, what are the developments for conceptual CAED concerning human computer interface and software, and what the requirements and challenges for future conceptual CAED system development might be.

During the conceptual design stage, the design is changing frequently and evolving [82], and the focus on detail is not as necessary as the need to generate and manipulate ideas quickly [20]. Designers create initial solutions, then modify or combine them and create concept variants to match the design requirements, placed on the product by either customers or the context of the product being designed [51,81]. Modelling using commercial 3D CAED systems requires concrete, precise and quantitative "design information as an input that is often not available at the conceptual design stage" [82]. At that stage specifications and constraints are often not fully established [32]. Designer's "attention is focused on the overall appearance of the model, and the exact dimensions, positions, tolerances, etc. are dealt with at later design stages" [65]. Design concepts are inherently uncertain and incomplete [72], and it is this ambiguity that can contribute to the development of design, often called design emergence [18]. This is why keeping design ideas vague, incomplete and sometimes even irrational, until they are sufficiently developed, is important during conceptual design [11,51]. CAED systems currently in use do not support intensive manipulation of graphical data to the degree required to enable this [1,66].

Although a CAED system can be used for most design stages, the designer needs to adapt to the CAED system [31]. Complex interfaces used to interact with CAED systems are not suitable for early conceptual design [20], as they lack seamless transition between activities and intuitive modes of interaction [69]. The majority of commercially available CAED systems have a menu based WIMP (Window Icons Menus Pointer) interface [65,82]. A WIMP interface requires extensive, often professional, training, due to the number of tools and procedures that need to be learned. A WIMP interface is referred to as traditional human computer interface in this paper. In terms of time, 3D CAED modelling has a steep learning curve and new users find the process of using the mouse and keyboard in a 2D plane to design in the 3D space tedious, lengthy and unintuitive [13,21,82]. Free-form spline modelling is used to design complex irregular shapes in CAED, and changes to splines require manipulation of splines via a large number of control vertices, which in spite of continuous development of CAED systems consumes large amounts of time and effort [34]. New mechanisms of interaction are required to make CAED systems easier to use [61]. They need to be intuitive and incorporate natural human actions [64,74,79]. Alternative human computer interface (HCI) solutions, such as gesture based interface, VR (Virtual Reality) supported interfaces, and haptic interfaces are now being considered to obtain faster communication between the user and CAED systems [17].

Technical aspects, architecture of the CAED systems and functionality of interfaces are important, but so are the characteristics of the users who interact with them, experience being a key characteristic. It has been established that experience was required in order for a user to successfully employ currently commercially used CAED systems [12]. More recent CAED systems are developed in academia with the aim of being quickly mastered regardless of experience levels of the users, however the majority of these are still in experimental stages [43,49]. During CAED interface development user experience is considered largely in the interface evaluation stage, potentially leading to user sourced requirements for conceptual design not being captured.

This review will focus on state-of-the-art research undertaken to improve underlying architecture, procedures and workflows of CAED systems developed by academic researchers to support conceptual design and better integrate it with detailed design, analysis, simulation and manufacturing; and specific interfaces developed to improve interaction between the human and computer. By reviewing the literature exploring these two topics, we aim to identify the latest developments in computational support for the conceptual design stage in engineering design, and identify envisaged challenges.

Characteristics of conceptual design, and benefits and drawbacks of use of CAED for conceptual design, identified in the literature, are given in Sections 3 and 4. Requirements for CAED and interface development identified in the literature are presented in Section 5. The review of the recent developments in conceptual CAED software prototypes and HCI interfaces are given in Sections 6 and 7, respectively. Then a discussion is provided in Section 8 and conclusion in Section 9.

2. Inclusion criteria

Only papers published post 2000 were included in this review, similarly to what Ferguson et al., 2014 did in their review, as the latest developments in technology and computing are a large contributor to the emerging CAED development for the conceptual design stage. While papers published before 2000 are just as likely to explore the topics this review is focusing on, the technology available to the authors would simply not be comparable, as the underlying computational technology has become both more powerful and less costly, and thus more attainable in the last 16 years.

Conceptual engineering design is the focus of the review, therefore major engineering databases were searched: Biotechnology and BioEngineering Abstracts (ProQuest), Compendex, Engineering Research Database (ProQuest), Science Direct, SCOPUS, Technology Research Database (ProQuest), and Web of Science.

To support the discussion behind the need for new conceptual CAED systems relevant papers discussing the related issues but not providing their own prototypes have also been reviewed. Papers