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A21 - SUMMARIES OF SOME SELECTED PAPERS FROM STREAMS 6

CAD TOOLS AND DESIGN FOR X AND MECHATRONICS

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The summary has three sections. Section 1 provides a brief abstract of each of the thirty one papers summarised. Section 2 provides a broad overview of the produce development stages, activities and applications on which the papers have focused, and the popular technologies used. Section 3 places the papers with respect to the stages of the design research methodology (DRM) developed by Blessing, Chakrabarti and Wallace [32].

1 *A Summary of the papers*

In the paper entitled “Towards an IT supported front end of product development” [1], Felix Nyffenegger et al. emphasise the importance of early product development stages for innovation. They stress that the front end of product development must be flexible and structured, and develop software tools that allow tailoring of a generic process to the requirements of a particular product definition project, and guide the user for configuration of a project specific process model.

In the paper “Joining standard and inventive design, application to injection moulding” [2], Eltzer et al. pick innovation as the key issue in global economy and engineering design as the main component of innovation. Inventive problem solving is risky as robust technical knowledge is absent, but innovation must be introduced. A design process is proposed that combines standard and inventive approaches, reusing known solutions for incremental problem solving or use TRIZ for radical innovation. The standard approach is used to gather knowledge for the inventive approach or to initiate system evolution together.

In their paper “The influence of billet processing on the mechanical properties of forged 6061 aluminium” [3], Leary and Burvill stress that in order to achieve higher goals of fuel economy, dynamic performance and emission, mass reduction is critical, and points to light alloys as a promising route to mass reduction. Since knowledge of processing light alloys and its consequences on the mechanical properties of the alloys unclear, they investigate this relationship and relate these to potential costs.

In their paper “Managing design alternatives: from the alternatives model towards an aided design system” [4], Nowak and Eynard take Ullman’s vision of the needs for an ‘ideal mechanical deign support system’ – the needs to manage product, process and alternatives data, and integrate between various kinds of information, and develop a support for designers to save, browse and reuse design information for mechanical engineering products.

In “Optimal spatial arrangement of shipbuilding blocks in the pre-erection area of shipyard” [5] Verghese and Yoon focus on spatial scheduling of building blocks in shipyard. Since there is little space in shipyards, optimal ways must be thought up for arranging building blocks. To achieve this, a spatial scheduler based on GA and Bottom-left algorithms is developed.

In their paper entitled “Principles for the development of a computer aided design tool” [6], Vargas-Hernandez and Shah developed a set of theoretical principles (criteria/goals) for creating computer aided conceptual design tools (i.e., what must be supported by any CACD tool), and implemented these into a CACD tool for designing electromechanical systems.

In a paper entitled “Introducing grid-based semi-autonomous evolutionary design systems” [7], Parmee et al. described the initial development of a problem solving environment that integrates data modelling and search, exploration and optimisation services located at different geographically distributed centres of expertise.

In their paper entitled “Integrating aesthetic criteria with a user-centric evolutionary system via a component-based design representation” [8], Machwe et al. discussed an interactive evolutionary design system using GA/agent based machine learning for supporting user evaluation and search/exploration for aesthetically pleasing, structurally feasible and cost effective designs in the domains of bridges, liquid containers and bench type steel furniture.

In “Towards an evolvable chromosome model for interactive computer design support” [9], Fan et al. pointed out that evolutionary design synthesis uses only few components and satisfy few requirements of the product – which is a limitation of the encoding used. They claim that the chromosome model of Domain theory encapsulates the most important parts and characteristics of designs, and propose to use this as the basis to create an interactive evolutionary design system for computer aided conceptual design.

In “Sensitivity as an assessment criterion for product spectra” [10], Maurer and Lindemann claim that current criteria for product structure analysis is applicable only to fully specified product constellations, and even though influence matrix is used for design planning to understand influences of critical elements of the plan on one another, to make it applicable for supporting product spectrum analysis, sensitivity must be added as an extension to existing criteria. This leads to identification of important elements in a product spectrum and elaboration of useful measures for its further development.

In a paper entitled “Experiments with a cameraphone aided design system” [11], Farrugia et al. point that since existing CAD systems are used mostly in later design stages while sketching is predominantly used for early embodiment. In order to combine the benefits of sketching with that of 3D modelling, various computer aided sketching tools are developed. However, this replaces that natural, portable and readily available paper medium. To alleviate this they propose a cameraphone based sketching system which allows designers to obtain visual representations of 3D geometric models from freehand sketches.

In their paper “Identifying requirements for rendering in conceptual design” [12], Tenneti and Duffy presents a study on aspects of rendering in conceptual design and their utility, showing that non-photo realistic rendering is used for better visualisation and communication, using fairly vague to very precise concepts. Also, absence of a sketchy look, lack of differentiation between essential and non-essential information and absence of exploring alternative solutions and inviting assumptions are found as most dissatisfying factors in current systems.

In “Human modelling benefits in workstation design” [13], Gauthier and Caron point out that human modelling - commonly used in aeronautical and automobile industries for design products and means of production – should be useful in other areas of design such as workstation design. The suitability of using human modelling in designing or modifying workstations is investigated using case studies. Results show that human modelling allows more rapid verification and communication of complex concepts.

In “Automatic design of a press brake for sheet metal bending” [14], Colombo et al. analyse the traditional design procedures of an SME for brake press design, and represent it using a knowledge based engineering development tool with a representation for product structure and design process for automated generation of 3D press brake virtual prototypes, 2D part drawings, and a bill of materials in conformity with standards of enterprise PDM.

In “Software architecture for flexible integration of simulation in the product development processes” [15], Hamri et al. maintain that behavioural simulation of structures for product assessment is widespread throughout the design process, implying the need for an ability to handle a diversity of configurations by the simulation software used. However, this is limited by the allowable time and cost to prepare the model. The have developed a software for this purpose, the architecture of which allows a wide range of models to be taken as input.

In their paper “Virtual synthesisers for mechanical gear systems” [16], Starling and Shea aim to enhance innovative design through the development of new computational synthesis tools, and point that aiding conceptual and embodiment design are essential but difficult. A simulation-driven synthesis method using a parallel grammar, geometry-based evaluation and multi-objective search is developed for this purpose and illustrated using gear-box problems.

In “Configuration synthesis of a variable complexity truss” [17], Antonsson et al. take as key challenge in engineering complex systems the ability to rapidly explore the range of possible solutions. This paper explores the use of genetic algorithms for designing structures for spacecraft. The basic GA is modified to include multiple levels of search to help reduce the threshold required to vary the topology of the structure. The method is validated and applied.

In a paper entitled “Sensitivity analysis: a priori and post facto” [18], Greiss et al. state that the use of sensitivity analysis allows key parameters that affect a system to be identified and remedial actions taken. The propose to use data mining analysis of manufacturing data for sensitivity analysis to be done post facto without requiring analytical modelling unlike that needed in an a priori sensitivity analysis. The work is validated by comparing results from the post facto analysis with reliable a priori analytical data.

In “Research study in support creativity software as tool to assist the conceptual design stage” [19], Chaur & Lloveras compare the role a series of creativity support software on enhancing creativity of designers during early stages of the design process. The creativity method alternatives (in software form) assessed are mind maps, brainstorming, TRIZ and Synectics, and the evaluation criteria used are creativity flexibility, fluidity, originality and elaboration.

In “Applying the new VDI design guideline 2206 on mechatronic systems controlled by a PLC” [20], Bathelt et al. emphasise the control, electrical and mechanical design aspects to be considered simultaneously through the deign process for mechatronic products – one that is provided by VDI guideline 2206. This work customises this guideline for designing PLC controlled mechatronic systems, and uses this in an industrial case study that shows promise.

In the paper entitled “Semantic web services for the knowledge based design of mechatronic systems” [21], Bludau and Welp view mechatronic systems design as complex and hence knowledge intensive, and current design support systems as relatively poor in supporting context sensitive retrieval and processing of design information. The objective of this paper is to present a generic platform for configuration and for offering high quality information to interdisciplinary design teams using semantic web.

In their paper “Analysis of 90 degree pop up structures for CAD systems” [22], Mak et al. focus on design of crafts (paper pop-up structures). These are traditionally prepared manually using trial and error. In recent years attempts are made to enable more efficient crafting methods on computer-aided platforms. This paper discusses properties of 90-degree pop up structures and the use of planar graphs in representing and designing them on CAD systems.

In “Model based design of actuation concepts: a support for domain allocation in mechatronics” [23], Jansen and Welp view the task of domain allocation (which function to be realised by which domain) as a major step in mechatronic systems design. This paper presents a methodical approach for developing mechatronic product concepts. A model-based method for domain allocation is developed by analysing current methods for conceptual design of mechatronic products.

In their paper entitled “A theory-based ontology of design induced error” [24], Shin et al. point the existence of errors and failures as an intrinsic part of engineered systems, leading to negative effects starting from frustration to catastrophic failures. The paper examines how it might be possible to assist designers in identifying potential sources of design-induced errors and to find solutions that can avoid the reference of these.

In “Applying design for manufacture and assembly techniques to large scale weldments produced in small volumes” [25], Stauffer and Smith identify that current design for manufacture and assembly techniques are not easy to apply to large-scale weldments produced in small volumes. However, the claim that the general approach is still valid and valuable for reducing assembly costs. A technique, and associated design strategies and guidelines are developed specifically for these types of products and parts.

In the paper “Don’t engineers care about occupational health and safety” [26], Broberg claims that even though engineering design is a strong determinant of usability and industrial ergonomics, engineers often do not take this into account into engineering projects. A survey to understand the significance of the engineering domain, job tasks, organisational position and industrial branch for engineers’ perception of their role and options in integrating ergonomics into engineering is discussed in this paper.

In “Ontology based transformation from an extended functional model to FMEA” [27] by Koji et al., it is found that conceptual design knowledge of functions of products and unintended phenomena are currently scattered in different forms; in order to promote sharing this knowledge, a knowledge transformation system, based on extended functional models to FMEA sheets using ontology engineering, is proposed.

In “Approach for integrated achievement of the cost target” [28], Nissl and Lindemann view target costing as a multidisciplinary process, and note that employees have difficulties relating their decisions to later product costs. The presented approach provides support for all departments involved in product development, These include data, methods and tools for component costing, help to visualise cost progression in value engineering, and integration of all associates into the value engineering process.

In the paper “Impact of virtual reality simulation tools on DFA and product development process” [29] by Mitchevitch et al., the advantages and disadvantages of using current assembly/disassembly simulation methods, particularly for complex systems with deformable parts, are presented. This, along with a comparative analysis of VR based simulation methods with current DFA methods, is used to establish the potential for virtual reality approaches for assessing assemblability.

In their paper “Computer aided evaluation of design rules for micro parts” [30], Albers et al. argue that since embodiment of micro parts is limited by manufacturing technologies imposing many rules on manufacturability, these must be made available during design, and preferably applied in an automated way to check parts against them so as to develop optimal manufacturing of primary micro parts. Such a system is presented in this paper.

In the paper entitled “The development of a systematic design for changeover methodology” [31], Reik et al. argue that in order to reduce non-value-added activities in manufacturing and better respond to customer demands, flexibility and responsiveness must be targeted, which require rapid changeover between operations. However, there is no formal design for changeover methodology. The paper proposes such a methodology.

2 Overview of the stages, activities, applications and technology

The following table summarises the stages, activities and application domains of the papers. Where a cell is left blank, the paper does not mention this aspect explicitly.

paper	**Product development stages**	**Activities**	**Application**
1	Early stages (preliminary assessment, product definition, project planning)	Problem formulation before requirements	engineering systems
2	Conceptual design	Problem formulation and solving	engineering systems
3	Conceptual design		engineering systems
4	embodiment design	Material selection	automobiles
5	manufacturing stage	Optimisation of spatial scheduling	ships
6	Conceptual design		
7	Embodiment design	Configuration optimisation	undersea vehicle
8	Embodiment design	Configuration optimisation	bridges
9	Conceptual design		engineering systems
10	Early stages of design	Product spectrum analysis	
11	Early embodiment stages of design	Sketching activities	
12	Conceptual design	Rendering activities	
13	Embodiment design	Ergonomic analysis	
14	Detail/parametric (re)design		press brakes
15	Embodiment and detailed stages	Simulation	
16	Embodiment design	synthesis	mechanical gearbox
17	Embodiment design	synthesis	truss systems
18	Whole design process	Information extraction for reuse	
19	Conceptual design	Supporting creativity	
20	Whole design process		mechatronic systems with PLC
21	Whole design process	Information providing	mechatronic systems
22	Design process		Paper-pop-up structures
23	Conceptual design		mechatronic systems
24		Analysis of potential errors	
25	Embodiment design	DFMA	complex low volume weldments
26		Ergonomics in engg design	
27		Analysis/avoidance of unintended behaviours	
28	Early stages of design	Cost estimation	
29		Assemblability assessment	complex deformable systems
30		Manufacturability assessment	primary shaped micro-parts
31		Changeover assessment	manufacturing equipment

As can be seen from the above table, most of the work is focused on supporting early stages of design, in a variety of aspects including creativity, costing, DFMA, manufacturability, changeover etc. The application domains are largely within engineering systems category, but often quite various and specific, e.g., ships, automobiles, manufacturing equipment, micro systems, mechatronic systems etc.

An analysis of the keywords used in the designs reveal the following pattern. The most popular activities of work seem to be visualisation and simulation, followed by creativity and synthesis, collaboration and communication, and knowledge based engineering and management. The next area is DFMA, followed by functional modelling and representation, optimisation, information and data modelling, product structuring, failure analysis, costing and early design sketching and rendering. A variety of technologies are used, the most popular being evolutionary computation, and an increasingly popular interactive evolutionary computation. Data mining, sensitivity analysis, ontology based techniques and semantic web are also used. A number of papers have been written on ergonomic aspects, and mechatronic systems seem to be a popular area of application.

3 Specific Areas of DRM Covered and Research Methods Used

In terms of the design research methodology of Blessing, Chakrabarti and Wallace [32], the focus of the papers seems to be primarily on method development, which is hardly surprising. The criteria for research success and Descriptive study I (i.e., understanding of the influences on research success) are mostly based on literature. In about a quarter of the cases, a Descriptive Study I was carried out by the researchers to identify the influences. In majority of the cases, Descriptive Study II (method evaluation) is preliminary. In summary, majority of the papers focus is primarily on method development, and relatively less on their evaluation, which probably shows their work-in-progress character.

In terms of the research methods used, these include protocol studies, questionnaire surveys, semi-structured interviews, and analyses of past cases and artefact documents. The most common methods seem to be a critique of existing literature. The subjects used, where applicable, vary between experienced designers and undergraduate students.

References

[1] Towards an IT supported front end of product development
Felix Nyffenegger, Nadja Jamali, Carmen Kobe, Markus Meier
[2] Joining standard and inventive design, application to injection moulding
Thomas Eltzer, Emmanuel Cailaud, Denis Cavallucci, Philippe Lutz
[3] The influence of billet processing on the mechanical properties of forged 6061 AL
Martin Leary and Colin Burvill
[4] Managing design alternatives: from the alternatives model towards an aided design system
Pierre Nowak, Benoit Eynard
[5] Optimal spatial arrangement of shipbuilding blocks in the pre-erection area of shipyard
Ranjan Verghese, Duck Young Yoon

[6] Principles for the development of a computer aided design tool
Noe Vargas-Hernandez and Jami J. Shah
[7] Introducing grid-based semi-autonomous evolutionary design systems
IC Parmee, J Abraham, M Shackelford, D Spilling, OF Rana, A Shaikhali
[8] Integrating aesthetic criteria with a user-centric evolutionary system via a component-based design representation
Azahar T Machwe, IC Parmee, John C Miles
[9] Towards an evolvable chromosome model for interactive computer design support
Zhun Fan, Mogens M Andreasen, Jiachuan Wang, Erik D Goodman, Lars Hein
[10] Sensitivity as an assessment criterion for product spectra
Mail Maurer, Udo Lindemann
[11] Experiments with a cameraphone aided design system
Farrugia Philip J, Borg Janothan C, Camilleri Kenneth P, Spiteri Christopher
[12] Identifying requirements for rendering in conceptual design
Raji Tenneti and Alex Duffy
[13] Human modelling benefits in workstation design
Fancois Gauthier, Hugues Caron
[14] Automatic design of a press brake for sheet metal bending
Giorgio Colombo, Ambrogio Girotti, Edoardo Rovida
[15] Software architecture for flexible integration of simulation in the product development processes
Okba Hamri, Jean-Claude Leon, Franca Giannini, Bianca Falcidieno
[16] Virtual synthesisers for mechanical gear systems
Alex C Starling and Kristina Shea
[17] Configuration synthesis of a variable complexity truss
Erik Antonsson, Fabien Nicaise, Tomonori Honda
[18] Sensitivity analysis: a priori and post facto
MD Greiss, SJ Culley, BJ Hicks
[19] Research study in support reativity software as tool to assist the conceptual design stage
Jairo Chaur, Joaquim Lloveras
[20] Applying the new VDI design guideline 2206 on mechatronic systems controlled by a PLC
Jens Bathelt, Anders Jonsson, Christian Bacs, Stefan Dierssen, Markus Meier
[21] Semantic web services for the knowledge based design of mechatronic systems
Christian Bludau and Ewald G Welp
[22] Analysis of 90 degree pop up structures for CAD systems
KW Mak, SB Tor, YT Lee
[23] Model based design of actuation concepts: a support for domain allocation in mechatronics
Sebastian Jansen and Ewald G Welp
[24] A theory-based ontology of design induced error
IJ Shin, JS Busby, RE Hibberd, CA McMahon
[25] Applying design for manufacture and assembly techniques to large scale weldments produced in small volumes
Larry Stauffer and Wesley Smith

[26] Don't engineers care about occupational health and safety
Ole Broberg
[27] Ontology based transformation from an extended functional model to FMEA
Yosuke Koji, Yoshinobu Kitamura, Riichiro Mizoguchi
[28] Approach for integrated achievement of the cost target
Alexandra Nissl and Udo Lindemann
[29] Impact of virtual reality simulation tools on DFA and product development process
Alexei Mitchevitch, Jean-Claude Leon, Alexandre Gouskov
[30] Computer aided evaluation of design rules for micro parts
A Albers, N Burkardt, J Marz, S Hauser
[31] The development of a systematic design for changeover methodology
Reik MP, Acintosh RI, Owen GW, Mitcham AR, Culley SJ
[32] Blessing, L.T.M, Chakrabarti, A., and Wallace, K.M. A Design Research Methodology, Proceedings of the International Conference in Engineering Design, Prague, Vol. 1, pp-50-55, 1995.

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