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INTEGRATION OF DESIGN AND TECHNOLOGY – A COMPUTATIONAL APPROACH

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ABSTRACT
Design as an intelligent behaviour has been the subject for researches in Artificial Intelligence, Cognitive Sciences, Computer Sciences for several decades. The emergence of a new field in computational design or design computing has an impact on design education, especially at postgraduate level. The Design Technology Research Centre in the School of Design of the Hong Kong Polytechnic University was established seven years ago with a programme for design research and postgraduate design education in this new field of computational design. Over the last seven years, the DTRC established strong collaborations with various design education institutions in Hong Kong and mainland China for the integration of design and technology. In this paper, the work of the DTRC is presented and evaluated in terms of its effectiveness in the context of establishing a module for postgraduate design research and education in Hong Kong and mainland China, when considering design at the centre of a new environment supported through an integrated application of intelligent computational support systems.

Keywords: generative design, collaborative design, complex form, computational design

1 COMPUTATIONAL DESIGN – A DTRC RESEARCH PROGRAMME

The Design Technology Research Centre (DTRC) in the School of Design of the Hong Kong Polytechnic University was established in 1997 by Professor John Hamilton Frazer, with a research programme based on the belief that the design paradigm is shifting and design methodology of the future is increasingly becoming different from today. The computational support for this paradigm must therefore match this shift by moving beyond specific passive tools to more holistic active environments [3]. The way forward is to build intelligent and interactive tools, systems and environments based on a new and generic model of design and making, based on a computer enhanced design process [4]. Intelligent behaviour or creative thinking in terms of divergence (exploration) and convergence (optimisation) are enhanced by such tools, systems and environments interacting with users and designers in a collaborative manner. Such environments may reveal totally new working methodologies for designers and may even empower non-designers such as clients and users to participate in the design process in ways which were previously not possible [4].
The DTRC aimed at going beyond mere assistance in computer supported design that relies only on geometric representations of product data incapable of adapting, collaborating and learning. In our research, design is seen as part of a process and in a holistic context, rather than the description of some artefacts in isolated contexts. With

this new thinking, many fundamental issues needed to be researched and new computational techniques developed in a multidisciplinary design domain. In such an approach, knowledge and techniques in Artificial Intelligence and Computational Design must be combined with the design expertise and domain knowledge for the development of new software prototypes and demonstrations, through which better and more intelligent support to design process are established and verified, through real design examples. The development of such tools, systems, and environments relies on the research into a unified data structure of space, information and knowledge, an alternative computer enhanced design process, and an environment of design that relocates the user, the designer and the tool [12].

Among many research projects carried out by the DTRC over the last seven years, three paradigms have been extensively researched:

- Generative paradigm – The development of generative and evolutionary systems for intelligent design exploration and optimisation,
- Collaborative paradigm – The implementation of agent based collaborative design frameworks and systems supporting the design team,
- Complex form paradigm – The formulation of complex 3D forms and product data models using algorithmic and process based methods for design exploration and visualisation.

The research activities in these areas define a scope of design research vital for advancing the field and for contributing to postgraduate level design education. In these areas, theoretical models, computational methodologies, and software prototypes have been developed by the DTRC to demonstrate the potentials of intelligent design computing environments in design education, design research and design practice [12].

2 GENERATIVE PARADIGM

Generative paradigm in computational design refers to an approach by which a large number of alternative design solutions are generated by a computer system that employs one of the computational techniques such as genetic algorithms, cellular automata, generate and test, and functional synthesis. A generative design is characterised by an evolutionary process of generating a large number of new concepts and forms of design based on the primitive concepts and forms that are easy to define and to evolve. The process is fast and automatic but there are many ways by which this automated process can be controlled or influenced by designers whose knowledge and preference are part of the input to the system in the form of primitives, rules, constraints, evaluation criteria, or environments. How to define primitives, rules, constraints, evaluation criteria and environments is a key and a difficult issue for the application of generative and evolutionary algorithms in product design [4].

In the generative paradigm we have demonstrated the possibility of evolving large numbers of alternative design concepts in 3D forms, ranging from simple products such as wine glasses and lamp shades, to more difficult and complex objects such as human facial characters [1, 2, 5, 6]. Our early research in generative paradigm concentrated on the development of applications demonstrating the use of genetic algorithms (GA) as a exploration tool manipulating data structures called “rudiments” and “formatives” with evolving parameters for both product and process knowledge [3, 4, 11]. Attempts were also made to generalise GA based approach to more generic frameworks in which generative techniques are used in software support kernels as inference mechanisms for enhancing design exploration in a more systematic manner [1] or to define an alternative way for generating design solutions in domain of architecture design in which evolutionary design schemas are developed in advance for a wide range of design tasks, from which design proposals are then evolved considering the user requirements and environments representing the specific circumstances of the design problems [8].

While our early systems utilising genetic algorithms for product design applications focused on the artificial selection strategy for a divergent exploration of large numbers of design alternatives, other selection and evaluation strategies are currently being investigated. One project tackled the problem of combining convergent and divergent thinking in generative design by the formulation of aesthetic evaluation and selection strategies in a facial character evolution system based on an integration of genetic algorithms and neural networks [6], whilst another project addressed the issue of deriving new shape grammar rules for the configuration of digital camera forms within a generative design environment, in which genetic algorithms and 2D shape grammars are combined with an external solid modelling system.

3 COLLABORATIVE PARADIGM

Our research on collaborative design technology is primarily concerned with the development of cognitive and computational models of intelligence design collaboration. A number of collaborative system architectures have been developed over the last seven years. These included Multi Agent Design System (MADS) [9], Virtual Collaborative Design Environment [12], and more recently an agent-based design collaboration system modelling design [2] agents as intelligent data sources and design knowledge sources. In MADS, there are three classes of agents: management agent, tool agent and design agent. These agents are situated at different layers of a collaborative design system, with a hierarchical relation that determines the authority of each agent in the group, which is derived from a mapping from a collaborative design process to an agent organisational structure. MADS supported product design applications which generated lamp shades using a solid modelling kernel and an external CAD system. In this particular implementation, the MADS architecture successfully supported the exchange of 3D solid product data models across the network [9].

In order to develop a common system architecture by which we can collaborate with mainland Chinese design institutions via the Internet, in 2001, we proposed the Virtual Design Collaboration Environment (VCDE) and the VCDE was subsequently explored by the students from Zhejiang University under a joint PhD supervision scheme between Zhejiang University and The Hong Kong Polytechnic University. However, up to now the software support for the VCDE and the application data server have not been fully developed due to the slow response time of the Internet. We intend to carry out more research to overcome the difficulty in gathering experiment data and design resources through the VCDE.

In a more recent project, we developed a new agent design system based on the architecture of MADS [2]. In this system, agents are formulated using a generic interface. Based on this interface, communication agents, design assistant agents, and design knowledge agents are further generalised in a single platform with a new implementation platform. More design examples including Chinese lattice patterns and abstract architecture forms are used to test this new platform. Textual mapping and colouring scheme are also added to the agent based design system. Although this new platform is seen as an improvement to the MADS in that it formulated various design agents, the platform itself still does not posses enough design knowledge to be a full scale design support system. The product models generated are still limited to 2D geometric profiles revolved around a centre axis [2].

- Single user and single domain based design support systems, tools, and environments are being replaced by networked and multidisciplinary design environments. However, explosive and unstructured information of large quantity and piecewise and incomplete knowledge about design technology across the web make it hard for designers to gather and apply knowledge to the problems at hands.

Agent technology is employed to support the following collaborative design operations: constructing a design solution using existing product data models available in a web-based knowledge base and then pass the solution to other members of a design team for further analysis and modification; proposing a new product data model as a building block that can be used by members of a design team; working out a design solution or multiple design solutions jointly with members of a design team using shared product data models through a process of exploration, negotiation and learning; and proposing a change to an existing design solution or an existing product data model created by other members of a design team using the integrated design tools available.

4 COMPLEX FORM PARADIGM

Generation and visualisation of primitive as well as complex forms in a computer based enhanced design process are essential for designers to create and evaluate the concepts and 3D forms being generated. The issue is more complicated in a virtual environment in which a full immersive or interactive effect may be expected. Professor Frazer argued that design as a discipline lacks a rigorous theory for creating form, but so too does natural science. Science seeks to understand the products of nature whilst designers seek to create new forms. Rather than design always borrowing theory from other fields, could a general theory of form emerge from studying creative design [4,5, 12].

In order to provide a foundation for the development of a new generation of design tools, systems and environments, the DTRC focused on the development of 3D complex geometric forms that can be visualised and evolved in a virtual computational design environment. This research tackled the following problems:

- Building a library of complex form that helps designers to explore 3D design concepts and structures,
- Adopting a soft modelling approach by which 3D models of a product can be built using schematic and object-oriented data structures manipulated by highly integrated algorithmic and spatial reasoning programs,
- Establishing the mechanisms with which various data structures can be combined or split to allow new data or new forms to be derived using generative techniques such as Genetic Algorithms or Neural Networks,
- Implementation of a visualisation interface to demonstrate the process in which these data structures are used in design applications in an interactive manner.

Models and the corresponding class hierarchy of complex functions have been implemented in a symbolic approach in which sophisticated reasoning software packages are integrated with 3D visualisation technology including solid modelling technology. The research in this area produced a database of images and solid models which can help designers for creating new designs. Several interactive graphic models are built for real time image development. Applications included:

- Algorithmic and spatial reasoning mechanisms for complex forms,
- Scientific visualisation of nonlinear surface modelling problems, and
- Surface and solid reconstruction by evolutionary computing techniques.

In particular, we have developed methods combining algorithmic and AI methods for the creation and generation of highly complex architectural forms which would otherwise be impossible to build using the existing modelling tools. In an application, rules developed by architects for the design of evolutionary towers were used to model and visualise the highly complex data structures of tower buildings in the city of Groningen [10].

5 RELEVANCE TO DESIGN EDUCATION

In making a connection between design research and design education at postgraduate level in order to provide design teaching with the latest findings, several issues need to be considered:

- Understanding design process, designers, and users,
- Student background and knowledge structure,
- Generalisation versus specialisation of knowledge for design,
- Research methodologies and platforms,
- Integration of aesthetic and scientific approaches to design, and
- Validation of prototype tools and environments through real design examples.

Understanding design and supporting design activities are at the centre of computational design intelligence that has become one of major challenges for the field of Artificial Intelligence, Computer Sciences and Cognitive Sciences in the last three decades. Various techniques and methods have been developed in these fields for supporting design as an intelligent behaviour of exploration or search in design. These techniques and methods have been developed largely in a top down manner. That is, design as a creative act is modelled in an information process or a knowledge model as a recursive process of generation, evaluation, and exploration. AI and computational techniques such as genetic algorithms, neural networks, cellular automata etc. are employed as inference tools for the exploration of alternative design solutions or for the optimisation of the best solution if the selection and evaluation criteria can be formulated to control the evolution. Architectures of intelligent design support systems are then proposed and implemented within an object-oriented environment for testing and evaluating the results generated. In this top-down manner, generic systems are developed and design examples (often simplified to a large extent) are used as the evaluation cases.

The educational background and knowledge structure of research students at MPhil/PhD level are significantly different from that at undergraduate level. Research students in design with computing and engineering background are mostly likely to take a top down approach to developing intelligent design tools as discussed above. However, there is strong evidence suggesting that this approach needs revision. The reason is that the design examples or knowledge obtained by the students to show the relevance of a new computational design methodology are often limited to simplified cases of highly abstract nature. It is therefore difficult to use the prototype tools developed by research students directly in design teaching or design practice since the interfaces implemented by research students are often below the expectation of designers and users.

In order to overcome this problem, increasingly a bottom-up approach needs to be introduced for the students to start from a domain of design and acquire extensive knowledge in the domain first, which can then be coded in computational representations and generalised through an integrated application of AI and computational techniques. This product-oriented and process-oriented approach makes it easier to work with designers and users. While the top down approach represents a knowledge specialisation process, the bottom up approach is a knowledge generalisation process. In both processes, it is important to put design at the centre of student research project. The knowledge specialisation process requires that students acquire fundamental theories and methodologies in abstract and generic contexts before they explore the applications of these theories and methodologies in specific domains and business contexts. The knowledge generalisation process requires that students utilise their experiences and skills in a more refined and systematic manner by updating their knowledge structures with the latest thinking and findings in computational design theory and design methodology research.

The methodologies and platforms used in design research are significantly different from those used in design teaching. Research in computational design requires design skills beyond a product domain. A high level of innovative design thinking is required for the formulation of a new process or a new approach to the establishment of a design environment or the development of an intelligent design tool, which must be implemented, tested and validated. The ability and skills in design computation are essential for future designers who need to configure their own tools or systems in order to create designs utilising the cutting edge technology in an increasingly connected and collaborative design society. In this aspect, the three major research areas of the DTRC, i.e., generative paradigm, collaborative paradigm and complex form paradigm provided a strong basis for linking design with new technology in context of supporting design practice as well as design education. In our research, several major methodologies of design computing linking 3D product data models with generative processes operating in Internet enabled environments through synchronous and asynchronous design collaborations have been investigated and tested.

In order to make the design research outcomes in the form of prototypes of design support system available either as design tools or a design teaching support systems, it is necessary to evaluate them in both aesthetic and technological context with the formulation of quantitative and qualitative evaluation criteria and the participation of designers and users. This issue is currently being addressed by the DTRC.

6 CONCLUSIONS

Seven years of research on computational design by the DTRC established an excellent foundation which needs to be further consolidated through a strong connection with design practice and design education for further development of technologies and industrial exploitation of the methods and prototypes developed. The developments of new curriculum for design education are in the process of fast evolving and integration in Hong Kong and mainland China [7]. There is a need for strong support through design researches and international collaborations in the areas of intelligent design computing and computer supported collaborative design.

In this paper, we have highlighted the main research areas and computational methodologies of the DTRC in the past seven years, and discussed the issues related to the application of these methodologies to design practice and design education, in which design is at the centre of activities supported by computational design technology in an intelligent, interactive and collaborative manner.

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REFERENCES

[1] Chan K. H., Frazer J. H., Tang M. X., 'An Evolutionary Framework for Enhancing Design', Artificial Intelligence in Design '02, Cambridge University, UK, July 2002, pp 383-403.

[2] Fang W. D., Tang M. X., Frazer, J. H., 'Supporting Collaborative Design in an Agent Based Environment', published at the 16th International Conference on Industrial & Engineering Applications of Artificial Intelligence and Expert Systems (IEA/AIE2003), Paper No. 085-02.

[3] Frazer, J. H., 1995, "An Evolutionary Architecture", published by Architecture Association, London, 1995.

[4] Frazer J.H., Tang M. X., 'Intelligent Data Structures and Computational Techniques for Generative and Evolutionary Design', Proceedings of the 30th International Conference on Computers & Industrial Engineering, Greece, June/July 2002, pp 245-250.

[5] Gero, J., 2002, "Artificial Intelligence in Design" Proceedings of International Conference on Artificial Intelligence in Design 2002, July, 2002, Cambridge University, UK.

[6] Gu Z. Y., Tang M. X., Frazer, J. H., 2004, "Formulation of Aesthetic Evaluation and Selection in a Facial Evolution System", accepted for presentation and publication at the 1st International Conference on Design Computing and Cognition, July, 2004, MIT, USA.

[7] Heskett, J., 2003, 'Shaping the Future, Design for Hong Kong', A Design Task Force Report by the Hong Kong Polytechnic University.

[8] Janssen P., Frazer J. H., Tang M. X., 'Evolutionary Design Systems and Generative Systems', Applied Intelligence, Vol. 16, No. 2., pp.119-128 (2002).

[9] Liu H., Tang M. X., Frazer, J.H., 'A Knowledge Based Collaborative Design Environment', Proceedings of Agents in Design 2002, MIT, August, 2002, Gero & Brazire FMT (eds.), pp 233-246.

[10] Liu X.Y., Frazer J. H., Tang M. X., 'Visualization and Genetic Algorithms in Minimax Theory for Nonlinear Functional, International Journal of Scientific Computing, 18 (1): 49-68, February 2003.

[11] Sun J., 2002, "A Framework for Supporting Generative Product Design Using Genetic Algorithms", PhD Thesis, The Hong Kong Polytechnic University.

[12] Tang M. X., Frazer, J. H., Janssen, P., 2002, 'The Design Technology Research Centre', published by the School of Design, the Hong Kong Polytechnic University.

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