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Computational Construction Kits for Geometric Modeling and Design

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Computational Construction Kits for Geometric Modeling and Design (Panel Abstract)

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Abstract

Although a current hot topic, tangible user interfaces (TUIs) have been studied for quite some time. One particular kind of TUI has been investigated repeatedly: during the past 20 years several groups have developed "intelligent" building blocks that can self-describe the geometric structures into which they are assembled. These computational construction kits (CCKs) give users an extremely intuitive way to express 3D geometry, and have been used for a variety of different geometric modeling and design applications. In this panel we will review the development of CCKs, from the first such systems to the most recent, and speculate about future developments. The panelists will present and demonstrate artifacts from several CCKs, most of which have not been shown previously at SIGGRAPH, CHI, UIST, or I3D.

Keywords: Tangible user interfaces, transmedia, geometric modeling, human-computer interaction.

1 Panel Description

The last eight years have seen a flood of innovative papers on tangible user interfaces (TUIs): even restricted to major forums (CHI, SIGGRAPH, and UIST), the list is impressive [31, 23, 11, 25, 37, 12, 22, 33, 34, 38, 42, 7, 24, 26, 27, 32, 39, 40, 41, 43, 20, 29, 6, 28]. These publications consider TUIs for all kinds of applications, but only four very recent ones [7, 29, 6, 28], two papers and two demos, concern the creation of 3D geometric models, one of the fundamental tasks in computer graphics.[1] This might seem surprising, because many popular children's toys are tangible manipulables that can be used to create 3D physical constructs, e.g., Lincoln Logs™, Lego™, K'nex™, and multiple variants of the basic wooden building block. The physical models created with these toys can be as detailed as any CAD model. Suitably instrumented, could simple construction toys provide easy-to-use tangible mechanisms for describing 3D geometry directly to a computer?

In fact, there is a body of work on TUIs for 3D geometric modeling, none of it referenced in the research literature prior to the demonstration summary by Anderson et al. in the 1999 UIST proceedings [7]. During the past 20 years, several groups have developed "intelligent building blocks"[2] that can self-describe the geometric structures into which they are assembled. These computational construction kits (CCKs) give users an extremely intuitive way to express 3D geometry—building with blocks is a skill mastered in kindergarten—and have been used for a variety of different geometric modeling and design applications. In this panel we will review the development of CCKs, from the first such systems to the most recent. We will also speculate about future developments: Will CCKs eventually be the basic tools of a new building industry for virtual environments, or are they merely a research toy, unlikely to ever supplant WIMP-based CAD systems?

To our knowledge, all known building-block CCKs developed prior to 2000 are represented on the panel: Robert Aish is the holder of the first patent for a geometric-modeling TUI [2, 1, 3]; also a participant from the very beginning, John Frazer has conducted more CCK research than anyone else [18, 19, 14, 13, 17, 15, 16]; Tony Patera pioneered the use of CCKs for engineering design and computation [8, 5, 4]; and Jamie Frankel has been a principal contributor to one of the most recent and ambitious CCK projects [7, 6]. Between them the panelists have developed seven different implemented CCKs, each of which uses different connectional, communicational, and computational technologies. The target applications of the seven projects also differ significantly.

2 Biographies

Robert Aish

Robert Aish is the Senior Scientist at Bentley Systems, a worldwide leader in engineering software. He studied Industrial Design at the Royal College of Art in London, and received a Ph.D. in Human Computer Interaction from the University of Essex. Before joining Bentley he worked at Ove Arup, Intergraph, and YRM.

[1] The AlgoBlock [35, 36] and Triangles [21, 22] systems share many common characteristics with the CCKs described below. However, the target application of these systems is visual/tangible programming, not geometric modeling; and both systems enable the description of general 2D structure only, not 3D.

Two other TUI systems for geometry input also deserve mention: the "Active Lego™ Baseplate Project" at MIT [30] addressed the issue of geometric modeling, but it was only a paper design, and was never implemented. The Monkey™ is a posable articulated linkage that is used as a TUI for keyframing and performance capture [9]; it is a successful product.

[2] This phrase was probably first used in a 1985 magazine article by Barrie Evans [10].

James L. Frankel

James L. Frankel is the President of Frankel and Associates, a consulting firm in the computer-systems field. His clients include MERL, MIT's Lincoln Laboratory, Stratus Computer, and Open Market. He has held research and/or leadership positions at Thinking Machines Corp., Digital's Corporate Research Group, Xerox PARC, and IBM T.J. Watson Research Lab. He holds a Ph.D. from Harvard University.

John H. Frazer

John H. Frazer (AA Dip1, MA (Cantab), FCSD, FRSA) has been Swire Chair Professor and Head of School of Design, Hong Kong Polytechnic University since July 1996. Previously he was Professor of Computer Aided Design at the University of Ulster, Head of School of Art and Design Research History and Criticism at Ulster Polytechnic, Unit Master at the Architectural Association, and Lecturer at Cambridge University. From 1983 to 1996 he served as Director of Autographics, a pioneering microcomputer-based computer-graphics and interactive-interface-design firm. Prof. Frazer was elected Fellow of the Royal Society of Arts in 1989 and Fellow of the Chartered Society of Designers in 1996.

Anthony T. Patera

Anthony T. Patera is Professor of Mechanical Engineering, Massachusetts Institute of Technology; Deputy Director of the Singapore-MIT Alliance (SMA); and Chair of the SMA Programme in High Performance Computation for Engineered Systems. He formerly served as Co-Director of the MIT Supercomputer Facility. Prof. Patera has undergraduate and graduate degrees in Mechanical Engineering, and a doctorate in Applied Mathematics, all from MIT. Professor Patera has received research awards nationally (AIAA) and internationally (Lombardy Academy of Arts and Sciences, Milan, Italy). He is a longstanding member of the Defense Sciences Research Council.

Joe Marks

Joe Marks is the Director of MERL's Cambridge Research Laboratory. He received his Ph.D. in 1991 from Harvard University. He has also worked at Bolt Beranek and Newman, Inc., and at Digital's Cambridge Research Laboratory.

3 Position Statements

Robert Aish

The "Building Block" project was an extension of a research project called "Computer Aids for Design Participation" conducted at the ABACUS Research Unit at the School of Architecture and Building Science, at the University of Strathclyde, Glasgow. The major part of this project was the development of the PARTIAL CAD program and its use in various experimental trials. PARTIAL was a research tool to explore how lay participants (as opposed to professional designers, such as architects) could participate in the design of particular building types.

The original ideas for this system were then published in 1979 [2] with US and UK patents granted in 1981 and 1982 [1]. Subsequent Noakes and Aish developed a more sophisticated system intended to explore more complex (and realistic) building topology, including overhangs and arches [3]. This work was supported by the British Technology Group and Ove Arup and was realized at the University of Essex. This systems was successfully integrated with building-performance software, developed at Ove Arup, and showed that the overall form and configuration of a building could be physically modeled, with resulting heating and cooling loads being calculated from the geometry extracted from the physical model.

A key assumption of TUI research is that there are advantages for the designer if he interacts directly with the physical design model. But is this assumption valid? For example, how can we combine in a single design tool the tangible concept of direct manipulation with the intangible notion of constraints, which is central to many modern CAD systems?

James L. Frankel

Trends in computer hardware allow the embedding of processors within many common devices. At MERL we have built upon the existing work in the field to create a set of Lego™-like blocks that can be used as a self-describing interactive 3D tangible input device [7, 6]. By building three-dimensional models using these blocks, the geometry of the resulting structure is accessible to a computer without the need to use complex CAD tools. The blocks communicate with each other and with a Windows PC via message passing. These messages describe the geometric configuration of the blocks and allow commands to be sent to transducers in the blocks (e.g., LED's, speakers). They also allow status messages to be sent describing the state of sensors (e.g., motion and touch sensors). We have built structures comprising as many as 560 blocks.

Two demonstration applications for the blocks have been developed. For architects and would-be architects, we have created an easy way to design and prototype new buildings in different architectural styles. The architect builds a structure from our intelligent blocks; then, a program automatically recognizes architectural elements—e.g., walls, corners, roof, doors, and windows—and renders them thematically. The result is a building that might appear as a brick house or a fanciful castle, depending on the user's selection of an interpretive rendering style.

In our second demonstration application, a building constructed from our blocks can be imported into a Quake™ world and a player can enter this model in the virtual world. Over the Internet, many players, each with their own physical block model of their structures, might play in a world that merges the physical with the virtual.

John H. Frazer

"Intelligent Physical Modeling Systems" was the name originally used by the Frazer team for a technique of using reconfigurable physical models with embedded microelectronics as a data input device for generating virtual objects or environments. The first working prototype was developed and demonstrated by the Frazers in 1979, and a series of patents were filed for a variety of electronic techniques for which working prototypes were also constructed and demonstrated (1979-82). Practical applications followed with the design and construction by the Frazer team of a working interactive model of the Generator project designed by the architect Cedric Price for the Gillman Paper Corporation in 1980, and an interactive design kit for self-builders for the architect Walter Segal in 1982.

Techniques were developed for dealing with complex geometries including curved forms. Only with the simplest systems was one-to-one mapping employed, with just a scalar transformation from actual block to virtual form. Most systems included more complex mapping including variable scaling, translation, and the description of more complex geometries based on a state code associated with each component. In some cases the state code was dynamically reassigned and even displayed on the building block. This was highly economic with the same set of components being used for a variety of different applications.

There was a flurry of interest and the Frazer systems were demonstrated at several conferences [18, 19, 14, 13] and at venues in London: Barbican, Building Centre, and the Architectural Association.

The Frazers renewed their investigations in 1989 with a group of students at the Architectural Association and constructed a *Universal Constructor* in the form of a three-dimensional re-configurable array processor. In 1995 the prototypes were restored to working order for an exhibition at the Architectural Association and published in a book [16]. The exhibition and the book positioned these techniques in relation to recent developments.

In my presentation I will first briefly review the various techniques developed by the Frazer team over 20 years, emphasizing the concept of dynamically reassignable mapping, but then concentrate on establishing the current significance of the convergence of physical and virtual modeling that is now taking place.

Anthony T. Patera

Beginning in the mid-1980s, Dr. Daniel Dewey and I worked on a new concept we dubbed Geometry-Defining Processors (GDPs). As originally conceived, GDPs would be a sort of "programmable matter." Poured into a mold of any given shape, these minute spherical processors would first communicate with nearest neighbors to recreate, or "define," the geometry in which they found themselves; they would then simulate the behavior of the object they thus defined—for example, predict the deformations and temperatures in a solid—by solving the associated partial differential equations of continuum mechanics. The GDPs would therefore constitute a fast and readily reconfigurable geometric preprocessor and mesh generator; and also a massively parallel processor with interconnections optimally matched to the underlying computational problem of interest.

As put into practice by Dewey, myself, and several students, the prototype GDPs were a bit less grand than our initial plans. The GDPs built in the 1980s were not so minute, were not so pourable, and did not house much processing capability on-board. But the cubical elements ("smart building blocks") did indeed communicate optically with nearest neighbors to define the geometry of their readily reconfigured assemblage; and it was clear that, with advances in technology, there was little to prevent us from achieving our original goals. A paper describing the prototype GDPs, with application to a heat transfer fin optimization problem, appeared in 1989 [4].

At the end of the 80s Dewey and I turned from GDPs to our usual research in astrophysics and numerical analysis, respectively. But it is clear from recent interest that the time has perhaps come for reconfigurable assemblies of processors that can understand, define, and communicate their geometry, and perform calculations that exploit this unique physical-space to computational-space identification.

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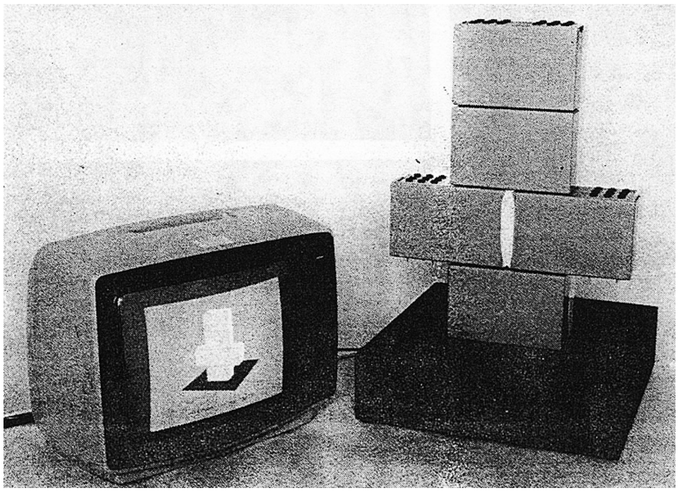

Figure 1: Aish's "Building Blocks" [2]. A physical block structure and its computed shape are shown. Reproduced from [10].

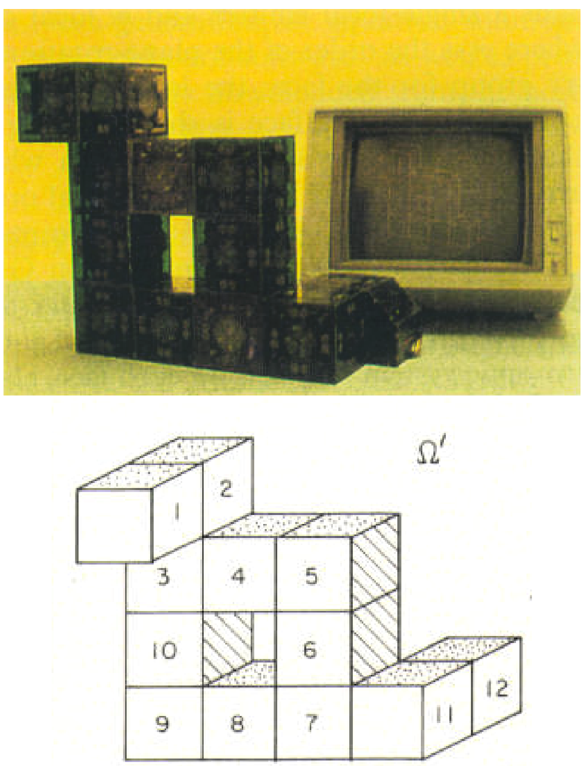

Figure 2: The "Geometry Defining Processors" of Anagnostou, Dewey, and Patera [4]. This CCK was originally designed for interactive geometry input, mesh generation, and the optimal parallel solution of partial differential equations. The figure shows a physical structure and the corresponding computed structure.

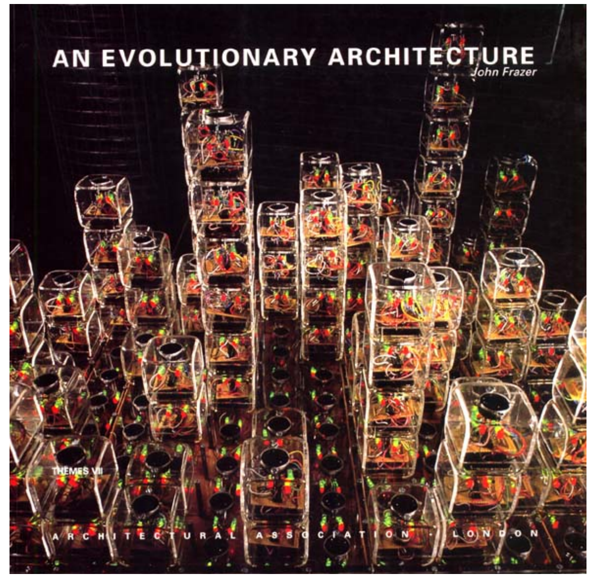

Figure 3: The cover image from *An Evolutionary Architecture*, by John Frazer, which shows the "Universal Constructor," one of several CCKs developed by Frazer and his colleagues for a variety of architectural modeling and design applications [16].

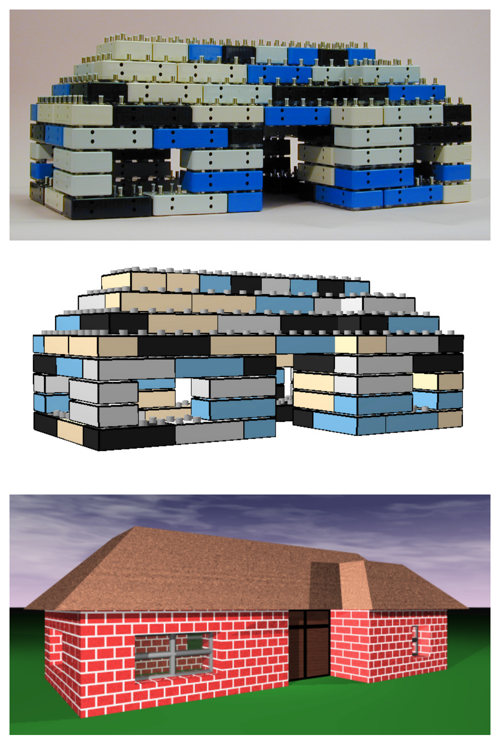

Figure 4: The MERL Blocks [7, 6]: a physical block structure comprising 98 blocks; and renderings of the virtual model recovered from the structure, one literal and one interpreted. The literal rendering uses associated shapes and colors to render the blocks. The virtual model is augmented automatically for the interpreted rendering.