Theme:

Title: **From design information management to virtual design prototyping**

Author(s): Alexander Koutamanis

Institution(s): Faculty of Architecture, Delft University of Technology, The Netherlands

E-mail(s): a.koutamanis@bk.tudelft.nl

Abstract: *Architectural practice is currently characterized by intensive (if not always intelligent or efficient) use of computerized tools for rather strictly defined tasks. Especially in areas like representation computerization is rapidly becoming the obvious solution, even though the efficiency and effectiveness of existing tools has yet to match the requirements of current architectural problems or the performance of related disciplines. Attempts to improve on existing representations fall under two main approaches. The first is the bottom-up development of structure and meaning in the representations used for each application area and bilateral correlation of these representations. The second is institutional classification and standardization of design information for all application areas. Both approaches aim at design information management using a central representation that integrates partial descriptions. The true potential of this representation is virtual design prototyping. The demands and possibilities of virtual design prototyping generate specific expectations for the evolution of design information management. A promising solution is the derivation of entity standardization and correlation not from conventional (apparent) domain knowledge and current computer practices but from the cognitive principles which provide a comprehensive yet compact basis for a radical re-consideration of architectural representation.*

Keywords: *representation, design information management, virtual prototyping*

Computerization in architecture

Architectural applications have attracted significant attention in computational theory and technology from early on. Nevertheless, architectural practice is a relatively late arrival to computerization following the electronic revolution of the 1990s –or more precisely, the democratization and popularization of ICT in that period. The democratization of ICT has proved a deeper and more lasting influence on architectural computerization than the numerous methods and techniques that had been proposed by academic research into computer-aided architectural design (CAAD). Consequently, current computerization in architectural practice is characterized by intensive use of commercial tools for rather strictly defined tasks. These tools derive from either general-purpose software (text processing, spreadsheets, database management) or from software developed for related disciplines (geometric modelling, visualization, simulation). The relatively weak influence of CAAD on the application of such software means that computerization in practice may not be as intelligent or efficient as advertized. This is accentuated by the hasty introduction of new tools by commercial developers who are more interested in an early market share and rely on future adaptation in response to user feedback. Moreover, practice is exercising a disproportionate influence on CAAD research and teaching, which are increasingly preoccupied with commercial software as applied in practice rather than the improvement of performance in the corresponding tasks by means of computational methods and techniques.

Despite the comparatively poor performance of current approaches and techniques, computerization is generally accepted as the undeniable solution in crucial areas such as representation and communication. Activities without the computer in such areas are becoming unthinkable. The dominance of computational techniques in these areas is not impeded by the generally acknowledged fact that efficiency and effectiveness of existing tools have yet to match the requirements of current architectural problems. What makes this even worse is that the performance of tools for architectural design and building are clearly inferior to what is already achieved in related areas. Investment in architectural computerization is apparently justified more by the modernity of ICT than measurable improvements in efficiency, quality or other aspects of design and building performance.

This is painfully apparent in the fundamental area of representation, where practical applications are dominated by digital versions of analogue drawing (CAD). These reproduce the superficial structure of analogue architectural documents, turning overlay drafting into layer management and templates into libraries of predefined elements, but adding little in terms of information processing capabilities, as the primary purpose of CAD drawing remains the production of conventional analogue documents. Attempts to improve the structure, utility and performance of computerized representations are a basic concern in commercial and academic research and development. The main reason for the attention is that design representations permeate practically all application areas, as input sources (e.g. for design analysis), output containers (as in simulation) or background to design activities (e.g. communication). Representation improvements generally fall under either of the following approaches:

1. *Bottom-up local improvement and correlation:*
   Even within specific, familiar applications such as surface or solid modelling there is still scope for representation improvement and enrichment. This refers to general technical advancement due to technology transfer, as well as to the adaptation of technology to domain knowledge and practices. In both cases improvement of structure, meaning and utility is generally determined by the purposes of a single application and the domain requirements underlying the application. This means that different representations may diverge even in crucial aspects. Consequently, a corollary of local improvement is improvement of connectivity between different representations and corresponding tasks. Connectivity is normally restricted to bilateral information exchange.
2. *Top-down institutional classification and standardization:*
   The building industry has a long tradition in top-down classification and standardization, expressed as canons of architectural styles or as professional guidelines and frameworks for implementation. The former category has been in eclipse since the advent of Postmodernism in architecture. The latter had known its heyday in the reconstruction period (in conjunction with early building industrialization) and has re-emerged with the popularization of the computer as standards and norms for information exchange and representation. Rather than accepting de facto technical solutions, applied research and professional umbrella organizations have spearheaded development of classification and standardization structures for design and building representation like STEP and IFC. These have been variably envisaged as the structure of a single, central representation to be used for all tasks and aspects, as methods and procedures for the transfer of information and meaning between tasks or aspects, and as frameworks or prototypes for the representation of these aspects and tasks in a uniform, normalized manner.

Towards design information management

Regardless of approach most current attempts to improve architectural representation arguably aim at *design information management* on the basis of a central representation that integrates partial descriptions (corresponding to specific aspects or stages). Integration may result into a single document that contains all information pertaining to a specific project or into a number of compatible documents, preferably dynamically linked, e.g. by constraint propagation networks, into multilevel modular representations [1]. The degree of integration depends equally on the chosen approach and on pragmatic considerations. In proscriptive and prescriptive approaches norms and principles generally outweigh other issues, resulting into holistic systems. Descriptive approaches are more responsive to particular, low-level problems and to local solutions, which stimulate the use of multiple, compound representations [2].

The emergence of design information management derives from a wider introduction of management practices in designing and building. These are frequently imposed by external conditions (as with ISO 9001) and may be only obliquely related to the purpose and products of architecture and the results. Nevertheless, the introduction of management culture to architecture is motivated internally by two related ambitions of a profession: methodical underpinnings and codes of good practice. Objective methods that support rationalization and understanding of the profession, its function and contribution to society and culture, are essential not only for achieving a scientific status but also for the transfer of knowledge and technology. Similarly, transparent rules and criteria that express either pragmatic or methodical principles in practice are fundamental conditions for the wider acceptance of the profession's role and function, as well as for the improvement of its contribution [3]. The view of management as an expression of architectural priorities in terms of methods and practice codes is instrumental for explaining and positioning the various forms design information management takes and the levels it addresses.

Forms of design information management

Despite the generally recognizable goals of design information management in terms of specificity, continuity and communication in the design and construction process [4], we distinguish two alternative forms, stemming from two distinct priorities:

1. *Continuity of design and construction activities:* this refers to a fundamental problem in current architectural and building practices. Ensuring continuity in the information throughout all stages of the life cycle of the built environment can be achieved by a backbone consisting of a multilevel modular representation that provides input to other aspects, from functional analysis to facilities management [5, 6], or by seamless transition from designing to construction by means of representations capable of expressing formal and structural considerations [7, 8].
2. *Overview of design tasks and procedures* at a given moment (or a design stage) is an alternative to continuity. Rather than focusing on specific aspects and trailing them throughout the life cycle of the built environment, we can concentrate on the abstraction levels and priorities of a particular moment in the life cycle so as to provide correlation of representation and various analyses [9-11] or overviews of available options, solutions and alternatives, including analyses of building stock.

Levels of design information management

Introduction of management practices to designing and design information is constrained by the choice of subject matter. This is also related to the extent and depth of computerization, as well as to the role of computerization in management and designing:

1. *Product management* focuses on the specification of the design product, i.e. on representations that can be used for different tasks, from communication and evaluation to construction. This level follows closely current practices but, by substituting analogue with digital descriptions, creates new opportunities that derive from the general capabilities of the computer.
2. *Process management* concentrates more on the actions of parties involved and the interaction between them. Based on prescriptive or descriptive approaches process management uses clear definitions of the whole process and its discernible parts towards goals such as efficiency improvement. Given the weak structure of architectural designing, it is not surprising that process management is rapidly becoming a major focus of attention.
3. *Document management* can be seen as the technical counterpart of product management. Using novel techniques such as groupware and project extranets, document management attempts to promote cooperation and concurrency by expressing relations and dependencies in terms of document properties, such as topic, authorship or stage, and transparent links between documents [12]. As an extension of existing practices and conventions, document management is also becoming a priority in the computerization of architectural practice.
4. *Information integration* goes beyond the limitations and confines imposed by conventional design documents and focuses instead on the information they convey. By disposing with the integrity of the information carrier and the underlying conventions, it is possible to reduce the structure of partial representations to their bare essentials and use (dynamic) connections between them as a means for ensuring coherence, completeness, consistency and up-do-datedness. For example, the same basic representation of spaces and building elements may underlie the two and three-dimensional descriptions of a design’s form, serve as input and output for the automated analysis and evaluation of pedestrian circulation in the design (Figure 1), the analysis and visualization of natural and artificial lighting (Figure 2) and airflow simulation (Figure 3). These aspects refer to essentially different representation levels, i.e. respectively human interaction with built space, natural phenomena relating to surfaces bounding a space and zones or entities normally implicit in architectural representations such as the voxels in a space [13, 14]. Nevertheless, the common representational basis supports effective correlation between these levels in a manner appropriate to the aspects themselves and the use of design information for communication and decision-taking.

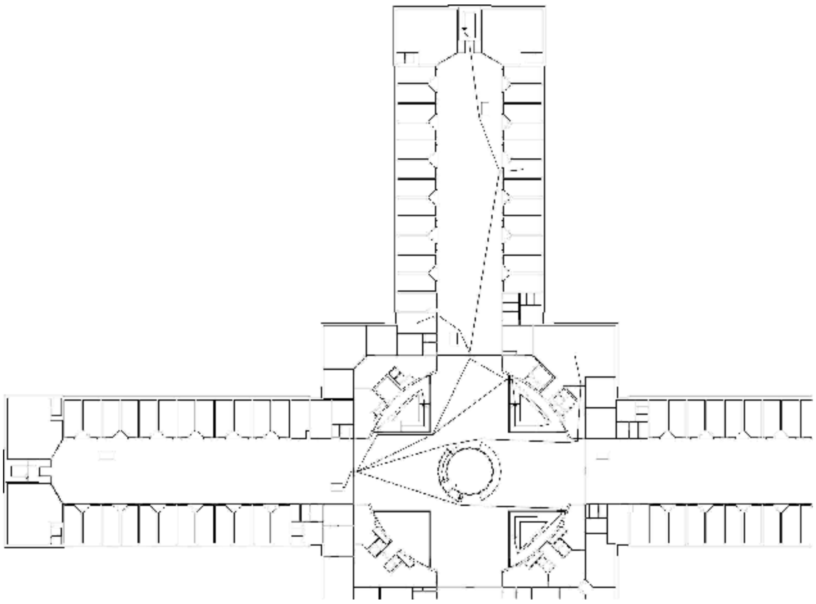

Figure 1. Route analysis [14]

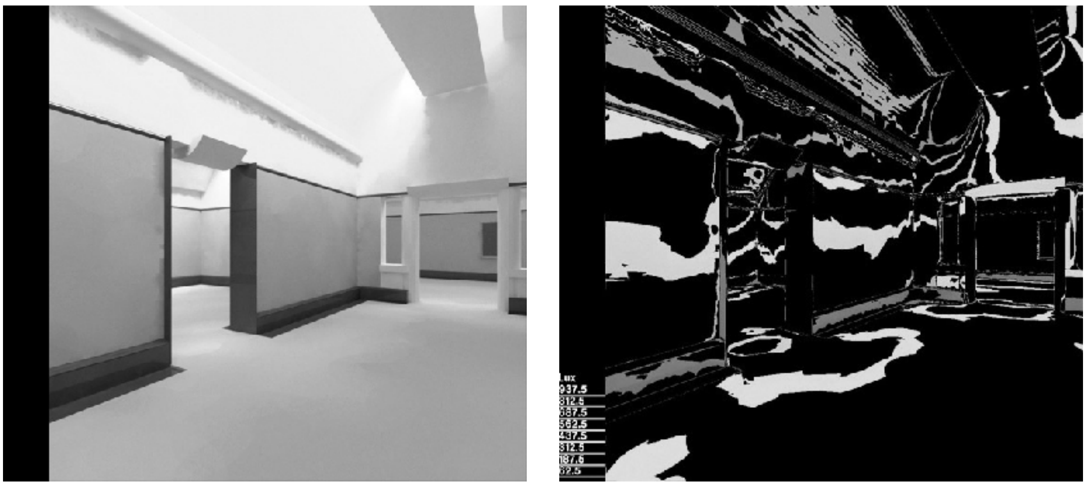

Figure 2. Light simulation (by A.M.J. Post)

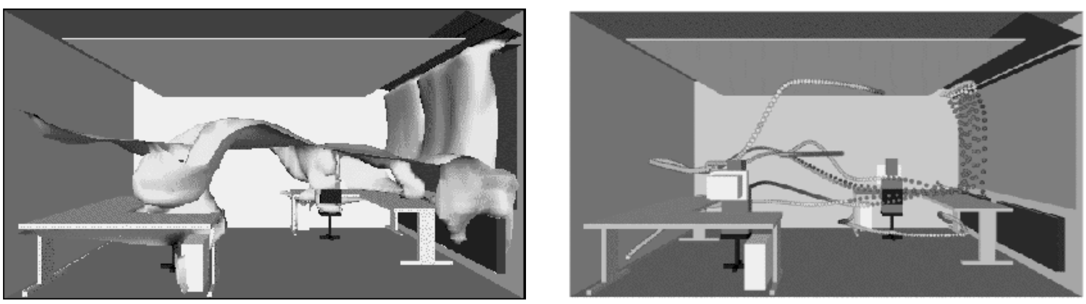

Figure 3. Airflow simulation (by H. Middelkoop)

Virtual design prototyping

What emerges as the common element of all forms and levels of design information management is a central representation that may have various structures, usually depending upon the underlying approach, and may vary from holistic to modular. Such a representation plays a crucial role in the registration and communication of design activities and decisions. However, the investment in time and effort required for creating and maintaining this representation still remains disproportionate to the expected return. The true potential of this central representation lies in *virtual design prototyping*: the development of a complete, consistent and responsive virtual description of a design's form, function, behaviour and performance. This description registers design actions but also propagates and evaluates them by means of realistic simulations of building behaviour and performance (including interaction with human activities). This is achieved by the convergence of ICT for design representation, decision support, analysis and simulation, presentation and communication towards an integrated, coherent and consistent information system that describes fully the design product (including its history). A virtual prototype supports:

1. *Reduction of design and production time:* fabrication and evaluation of experimental prototypes, e.g. full-scale modelling [11], is generally prohibitive for low-volume customized products such as buildings. Virtual prototypes also permit reduction of time and effort involved in iterative situations, as they transform sequences of discrete steps into concurrent actions.
2. *Cost reduction,* as less physical prototypes are required but also because of the high specificity of a virtual prototype and its correlation with manufacturing technologies and processes, including by means of rapid prototyping.
3. *Quality improvement* through the rapid development and evaluation of alternatives, as well as through the integration and high specificity of all relevant aspects in a virtual prototype. High specificity and completeness are also beneficial for analysis, as they facilitate advanced, accurate and precise simulations.
4. *Process optimisation:* arguably one of the most crucial contributions of virtual prototyping to the improvement of architectural performance concerns the ability to reshape architectural processes and test the emerging solutions in virtual environments. This is invariably associated with a move away form rigidly demarcated tasks towards flexible, adaptive networks that provide a transparent and responsive background to cooperation and concurrency [15, 16].

From the above we can formulate a number of basic principles for virtual design prototyping:

- *ICT minimalism:* reduction of redundancy in the techniques used and avoidance of technological exhibitionism, so as to minimize the practical burden of ICT without diminishing effectiveness
- *Utility beyond practical purposes,* i.e. not merely facilitating existing professional patterns and procedures by actively explore why and how these should be redefined. This also creates attention for domain priorities largely neglected in computerization and management, such as morphology and typology, which may redefine domain and methodical knowledge.
- *Synchronicity:* this is a fundamental difference with design information management where asynchronous modes are actually encouraged. Synchronicity in virtual prototyping is a prerequisite to concurrency and integration at the practical and technical level.

These apply to the four basic dimensions of a virtual prototype:

1. *Form*: representation of structure and appearance
2. *Function*: representation of activities and actors to be accommodated in the design
3. *Behaviour*: projection and simulation of how the form and the functional content of the design operate as systems comprising autonomous, interacting entities
4. *Performance*: evaluation of design and building performance through the correspondence between form and function and analysis of the design's behaviour

Representation

Probably the most significant lesson from a bottom-up evolution of design information management into virtual prototyping concerns the level of integration that can be achieved by proscriptive standardization: schemes like STEP and IFC may exhibit uncertainties and inadequacies due to confusion between means and ends, resulting into overconstrained data representations concerning just form rather than an overall framework for design [17]. Moreover, the imposition of Esperantist integrated models as a central structure actually impedes direct communication between aspects (direct translation), as well as experimentation with alternative approaches and emerging technologies [18]. Rather than relying on the imposition of order onto a complex and possibly vague network of tasks, actions and relations, we choose to acknowledge this network as one of the main factors of architectural creativity and attempt to improve consistency and coherence by facilitating and constraining (in a positive sense) the difference nodes in the network. The transition from design information management to virtual prototyping involves reduction of redundancy and completion of partial information, preferably through the recognition of relationships between partial descriptions, as well as with background information, including precedents. The purpose of parsing representations and communicating meaning and associations still suggests the use of reference models. However, such reference models should arguably function similarly to a dictionary with syntactic and grammatical capabilities that operates in the background and improves user input and feedback in a transparent, responsive manner [19].

Communication and interaction

In terms of design communication, virtual prototyping improves on what is achievable in design information management mainly with respect to specificity and integration, resulting from the ability of a virtual prototype to cover issues that may be implicit in the representations used for specific aspects. Also significant is improvement in interaction with stored information. In a virtual prototype this interaction is not confined to the scope and abstraction level of a particular representation and its connection to other representations but extends to the complete structure, functionality, behaviour and performance of the artefact designed. This is facilitated by the use of immersive VR interfaces that allow for extensive interaction simulation [20, 21], including extensive ergonomic analyses [22, 23].

Discussion

The transition from design information management to virtual prototyping is rather straightforward in terms of purpose and functionality. However, this does not automatically resolve problems relating to structure and approach. Issues such as synchronicity, continuity and comprehensiveness may be beyond the evolutionary possibilities of current approaches to design information management and their implementations. Institutional standardizations are limited to only a part of the life cycle, primarily formal aspects and a small range of abstraction levels. Bottom-up correlation is too pragmatic to escape the ad hoc constraints of existing computerization approaches and techniques. Such limitations are particularly evident in the scope and expressive power of computer representations. The realism of digital building representation (similarly to perspective in the Renaissance) should not obscure their conventional character. The extension of architectural representation to virtual prototyping, in particular with respect to interaction and autonomy, presupposes a thorough revision that might lead to new directions.

A suitable starting point is general computational models of perception and recognition which provide a better understanding of perceptual and cognitive devices that also underlie architectural design and analysis. These devices determine the decomposition of a scene and its elements into simple parts, such as the head, the body, the legs and the tail of an animal. The manner of the decomposition into parts does not depend on completeness and familiarity. An unfamiliar, a partly obscured animal or even a nonsensical shape are decomposed in a more or less the same way by all observers [24]. The detection of where parts begin and end is based on the transversality principle which states that whenever two shapes are combined their join is almost always marked by matched concavities [25]. Segmentation of a form into parts usually occurs at regions of matched concavities, i.e. discontinuities at minima of negative curvature. The results of the segmentation are normally convex or singly concave forms. One might expect an unlimited number of part types. However, *recognition-by-components* theory proposes that these forms constitute a small basic repertory of general applicability, characterized by invariance to viewpoint and high resistance to noise. These forms, called *geons*, are only 24 in number [24, 26]. Relations between geons derive from a similarly small set of five edge properties. Use of such a cognitive basis for representation in virtual prototyping facilitates ICT minimalism and extends utility beyond what is achievable with digital versions of analogue drawings and supports user interaction, as well as representation of domain knowledge outside the practical domain covered by design information managements, e.g. morphology and building aesthetics [27].

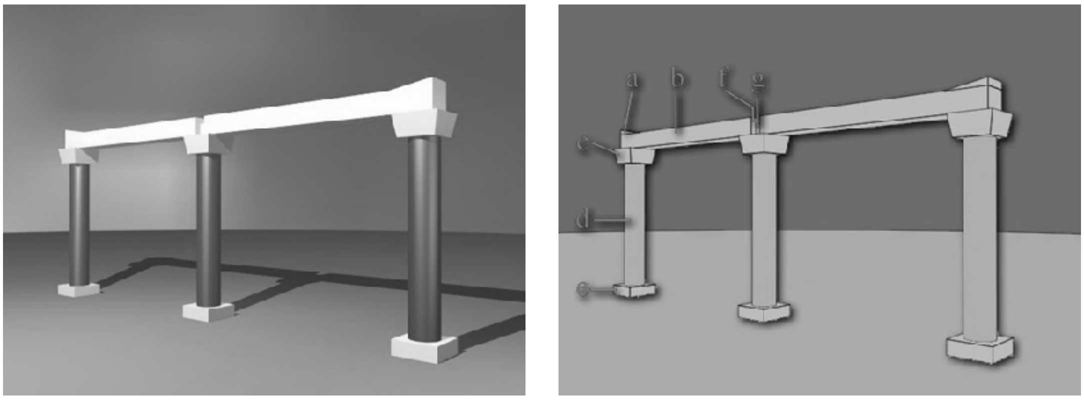

Figure 4. Architectural scene analysed in geons (left)

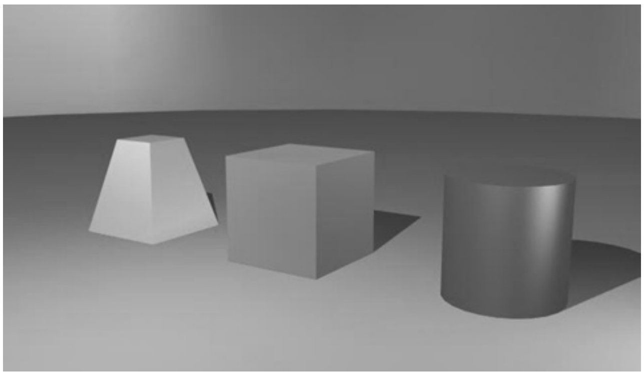

Figure 5. The geons in Figure 4

References

[1] A. Koutamanis, "Multilevel representation of architectural designs." in *Design and the net.* R. Coyne, M. Ramscar, J. Lee, & K. Zreik, Eds. Paris: Europia Productions, 1997.

[2] A. Koutamanis, "3 x 2 approaches to design management." in *Architectural information management.* H. Penttilä, Ed. Espoo: eCAADe & Helsinki University of Technology, 2001.

[3] A. Warszawski, *Industrialization and robotics in building.* New York: Harper & Row, 1990.

[4] G. Augenbroe & M. Prins, Eds. "Design management in the architectural and engineering office." CIB, Rotterdam 2001.

[5] M. v. Leusen & V. Mitossi, "A practical experiment in representation and analysis of buildings." in *4th Design and Decision Support Systems in Architecture and Urban Planning Conference.* Eindhoven, 1998.

[6] V. Mitossi & A. Koutamanis, "Spatial representations as the basis of formal and functional analysis." in *4th Design and Decision Support Systems in Architecture and Urban Planning Conference.* Eindhoven, 1998.

[7] M. Burry, J. Burry, & J. Faulí, "Sagrada Familia Rosassa: global computer-aided dialogue between designer and craftsperson overcoming differences in age, time, and distance." in *Reinventing the discourse.* W. Jabi, Ed. Buffalo, New York: ACADIA, 2001.

[8] B. Kolarevic, "Designing and manufacturing architecture in the digital age." in *Architectural information management.* H. Penttilä, Ed. Espoo: eCAADe, 2001.

[9] F. Ozel, "Architectural knwoledge and database management systems." in *Promise and reality.* D. Donath, Ed. Weimar: eCAADe & Bauhaus-Universität Weimar, 2000.

[10] A. Mahdavi, P. Mathew, et al., "Bi-directional computational design support in the SEMPER environment." *Automation in Construction*, vol. 6, pp. 353-373, 1997.

[11] A. Koutamanis & V. Mitossi, "Simulation for analysis: Requirements from architectural design." in *Full-scale modeling in the age of virtual reality*. B. Martens, Ed. Vienna: OKK, 1996.

[12] D. Hanser, G. Halin, & J.-C. Bignon, "Relation-based groupware for heterogeneous design teams." in *Architectural information management*. H. Penttilä, Ed. Espoo: eCAADe, 2001.

[13] A. Koutamanis & J. P. d. Hartog, "Simulation and representation: learning from airflow analyses in buildings." in *Computer aided architectural design futures 2001*. B. de Vries, J. van Leeuwen, & H. Achten, Eds. Dordrecht: Kluwer, 2001.

[14] A. Koutamanis, M. van Leusen, & V. Mitossi, "Route analysis in complex buildings." in *Computer aided architectural design futures 2001*. B. de Vries, J. van Leeuwen, & H. Achten, Eds. Dordrecht: Kluwer, 2001.

[15] K. Fliess & A. Jain, "Information technology, a catalyst for process optimization." in *Virtual prototyping. Virtual environments and the product design process*. J. Rix, S. Haas, & J. Teixeira, Eds. London: Chapman & Hall, 1995.

[16] J. Wagner & W. Steger, "Rapid prototyping: An approach beyond manufacturing technology." in *Virtual prototyping. Virtual environments and the product design process*. J. Rix, S. Haas, & J. Teixeira, Eds. London: Chapman & Hall, 1995.

[17] M. S. Bloor, A. McKay, et al., "Product *and* shape representation for virtual prototyping." in *Virtual prototyping. Virtual environments and the product design process*. J. Rix, S. Haas, & J. Teixeira, Eds. London: Chapman & Hall, 1995.

[18] J. Ovtcharova & A. S. Vieira, "Virtual prototyping through feature processing." in *Virtual prototyping. Virtual environments and the product design process*. J. Rix, S. Haas, & J. Teixeira, Eds. London: Chapman & Hall, 1995.

[19] A. Koutamanis & V. Mitossi, "A "spelling" checker for architectural drawings." in *CAADRIA 2001*, J.S. Gero, S. Chase, & M. Rosenman, Eds. Sydney: Key Centre of Design Computing and Cognition, 2001.

[20] H.-J. Bullinger, R. Breining, & W. Bauer, "Virtual Prototyping: state of the art in product design." presented at 26th International Conference on Computers *and* Industrial Engineering, Melbourne, 1999.

[21] J. M. Hollerbach, E. Cohen, et al., "Virtual prototyping for human-centric design." presented at 2000 NSF Design and Manufacturing Research Conference, Vancouver, 2000.

[22] V. Krovi, V. Kumar, et al., "Design and virtual prototyping of rehabilitation aids." *ASME Journal of Mechanical Design*, vol. 121, pp. 456-458, 1999.

[23] J. Deisinger & R. Breining. "Ergonaut: A tool for ergonomic analyses in virtual environments." in *Virtual Environments 2000. Proceedings of the 6th Eurographics Workshop on Virtual Environments*. J.D. Mulder & R. v. Liere, Eds. Vienna: Springer, 2000.

[24] I. Biederman, "Recognition-by-components: A theory of human image understanding." *Psychological Review*, vol. 94, pp. 115–147, 1987.

[25] D. D. Hoffman & W. Richards, "Parts of recognition." *Cognition*, vol. 18, pp. 65-96, 1985.

[26] I. Biederman, "Visual object recognition." in *Visual congition. An invitation to cognitive science. 2nd ed.* S. M. Kosslyn & D. N. Osherson, Eds. Cambridge, Massachusetts, 1995.

[27] A. Koutamanis, "On the evaluation of figural architectural goodness: A foundation for computational architectural aesthetics." in *CAAD Futures 1997*, R. Junge, Ed. Dordrecht: Kluwer, 1997.