

COMPUTATION: THE NEW REALM OF ARCHITECTURAL DESIGN

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edited by Gülen Çağdaş and Birgül Çolakoğlu

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Contents

Preface 5

Session 01: Digital Aids To Design Creativity 1 19

Beyond Representation 21
Real Time Form Finding of Tensegrity Structures with 3D ‘Compressed’ Components
Jerome Frumar, Yiyi Zhou

TetraScript: Development of an Integrated System Capable of Optimizing Light in a Circumscribed Space 31
Gonçalo Castro Henriques, José Pinto Duarte, António Carvalho Brito

Cylindrical Mesh Morphologies 39
Study of Computational Meshes Based on Parameters of Force, Material, and Space for the Design of Tension-Active Structures
Moritz Fleischmann, Sean Ahlquist

On Shells, Structural Landscapes and Performative Geometry 47
Oliver Tessmann, Klaus Bollinger, Manfred Grohmann

Tensegrity Structures of Helical Shape 53
A Parametric Approach
Katherine Liapi, Jinman Kim

Session 02: Digital Applications in Construction 59

Dynamic Coordination of Distributed Intelligence in Design 61
Tuba Kocatürk, Ricardo Codinhoto

Building Survey in Combination with Building Information Modelling for the Architectural Planning Process 69
Roland Göttig, Jörg Braunes

Building Information Modeling in the Architectural Design Phases 75
And Why Compulsory BIM Can Provoke Distress Among Architects
Anders Hermund

Drawing Transparencies 83
‘Responsible Responsiveness’ in Spaces Through Organic Electrochromism
Daniel Cardoso, Avni Argun, Carlos A. Rocha, Jose Gonzalez

The Building Performance Perspective for Interoperability 89
Requirements for a Future Analysis Network
Mustafa Emre İlal

Session 03: New Design Concepts and Strategies 1 95

Constructive Interpretation in Design Thinking 97

Nick Kelly, John Gero

Immaterial-Material Reality, Computation and Architectural Design 105

Şebnem Yalınay Çinici

On Computational Design and Critical Thinking in Architecture 113

Thorsten Michael Loemker, Katharina Richter

Design Games as a Framework for Design and Corresponding System of Design Games 119

N. Onur Sönmez, Arzu Erdem

Session 04: CAAD Curriculum 1 127

Introducing Interdisciplinary Collaboration into Design Curriculum 129

Identifying the Appropriate Technological Infrastructure

Mustafa Emre İlal, Serdar Kale, Altuğ Yavaş

Virtual Space Design: A Flexible Learning Model 137

Respecting Fragile Places in Virtual and Physical Realities

Tadeja Zupancic, Matevz Juvancic

Role of Studio Exercises in Digital Design Education 145

Case Study of the Nine-Square Grid

Tuğrul Yazar, Oya Pakdil

Experimental Design-Build 153

Teaching Parameter-based Design

Rüdiger Karzel, Heike Matcha

Session 05: Generative Design 1 159

From Formal to Behavioral Architecture 161

Few Notes on the Abstraction of Function

Aaron Sprecher, Paul Kalnitz

An Emergent Form Generation Method for Supporting Conceptual Design 167

Ethem Gürer, Gülen Çağdaş

Structural Evolution 173

A Genetic Algorithm Method to Generate Structurally Optimal

Delaunay Triangulated Space Frames for Dynamic Loads

Aikaterini Papapavlou, Alasdair Turner

Associative Architectural Design 181

The Potential of Land Economical and Ecological Factors

in Determining Variations in Housing Design

Fairuz Reza Razali, Syed Sobri Zubir, Rashidah Ab. Rahman, Wan Azhar Sulaiman

Session 06: Digital Aids To Design Creativity 2189

State of Affairs - Digital Architectural Design in Europe 191

A Look into into Education and Practice – Snapshot and Outlook

Michael Knight, Wolfgang Dokonal

Digital as a Tool/Reference for Architectural Conception 197

Examples from Two Agencies: Ateliers Jean Nouvel and Jakob+MacFarlane

Anne-Sophie Delaveau, François Guéna, Caroline Lecourtois

A Virtual Design Platform 205

Bridging Barriers When Designing with Computers

Sven Schneider, Frank Petzold

Animation as a Framework for Generative Design 213

Theodoros Dounas

Session 07: Shape Studies 1219

Point Worlds 221

Athanassios Economou, Thomas Grasl

Revisiting Shape Embedding 229

Hacer Yalim Keleş, Mine Özkar, Sibel Tari

Shape Grammars and Historical Town Renovations: A Case Study in Monte Alegre Do Sul 237

Giovana de Godoi, Gabriela Celani

Editing Shapes in a Prototype 243

Two- and Three-dimensional Shape Grammar Environment

Andrew I-kang Li, Liang Chen, Yang Wang, Hau Hing Chau

Session 08: City Modelling 1251

Computational Ontology of Urban Design 253

Towards a City Information Model

Nuno C. Montenegro, José P. Duarte

Sharing 3D City Models: An Overview 261

Emine Mine Thompson, Margaret Horne

On the Discovery of Urban Typologies 269

Data Mining the Multi-dimensional Character of Neighbourhoods

Jorge Gil, Nuno Montenegro, José Nuno Beirão, José Pinto Duarte

The Hellenistic City Model Inspired by Koolhaas 279

A Test Case for a Generic City Model

Jan Halatsch, Myrsini Mamoli, Athanassios Economou, Gerhard Schmitt

Session 09: Modes of Production287

Integral Computational Design for Composite Spacer Fabric Structures 289

Integral Processes of Form Generation and Fabrication for

Sandwich Structured Composites with 3D Warp-Knitted Textile Core

Achim Menges

Twister 299

An Integral Approach Towards Digital Design and Construction

Marco Hemmerling

Design, Fabrication, Digital 305

Between digital design and digital fabrication

Shaghayegh Shadkhoo, Jean-Claude Bignon

Légumes Urbaines: Digital Modeling Transformations + Prototype Fabrication

Based on the Egg Crate Construction Method 313

Simos Vamvakidis

Digital Design to Digital Production 323

Flank Milling with a 7-Axis CNC-Milling Robot and Parametric Design

Sigrid Brell-Çokcan, Martin Reis, Heinz Schmiedhofer, Johannes Braumann

Session 10: Collaborative Design331

Sharing Design Space 333

Remote Concurrent Shared Parametric Modeling

Jane Burry, Dominik Holzer

**Formalizing and Computing Ontologies to Speed Up
the Construction of Knowledge-based Collaborative Systems** 341

Three Different Approaches

Antonio Fioravanti, Gianluigi Loffreda

UNITALKS 349

A Blended Learning Platform for University Specific

Foreign Language Training for Architecture Students

Farid Mokhtar Noriega, John D. Fynn, Mary McDonald-Rissanen

What Happened to Collaborative Design 357

Henri Achten, Jakob Beetz

An Ontology-based Knowledge Representation Model

for Cross-Disciplinary Building Design 367

A General Template

Gianfranco Carrara, Antonio Fioravanti, Gianluigi Loffreda, Armando Trento

Session 11: New Design Concepts and Strategies 2.....375

Value through Precision, Beyond the Realms 377

Onur Yüce Gün

Translating Material and Design Space 385

Strategies to Design with Curved Creased Surfaces

Martin Tamke, Mette Ramsgard Thomsen, Serdar Asut, Kristoffer Josefsson

Bottom-up Design Inspired by Evolutionary Dynamics 391

Adaptable Growth Model for Architecture

Taro Narahara

The “Formalization” of the In-Formal 399

Design and Materialization Evolution of ‘Paramana’ Square as a Case Study

Dimitris G. Kontaxakis, Spiros I. Papadimitriou

Session 12: Design Tool Development 1407

A Parametric-Typological Tool 409

More Diversity for Mass Produced Single Family Homes Through Parametrized Design and Customized Mass Production

Heike Matcha, Gero Quasten

CloudNets 417

A Workbench for Emergent Urbanism and Architectural Form

Tim Schork, Andrew Burrow, Paul Minifie

Plan Layout Generator (PLG) 425

A Rule-Based Plan Layout Generator for Mardin Houses

Belinda Torus, Birgül Çolakoğlu

A Computable Language of Architecture 431

Description of Descriptor Language in Supporting Compound Definitions

Sora Key

Session 13: CAAD Curriculum 2439

Ontology for Computational Design 441

Computational Methods versus Cultural Processes

Volker Mueller

Designer as a Casual Coder 449

Overview of an Experimental Design Studio

Birgül Çolakoğlu, Tuğrul Yazar

Algebraic Geometry in Architectural Design 455

Günter Barczik, Oliver Labs, Daniel Lordick

Art and Literature as a Teaching/Learning Interface of

Mathematics for Students of Architecture 465

Arzu Gönenç Sorguç, Semra Arslan Selçuk

Session 14: Precedence and Prototypes473

A Meta-Cognitive Inquiry into Digital Fabrication 475
Exploring the Activity of Designing and Making of a Wall Screen

Aslı Arpak, Larry Sass, Terry Knight

Media-Augmented Surfaces 483

Embedding Media Technology into Architectural Surface to Allow a Constant Shift Between Static Architectural Surface and Dynamic Digital Display

Matthias Hank Haeusler

Thermochromic Information Surfaces 491

Interactive Visualization for Architectural Environments

David van der Maas, Mark Meagher, Christian Abegg, Jeffrey Huang

Effect on Architectural Representation through Dynamic and Static Design Methods 497

Chung-Yang Wang

Session 15: User Participation in Design.....505

Value Lab: a Collaborative Environment for the Planning of Future Cities 507

Jan Halatsch, Antje Kunze, Gerhard Schmitt

Participative Technologies: an Internet-based Environment to Access a Plural Design

Experience 515

Knowledge Modeling to Support User's Requirements Formalization

Armando Trento, Gianluigi Loffreda, Gökçe Kinayöğlu

Using Virtual Worlds as Collaborative Environments for Innovation and Design 523

Lessons Learned and Observations from Case Studies in Architectural Projects

Ehsan Ehsani, Scott Chase

Collective Design Network 533

Systems Thinking (Event-Pattern-Structures) and System Dynamics Modelling as a Design

Concept and Strategy

Nilüfer Kozikoğlu, Meral Erdoğan, Ahmet Kutsi Nircan, Fulya Özsel Akipek

Session 16: Simulation, Prediction and Evaluation 1541

Whispering Wind 543

Digital Practice and the Sustainable Agenda

Christophe Barlieb, Christoph Richter, Björn Greschner, Martin Tamke

Eco-Models 551

Modeling of a Digital Tool to Design Sustainable Buildings

Vida Gholipour, Jean-Claude Bignon, Laure Morel Guimaraes

Airport Schiphol 559

Behavioral Simulation of a Design Concept

Thomas Krijnen, Jakob Beetz, Bauke de Vries

Digital Fabrication and Component Optimization Using DFM 565

Integrating Two-Dimensional Cutting and Three-Dimensional Milling in Wood Panel

Fabrication

Eduardo Lyon

Session 17: Generative Design 2573

An Urban Grammar for Praia 575

Towards Generic Shape Grammars for Urban Design

José Beirão, José Duarte, Rudi Stouffs

A Generative Urban Grammar for Portuguese Colonial Cities, During the Sixteenth to Eighteenth Centuries 585

Towards a Tool for Urban Design

Alexandra Paio, Benamy Turkienicz

“Improvising” Architecture: A Fractal Based Approach 593

Özgür Ediz

Container Post Disaster Shelters – C-PoDS 599

A Generative Approach to Temporary Post-Disaster Sheltering

Sinan Mert Şener, Belinda Torus

Combining Triples 605

Using a Graph Grammar to Generate Courthouse Topologies

Thomas Grasl, Athanassios Economou, Cassie Branum

Session 18: Virtual Architecture613

Studying the Impact of Immersion on Design Cognition 615

Leman Figen Gül

An Interactive Tool for the Exploration of Contextual Architecture 623

Case Study: 18th Century Prior Park, Bath

John Tredinnick, Marion Harney

Ludic and Didactic Paths in a Cultural Heritage Building 631

Prototype of a Learning System

Sandro Varano, Tristan Truchot, Jean-Claude Bignon

Using Audio-Augmented Reality to Assess the Role of Soundscape in Environmental Perception 639

An Experimental Case Study on the UC Berkeley Campus

Gökçe Kınayoglu

Augmented Reality- Effective Assistance for Interior Design 649

Focus on Tangible AR study

Seung Yeon Choo, Kyu Souk Heo, Ji Hyo Seo, Min Soo Kang

Session 19: New Design Concepts and Strategies 3.....657

Systems 659

Constraining Functions Through Processes (and Vice Versa)

Gabriel Wurzer

Exploring Complex Forms in Nature Through Mathematical Modeling: A Case on Turritella

Terebra 665

Semra Arslan Selçuk, Arzu Gönenç Sorguç

Digital Architectonics in Practice 673

Aarhus Botanical Garden Hothouse Competition

Paul Shepherd

Biodigital Architecture 681

Alberto T. Estévez

Session 20: Shape Studies 2687

Refining the Computational Method for the Evaluation of Visual Complexity in Architectural

Images 689

Significant Lines in the Early Architecture of Le Corbusier

Josephine Vaughan, Michael J. Ostwald

Fractal Geometry of Architecture 697

Implementation of the Box-Counting Method in a CAD-Software

Wolfgang E. Lorenz

Fuzzy Rule Bases as a Tool of the History of Architecture 705

Application to the Analysis of Villas Designed by Adolf Loos

Zuzana Talašová, Henri Achten

Meta Form as a Parametric Design Language 713

Hsin-Yi Ho, Ming-Hung Wang

Session 21: Design Tool Development 2719

Material Systems 721

A Design Approach

Mads Brath Jensen, Henrik Rubæk Mortensen, Michael Mullins, Poul Henning Kirkegaard

A Data-Cluster Analysis of Façade Complexity in the

Early House Designs of Peter Eisenman 729

Michael J. Ostwald, Josephine Vaughan

Blender, an Open Source Design Tool: Advances and Integration in the Architectural

Production Pipeline 737

Theodoros Dounas, Alexandros Sigalas

Aided Architectural Sketching with Markov Models 745

Dromies and Recognition

Guéna François, Lecourtois Caroline

Comparison of Designers' Modeling Approaches During Architectural Design Process 753

Sema Alaçam Aslan, Gülen Çağdaş

Session 22: CAAD Curriculum 3759

Using Computers to Aid Creativity in the Early Stages of Design – or Not! 761
Rehabilitating the 2D/3D Physical Representation in Computer-Aided-Ideation

Tim Nøhr Elkær

Cognitive Styles and Performance in Traditional Versus Digital Design Media 769

Şule Taşlı Pektaş

The Impact of the Digital Design Process on a Traditional Design Studio 773

Comparative Analysis on the Impact of the Digital Design Process on a Traditional Design Studio

Bülent Onur Turan, Murat Soygeniş

Models of / Models for Architecture 781

Physical and Digital Modelling in Early Design Stages

Corneel Cannaearts

Experiment Digital Space: Composition with Elements Designed by

Mies van der Rohe and the Importance of their Web Presentation 787

Didactical Design Methods Applied in Design Studios for Architectural and Cultural Sciences in Brazil, University of São Paulo and in Germany, Leuphana University of Lüneburg

Ursula Kirschner, Anja Pratschke

Session 23: Simulation, Prediction and Evaluation 2793

Embodied Game Agents in Environmental Design Education 795

Ahmed Sarhan, Peter Rutherford

Animation vs. Simulation 803

Togan Tong, Erdal Devrim Aydın, S. Emre Pusat

Modelling the Ionic Capital 809

Paul Richens, Georg Herdt

Evolution of Design Support Methods – from Formal Systems to Environment 817

Aleksander Asanowicz

Session 24: City Modelling 2825

Reading Urban Spaces by the Space Syntax Method 827

A Proposal for the South Haliç Region

Deniz Erinsel Önder, Yıldırım Gici

Digital Monumentality in/for Public Spaces 835

Ahu Sökmenoğlu, Sevgi Türkkan

HYBRIDS 843

Urban Systems and Information

Marcella Del Signore, Bradley Cantrell, Barbara Roppo

Index of Authors.851

Formalizing and Computing Ontologies to Speed Up the Construction of Knowledge-based Collaborative Systems

Three Different Approaches

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Abstract: *Architectural design is a purpose-oriented collective process defined in time, split up into phases, carried out directly or indirectly by numerous professional profiles and characterized by the co-presence of numerous disciplines and specialist skills. The efficiency of a shared design among multiple designers depends on how much the actor's semantics of the used terms are interpreted correctly by all the other actors involved in the design process without misunderstandings. The chosen way to find an answer to these questions is the development of a Collaborative Architectural Design system based on Knowledge formalized by Ontologies. An ontology has been implemented using three different approaches to define an entity based on Lisp, Protégé and Altova.*

Keywords: *Collaborative architectural design; knowledge-based systems; ontologies; knowledge structure.*

Computational design

Computational design endeavours to quantify the desired properties, characteristics and behaviours (as humans always want to 'quantify' countable AND uncountable entities) of a building organism, which may be considered as a system – structured set of Spaces and Building Components designed to satisfy certain goals. This is a systemic conception of buildings: the only one that allows to formalize and compute function and behaviour. These goals may vary widely: from an epic achievement for one's era to which to dedicate one's entire life – the pyramids; or more prosaically, the construction of a sludge containment tank.

The importance of calculation in a society has always been fundamental (for instance, the incunabula used by the Sumerians for accounting purposes marked the birth of the alphabet) (Diamond, 1998). It has increased in complexity in an exponential fashion, from Pascal's machines to those of Babbage (Losano, 1973) to transistors and to the present-day networked computers. Likewise the subject of calculation was first the data, then structured data and lastly highly abstract concepts.

This exponential quantitative increase entrains a quantum leap: the increase in the memory element from 8-16-32-64-128 bits paralleled the transition from word processing to A.I. processing; the memory quantum leap from KBs to PBs has allowed entire knowledge libraries to be stored (significantly,

human memory may be quantified as around 10 TB). Conceptually this is the same difference as between a simple addition operation and Plato's *Cratylus*.

In line with this trend, we take for granted that anything that can be expressed lexically can be computed and be used for designing. However, we are aware of the limitations and ambiguities of all formal systems (Hofstadter, 1984), as well as of the fact that our hardware (our senses and our mind, at least in the basic sense, the capacity to interpret sensory data) helps us filter out the various ambiguities. In this sense, we are in agreement with the studies by Tagliasco (Manzotti e Tagliasco, 2001) that it is only by equipping the machines with sensitivity capability that they can perform intelligent tasks, i.e. to pass Turing's machine test. The sensory data (hot-cold, sight, smell, etc.) contextualize the formal expressions that describe reality. The classical example is Simon's ambiguity of the proposition "I saw the men on the hill with the telescope" (Simon, 1996, p. 79) that can be resolved by sensitivity tools interfaced with traditional A.I. tools.

Taking into consideration these limitations typical of existing design support tools, the field investigated consists of that of knowledge-based architectural design support systems, with specific reference to those referring to collaborative design.

This raises additional problems insofar as the 'entities' made up of quantities (= physical characteristics) and concepts (= non physical characteristics) on which computations are performed are 'manipulated by several hands': the actors (Wix, 1997) in the design process.

For this reason it is necessary to observe more attentively the design process as it exists today in architecture.

Architectural design process

Architectural design is a purpose-oriented collective process defined in time, split up into phases, carried out directly or indirectly by numerous professional profiles (all denoted as 'actors'), and characterized by

the co-presence of numerous disciplines and specialist skills which is part of a broader process aimed at the construction, maintenance, and ultimately the recovery or demolition of buildings (Carrara et al., 2009).

Once the actors have acquired the necessary information (books, reviews, on-line libraries, codes, etc.), reprocessed their own experiences and laid down their own design solutions, they ultimately have to interact with the other actors in such a way as to reciprocally combine into the overall design solution to which they all contribute by means of their own partial solutions they gradually develop. To make it possible, actors have to correctly understand of the information associated with the entities they often concurrently manipulate that make up the overall design solutions.

The deep differences in the actors' cultural and technical background, which are the outcome of a wide range of different professional and training experiences, are reflected in the extremely varied ways in which any actor knows and considers the entities (objects and processes, properties and relations) involved in the building process, that makes it extremely difficult for the actors to understand each other.

Till now exchanging contents, even among commercial applications has been very difficult to be done. As a matter of fact the export of proprietary BIMs, from their own file formats to the correspondent IFC one, are not equivalent due to their own different primary conceptual models of the building. Moreover, even though different specialist actors use the same integrated application tool (e.g. Revit, Triforma, etc.), the entities they consider can have different meanings and behaviours as belonging to different specialist domains.

As an instance, a window assumes different meanings and representations when related to different specialist domains (such as an architect's, structural engineer's, building scientist's and so forth) as the former ones are close linked to underlain models of the considered aspects of reality. From the point

of view of an architect, a window is an element of his/her knowledge domain that allows to relate each other interior with exterior of a building, how such a relationship is balanced, how much exterior is enjoyable from interior and the latter can be seen from the former, the rhythm that scans a façade, an element more or less important in comparison with a wall, etc. And its consequent representation-display, describing its form in a detailed or symbolic fashion with different scales.

For a structural engineer a window has many different functions: it is a aperture in a non load bearing wall and may be considered a lesser load, or else it is an absence of material in a shear-wall and a possible weak point of it. In the last case the representation is limited to the dimensions of the aperture and the weight of the window.

For a plant engineer, a window behaves as a 'flow tube' with reference to its energy contribution both to the whole building and to the rooms with which it is in direct contact in terms of heat, light and sound (which varies during the year, the day and each minute). Its representation involves its dimensions, its thermo-physical properties, and its colour, orientation, etc.

The physical element considered, the window, remains the same in actual reality although it is evident how its significance and function differ in the entities representing it in the three specialist domains. All these concepts particular for an actor are hard to understand for other actors.

Collaborative architectural design

With new technologies and the computers' network it's possible to think about a global work environment in which a building project can be (remotely) developed in a collaborative way so as actors of different disciplines with their own specific tools are involved in several collaborative design processes (Chen, 2004; Carrara and Fioravanti, 2007; Cheng, 2008).

The Collaborative Architectural Design can be improved by means of Knowledge Based Systems (KBSs) that allows designers to have an efficient support as they can 'capitalize' and 'managed' knowledge, expertise and experiences.

Nevertheless this promising approach has been proven successful in research programs, KBSs are remained at prototype level as the low growing process to implement them and as the ever increasing difficulties to check consistency and coherency (programmes must check every node in every chaining inheritance process). Both difficulties depend on the construction of KBSs: craft made, practically.

The low growing implementation is intensified by the rapid increase of professional skills in design process increasingly shows new specialist disciplinary fields. Moreover another element that thwarts the KBSs implementation is that in every field of knowledge, experts communicate by concepts at high level of abstraction with specific drawings, symbols and documents, according to their disciplinary field. That means usual instruments are used 'sur-reptitiously': not for directly carrying concepts, but for communicating symbols that other actors will 'decipher' ... In fact actors use their own terms and definitions to represent a building or component design by means of their own accustomed disciplinary jargon with which they can understand each other only within the same field (and sometimes not thoroughly).

The efficiency of a shared design among multiple designers depends on how much the actor's semantics (and successively, intentions and goals) of the used terms are interpreted correctly by all the other actors involved in the design process without any misunderstanding.

Our research aims at realizing a system that allows a mutual comprehension by means of a shared ontology among actors that realizes a true Collaborative Design as 'the ability to discuss a given topic at the same level of abstraction'. The main purpose is to create a collaborative working environment using

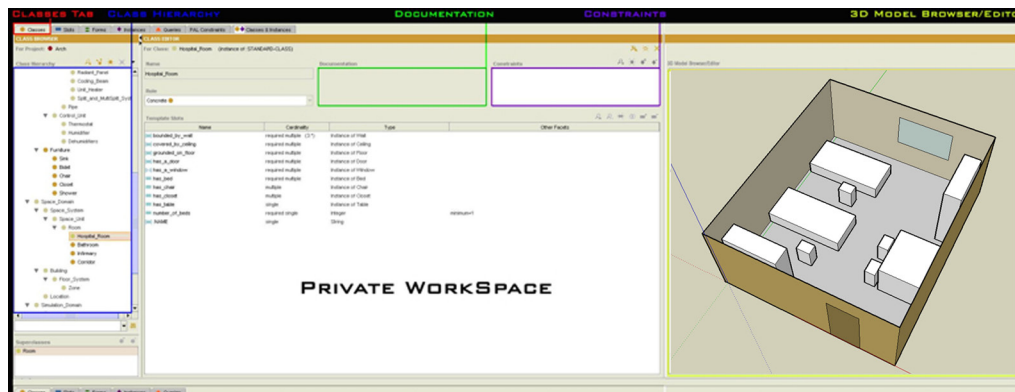


Figure 1
A screenshot of Architect's
Personal Design Workspace –
Arch. step1.0

usual known tools to the actors involved, the terminology they usually use and new instruments to map concepts during the entire process.

The interesting and innovative approach to deal with an effective implementation of entities for Knowledge Based Systems is the development of a multi dimensional model for ontology representation of different disciplines. Such a representation showing ontologies, constraints and design processes in a visual way helps actors to better understand the meanings of each entity according to the personal representation s/he chose. For any entity with multiple interacting actors, the representation allows an agreement between the ontologies of different disciplinary domains involved in the specific design process.

Allowing Multiple Shared Ontologies, each actor is free to map her/his own entities and meanings (his Private Knowledge) differently with the others ones according to the her/his own target within the overall project. An actor can also check all the constraints, both private and shared ones, using the implemented multi dimensional model editor and by the usual ICT tools. Hence the visual editor points out all the violated constraints implemented in ontologies and in semantics. In this way each actor is able to activate only the constraints s/he wants to check.

Sequence of a collaborative design session

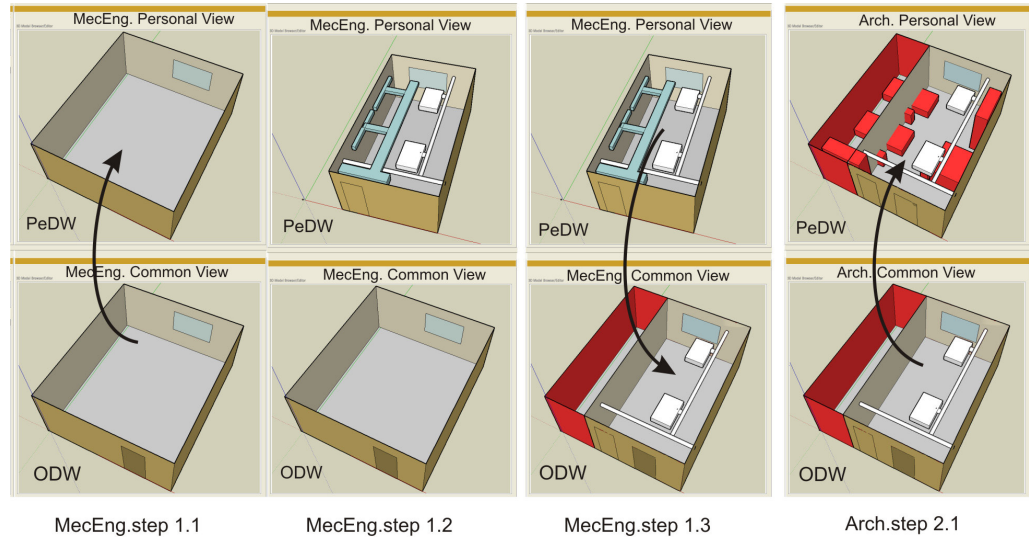
At the beginning of the project the Architect develops a layout of a patient room in her/is Personal Design Workspace – PeDW using her/is Specialist Knowledge Structure – SpKS with dimensions, furniture, door, window (Fig. 1, Arch.step1.0).

The dashboard of an actor allows to design in her/is own PeDW or directly in the Overall Design Workspace, ODW with her/is constraints, using her/is SpKS filtered entities. i.e. every entity of her/is SpKS is exported in this environment that s/he can see inside her/is dashboard by Common View of Project, and that can be conceived like a 'Test' DW as the ODW is influenced by constraints of other actors SpKS.

Then s/he filters this instance to the Common View, for ex. hiding the furniture. Notice that at this step s/he has not published yet to the ODW, so nobody can see anything nor can be influenced by her/is constraints.

After the Architect's design solution Arch. step 1.1 has been published, the Mechanical Engineer links to the server and 'privatizes' this design solution (Fig. 2, MecEng. step1.1) in her/is PeDW, then s/he includes this design solution in her/is PeDW by

Figure 2
Sequence of a collaborative
architectural design session:
MECEng. and ARCH steps



enriching data through the Filter (Fioravanti, 2008), and develops the project with her/his instruments adding her/his specialist entities (A.C. equipments, A.C. ducts); and/or modifying all entities s/he can see, for instance s/he moves the wall and makes the patient room shorter (Fig. 2, MecEng.step.1.2).

When the Mechanical Engineer considers her/his design solution ready to be published on the ODW, s/he can filter the instances/properties/rules s/he wants to hide to other actors (for instance air ducts, but not A.C. equipments) and then publishes her/his design solution in the ODW. The system finds out conflicts among instances changed by different authors pointing out each change (in red) (Fig. 2, MecEng.step.1.3).

Then the Architect imports this new design proposal from the ODW into her/his PeDW, checks it by means of her/his specialist constraints/rules/requirements, and s/he is warned the interference between the wall moved by the Mechanical Engineer and the furniture (Fig. 2, Arch.step.2.1).

Three representations for an ontology based design

The chosen way to find an answer to these questions is the development of a Collaborative Architectural Design system based on Knowledge formalized by several Ontologies that can significantly improve collaboration between different specialists (Ugwu, 2005; Fioravanti, 2008).

One of the greatest difficulties in this field is how to rapidly formalize the prototype entities making up the ontology of a specialist actor.

So far we have taken into consideration three types of formalization to model Systemic Knowledge of Building and its entities (components, building parts, characteristics, constraints, relationships) using different tools like Lisp, Protégé and Altova.

The first implementation was performed using pure Lisp. In this way it was possible to manipulate the instantiation and the inference engine 'on the fly' and to modify the characteristics of the entities



relatively freely and precisely, indeed ad hoc, but at the cost of a artisanal implementation.

The main characteristic of the entities is related to the 'type' of entity: the membership 'class'. This one is formalized by means of a custom made frame structure, similar to the one investigated by McCarthy, by means of an ISA slot (Is-A).

The advantage of being able to manipulate also this level of an entity's structure (which we may term a knowledge atom) is not only being able to change the inheritance of an entity but also to mix entity assemblies. The freedom we are given by this formal logic enables us to compose an entity of a class (whole-of, or assembly of) also from entities of different classes belonging from heterogeneous domains, for ex. Space domain and Building Component domain.

In our case we implemented the System of Spaces which, together with the System of Building Components, contribute to fully defining a building so that the two systems (normally separate) can be interfaced directly through an inversion of the inheritance relationship (a slot in the frame structure) with the assembly one.

At the time of instantiation this peculiarity makes it possible to simultaneously verify the constraints that are normally found on 'orthogonal' logical planes: classes and assemblies. As a matter of facts this approach, from a logical point of view, is

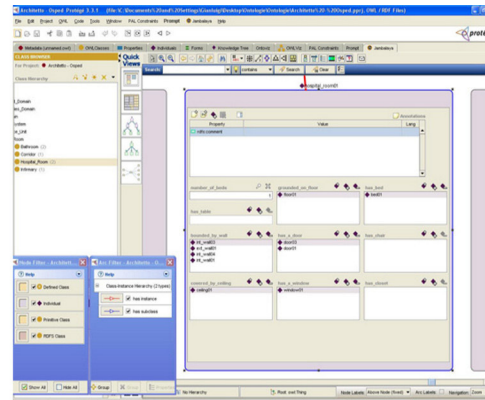


Figure 3
Main classes and an instance
visual representation

not rigorous, but in architectural design practice has been used from centuries.

A second approach to the formalization of the entities linked to building design was using an open-source tool: Protégé. The model of the building entities was formalized according to a the three-fold structure based on 'Meaning-Properties-Rules'.

The above-mentioned ontology editor not only allows class names to be attributed, extended meanings associated with them (descriptions) and properties (functions and fields to which values of a specific predetermined 'type' may be attributed), but also makes it possible to define, within the entity considered, a set of rules associated with them that determine relations between them and other entities, instances or attributes, in terms of constraints/specifications and/or goals of the design solution (Fig. 3).

In this case, the distinction between entity 'meaning' (name and description), 'properties' (slots and associated attributes) and 'relations' is sharp and well defined. The rules, in particular, are formalized by means of a software development kit (SDK) the PAL – Protégé Axiom Language; they operate on the instances of the ontology and establish relations, constraints and specifications associated with the entities to which they are applied.

The constraints checking and verification, as it is separated from the definition of the entity, is not contemporaneous with the instantiation of the

object and so the processes of verification and control of consistency, coherence and congruence are necessarily subsequent to the completion of the instantiation of the entities involved in the design solution.

Altova SemanticWorks® is another tool used by the authors to model entities involved in building design. In this case, although using the same formal language – the Ontology Web language (OWL) – used in Protégé, as no rule editing tool is provided (if-then protocols, verification cycles and/or normal computation operations), the set of verification and control processes must necessarily be developed outside the actual modelling process using different tools and combining them later. The user is therefore asked to verify the coherence of the rules implemented externally using the ontology implemented on SemanticWorks®. The approach followed by the authors was to implement rules using the above-mentioned PAL, exporting them in OWL and subsequently importing them into a SemanticWorks® formalized ontology. An inheritance type association is created between the rules and a ‘remote’ class denoted as PAL-CONSTRAINTS with which the concepts PAL-NAME, RANGE and STATEMENT specific to rule definition in Protégé are associated as properties of the PAL-CONSTRAINTS class.

Unlike the first approach proposed, the formalization by means of Altova and Protégé does not involve any internal ‘reflexive and dynamic modification’ capacity: it does not allow changes of its own structure except by means of a new edition/version of the entire or partial ontology.

Conclusions

In architectural/building design and construction the co-presence of numerous disciplines, specialist skills, actors and processes makes it very difficult to produce design syntheses of the problems pertaining to building, including architectural form, construction technology, load-bearing structures, engineering aspects, energy, and costs. These difficulties,

which may be all the greater the more ‘creative’ the design is, are often aggravated by misunderstandings, lack of data, privacy, ownership, and the different aims pursued by the various actors, owing to the closer links that exist between actors, activities, resources and culture.

The ontology based approach can suitably support a true collaboration among actors that often have competences overlapping each other and that are jointly responsible, so as they have a mutual interest in a successful outcome of their work.

The three representations aforesaid have positive aspects and drawbacks.

The first one, pure frame approach (in Lisp), has the ability to change on the fly the inheritance structure of an ontology without any new implementation of entities and as a consequence can support ‘aspects’ of the same instance, can mix the path of instantiation pursued by an inference engine, but till now can be implemented only with craftsmanship, oppositely any Sensitive Language Editor (the first one came from Digital Equipment Corporation!) imposes a fixed and uniform implementation.

The second, Protégé, has an excellent user interfaces and a powerful rule editor SDK, it is easier to interface with graphic programmes than the two others, but it is impossible to change rules during the elaboration process.

The third one, Altova, is a robust ontology editor with a well defined precise structure, intuitive user interface, but it lacks SDK tools, and it does not allow a dynamic object oriented programming.

All these representations speed up the implementation of well formed knowledge, that in turn makes knowledge-based system content rich.

Therefore from these considerations and after testing a few simple design problems it was evident that to develop an effective ontology for specialist actors of architectural design process it should be used a mix of these representation tools. Altova and Protégé may fulfil the exigency of Lower-Ontology Level and an open frame structure fits Upper-Ontology Level (Fioravanti, 2008).

The so defined ontology contributes to speed up the implementation a Knowledge-based Collaborative Design system for architectural design that, on the one hand, can avoid common mistakes, support consistency, coherence and the requirements of the project; on the other hand, by sharing knowledge, can improve the mutual awareness of design choices and spread innovations.

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Index of Authors

Ab. Rahman, Rashidah	181	Dokonal, Wolfgang	191
Abegg, Christian	491	Dounas, Theodoros	213, 737
Achten, Henri	357, 705	Duarte, José Pinto	31, 253, 269, 575
Ahlquist, Sean	39	Economou, Athanassios	221, 279, 605
Alaçam Aslan, Sema	753	Ediz, Özgür	593
Argun, Avni	83	Ehsani, Ehsan	523
Arpak, Asli	475	Elkær, Tim Nøhr	761
Arslan Selçuk, Semra	465, 665	Erdem, Arzu	119
Asanowicz, Aleksander	817	Erdoğan, Meral	533
Asut, Serdar	385	Erinsel Önder, Deniz	827
Aydın, Erdal Devrim	803	Estévez, Alberto T.	681
Barczik, Günter	455	<u>Fioravanti, Antonio</u>	<u>341</u> , 367
Barlieb, Christophe	543	Fleischmann, Moritz	39
Beetz, Jakob	357, 559	François, Guéna	745
Beirão, José Nuno	269, 575	Frumar, Jerome	21
Bignon, Jean-Claude	305, 551, 631	Fynn, John D.	349
Bollinger, Klaus	47	Gero, John	97
Branum, Cassie	605	Gholipour, Vida	551
Braumann, Johannes	323	Gigi, Yıldırım	827
Braunes, Jörg	69	Gil, Jorge	269
Brell-Çokcan, Sigrid	323	Gonzalez, Jose	83
Brito, António Carvalho	31	Gönenç Sorguç, Arzu	465, 665
Burrow, Andrew	417	Göttig, Roland	69
Burry, Jane	333	Grasl, Thomas	221, 605
Cannaerts, Corneel	781	Grescher, Björn	543
Cantrell, Bradley	843	Grohmann, Manfred	47
Cardoso, Daniel	83	Guéna, François	197
Carrara, Gianfranco	367	Guimaraes, Laure Morel	551
Celani, Gabriela	237	Gül, Leman Figen	615
Chase, Scott	523	Gün, Onur Yüce	377
Chau, Hau Hing	243	Gürer, Ethem	167
Chen, Liang	243	Halatsch, Jan	279, 507
Choo, Seung Yeon	649	Hank Haeusler, Matthias	483
Codinhoto, Ricardo	61	Harney, Marion	623
Çağdaş, Gülen	167, 753	Hemmerling, Marco	299
Çolakoğlu, Birgül	425, 449	Henriques, Gonçalo Castro	31
De Godoi, Giovana	237	Herd, Georg	809
De Vries, Bauke	559	Hermund, Anders	75
Del Signore, Marcella	843	Ho, HsinYi	713
Delaveau, Anne-Sophie	197	Holzer, Dominik	333

Horne, Margaret	261	Mueller, Volker	441
Huang, Jeffrey	491	Mullins, Michael	721
İlal, Mustafa Emre	89, 129	Narahara, Taro	391
Jensen, Mads Brath	721	Nircan, Ahmet Kutsi	533
Joseffson, Kristoffer	385	Noriega, Farid Mokhtar	349
Juvancic, Matevz	137	Ostwald, Michael	689, 729
Kale, Serdar	129	Özkar, Mine	229
Kalnitz, Paul	161	Özsel Akipek, Fulya	533
Kang, Min Soo	649	Paio, Alexandra	585
Karzel, Rüdiger	153	Pakdil, Oya	145
Kelly, Nick	97	Papadimitriou, Spiros I.	399
Key, Sora	431	Papapavlou, Aikaterini	173
Kınayoğlu, Gökçe	515, 639	Petzold, Frank	205
Kim, Jinman	53	Pratschke, Anja	787
Kirkegaard, Poul Henning	721	Pusat, S. Emre	803
Kirschner, Ursula	787	Quasten, Gero	409
Knight, Michael	191	Razali, Fairuz Reza	181
Knight, Terry	475	Reis, Martin	323
Kocatürk, Tuba	61	Richens, Paul	809
Kontaxakis, Dimitris G.	399	Richter, Christoph	543
Kozikoğlu, Nilüfer	533	Richter, Katharina	113
Krijnen, Thomas	559	Rocha, Carlos	83
Kunze, Antje	507	Roppo, Barbara	843
Labs, Oliver	455	Rutherford, Peter	795
Lecourtois, Caroline	197, 475	Sarhan, Ahmed	795
Li, Andrew I-kang	243	Sass, Larry	475
Liapi, Katherine	53	Schmiedhofer, Heinz	323
Loemker, Thorsten Michael	113	Schmitt, Gerhard	279, 507
<u>Loffreda, Gianluigi</u>	<u>341</u> , 367, 515	Schneider, Sven	205
Lordick, Daniel	455	Schork, Tim	417
Lorenz, Wolfgang E.	697	Seo, Ji Hyo	649
Lyon, Eduardo	565	Shadkhov, Shaghayegh	305
McDonald-Rissanen, Mary	349	Shepherd, Paul	673
Mamoli, Myrsini	279	Sigalas, Alexandros	737
Matcha, Heike	153, 409	Soygeniş, Murat	773
Meagher, Mark	491	Sökmenoğlu, Ahu	835
Menges, Achim	289	Sönmez, N. Onur	119
Minifie, Paul	417	Sprecher, Aaron	161
Montenegro, Nuno C.	253, 269	Stouffs, Rudi	575
Mortensen, Henrik Rubæk	721	Sulaiman, Wan Azhar	181

Şener, Sinan Mert	599
Talašová, Zuzana	705
Tamke, Martin	385, 543
Tarı, Sibel	229
Taşlı Pektaş, Şule	769
Tessmann, Oliver	47
Thompson, Emine Mine	261
Thomsen, Mette Ramsgard	385
Tong, Togan	803
Torus, Belinda	425, 599
Tredinnick, John	623
Trento, Armando	367, 515
Truchot, Tristan	631
Turan, Bülent Onur	773
Turkienicz, Benamy	585
Turner, Alasdair	173
Türkkan, Sevgi	835
Vamvakidis, Simos	313
Van der Maas, David	491
Varano, Sandro	631
Vaughan, Josephine	689, 729
Wang, Chung-Yang	497
Wang, Ming-Hung	713
Wang, Yang	243
Wurzer, Gabriel	659
Yalim Keleş, Hacer	229
Yalınay Çinici, Şebnem	105
Yavaş, Altuğ	129
Yazar, Tuğrul	145, 449
Zhou, Yiyi	21
Zubir, Syed Sobri	181
Zupancic, Tadeja	137

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