COMPUTATION: 
THE NEW REALM OF ARCHITECTURAL DESIGN

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edited by Gülen Çağdaş and Birgül Çolakoğlu
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Prof.Dr. Gülen Çağdaş  
(cagdas@itu.edu.tr)  
İstanbul Technical University Faculty of Architecture  
Inst. of Science & Tech., Architectural Design Computing Graduate Programme  
İstanbul, Turkey

Assoc.Prof.Dr. Birgül Çolakoğlu  
(colak@yildiz.edu.tr)  
Yıldız Technical University Faculty of Architecture  
Inst. of Science & Tech., Computational Design Graduate Programme  
İstanbul, Turkey

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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 Ilal
Session 03: New Design Concepts and Strategies .......................... 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 .............................................. 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 .............................................. 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 2 ................................. 189
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 1 ................................................................. 219
Point Worlds 221
Athanassios Economou, Thomas Grasl
Revisiting Shape Embedding 229
Hacer Yalım Keleş, Mine Özkar, Sibel Tari
Shape Grammars and Historical Town Renovations: A Case Study in Monte Alegre Do Sul 237
Giovan 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 1 ............................................................... 251
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 Production .............................................287

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 Shadkhou, 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 Design .............................................331

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

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. Papadimtriou

Session 12: Design Tool Development 1

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 2

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 Prototypes ..............................................473
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 Kınayoğlu

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 Kozikoglu, Meral Erdogan, Ahmet Kutsi Nircan, Fulya Ozsel Akipak

Session 16: Simulation, Prediction and Evaluation 1 .....................541
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 2 .................................................................573
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 Architecture ..............................................................613
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 Kinayoğlu
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 Gönenc Sorguç
Digital Architectonics in Practice ........................................ 673
Aarhus Botanical Garden Hothouse Competition
Paul Shepherd
Biodigital Architecture ........................................ 681
Alberto T. Estèvez

Session 20: Shape Studies 2 ........................................ 687

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 2 ........................................ 719

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 3 .......................................................759
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 Cannaerts
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 2 .........................793
Embodied Game Agents in Environmental Design Education 795
Ahmed Sarhan, Peter Rutherford
Animation vs. Simulation 803
Togan Tong, Erdal Devrim Aydin, 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 2 ..........................................................825
Reading Urban Spaces by the Space Syntax Method 827
A Proposal for the South Haliç Region
Deniz Erinsel Önder, Yıldırım Gigi
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

Antonio Fioravanti¹, Gianluigi Loffreda²
¹,²Dept. Architecture and Urban Planning – Sapienza University of Rome
http://www.dau.uniroma1.it
¹antonio.fioravanti@uniroma1.it, ²gianluigi.loffreda@uniroma1.it

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
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...
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.step.1.0).

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. step.1.1) in her/is PeDW, then s/he includes this design solution in her/is PeDW by
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 enriching data through the Filter (Fioravanti, 2008), and develops the project with her/is instruments adding her/is 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/is 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/is 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/is PeDW, checks it by means of her/is 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).

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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 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 allows 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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References


## Index of Authors

<table>
<thead>
<tr>
<th>Name</th>
<th>Page Numbers</th>
<th>Name</th>
<th>Page Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ab. Rahman, Rashidah</td>
<td>181</td>
<td>Dokonal, Wolfgang</td>
<td>191</td>
</tr>
<tr>
<td>Abegg, Christian</td>
<td>491</td>
<td>Dounas, Theodoros</td>
<td>213, 737</td>
</tr>
<tr>
<td>Achten, Henri</td>
<td>357, 705</td>
<td>Duarte, José Pinto</td>
<td>31, 253, 269, 575</td>
</tr>
<tr>
<td>Ahlquist, Sean</td>
<td>39</td>
<td>Economou, Athanassios</td>
<td>221, 279, 605</td>
</tr>
<tr>
<td>Alaçam Aslan, Sema</td>
<td>753</td>
<td>Ediz, Özgür</td>
<td>593</td>
</tr>
<tr>
<td>Argun, Avni</td>
<td>83</td>
<td>Ehsani, Ehsan</td>
<td>523</td>
</tr>
<tr>
<td>Arpak, Aslı</td>
<td>475</td>
<td>Elkær, Tim Nøhr</td>
<td>761</td>
</tr>
<tr>
<td>Arslan Selçuk, Semra</td>
<td>465, 665</td>
<td>Erdogan, Meral</td>
<td>533</td>
</tr>
<tr>
<td>Asanowicz, Aleksander</td>
<td>817</td>
<td>Erinsel Önder, Deniz</td>
<td>827</td>
</tr>
<tr>
<td>Asut, Serdar</td>
<td>385</td>
<td>Estévez, Alberto T.</td>
<td>681</td>
</tr>
<tr>
<td>Barczik, Günter</td>
<td>455</td>
<td>Fioravanti, Antonio</td>
<td>341, 367</td>
</tr>
<tr>
<td>Barlieb, Christophe</td>
<td>543</td>
<td>Fleischmann, Moritz</td>
<td>39</td>
</tr>
<tr>
<td>Beetz, Jakob</td>
<td>357, 559</td>
<td>François, Guéna</td>
<td>745</td>
</tr>
<tr>
<td>Beirão, José Nuno</td>
<td>269, 575</td>
<td>Frumar, Jerome</td>
<td>21</td>
</tr>
<tr>
<td>Bignon, Jean-Claude</td>
<td>305, 551, 631</td>
<td>Fynn, John D.</td>
<td>349</td>
</tr>
<tr>
<td>Bollinger, Klaus</td>
<td>47</td>
<td>Gero, John</td>
<td>97</td>
</tr>
<tr>
<td>Branum, Cassie</td>
<td>605</td>
<td>Gholiopour, Vida</td>
<td>551</td>
</tr>
<tr>
<td>Braumann, Johannes</td>
<td>323</td>
<td>Gigi, Yıldırım</td>
<td>827</td>
</tr>
<tr>
<td>Braunes, Jörg</td>
<td>69</td>
<td>Gil, Jorge</td>
<td>269</td>
</tr>
<tr>
<td>Brell-Çokcan, Sigrid</td>
<td>323</td>
<td>Gonzalez, Jose</td>
<td>83</td>
</tr>
<tr>
<td>Brito, António Carvalho</td>
<td>31</td>
<td>Gönenç Sorguç, Arzu</td>
<td>465, 665</td>
</tr>
<tr>
<td>Burrow, Andrew</td>
<td>417</td>
<td>Götting, Roland</td>
<td>69</td>
</tr>
<tr>
<td>Burry, Jane</td>
<td>333</td>
<td>Grasl, Thomas</td>
<td>221, 605</td>
</tr>
<tr>
<td>Cannaerts, Conneel</td>
<td>781</td>
<td>Grescher, Björn</td>
<td>543</td>
</tr>
<tr>
<td>Cantrell, Bradley</td>
<td>843</td>
<td>Grohmann, Manfred</td>
<td>47</td>
</tr>
<tr>
<td>Cardoso, Daniel</td>
<td>83</td>
<td>Guéna, François</td>
<td>197</td>
</tr>
<tr>
<td>Carrara, Gianfranco</td>
<td>367</td>
<td>Guimaraes, Laure Morel</td>
<td>551</td>
</tr>
<tr>
<td>Celani, Gabriela</td>
<td>237</td>
<td>Gül, Leman Figen</td>
<td>615</td>
</tr>
<tr>
<td>Chase, Scott</td>
<td>523</td>
<td>Gün, Onur Yüce</td>
<td>377</td>
</tr>
<tr>
<td>Chau, Hau Hing</td>
<td>243</td>
<td>Gürer, Ethem</td>
<td>167</td>
</tr>
<tr>
<td>Chen, Liang</td>
<td>243</td>
<td>Halatsch, Jan</td>
<td>279, 507</td>
</tr>
<tr>
<td>Choo, Seung Yeon</td>
<td>649</td>
<td>Hank Haeusler, Matthias</td>
<td>483</td>
</tr>
<tr>
<td>Codinhoto, Ricardo</td>
<td>61</td>
<td>Harney, Marion</td>
<td>623</td>
</tr>
<tr>
<td>Çağdaş, Gülen</td>
<td>167, 753</td>
<td>Hemmerling, Marco</td>
<td>299</td>
</tr>
<tr>
<td>Çolakoğlu, Birgül</td>
<td>425, 449</td>
<td>Henriques, Gonçalo Castro</td>
<td>31</td>
</tr>
<tr>
<td>De Godoi, Giovana</td>
<td>237</td>
<td>Herdt, Georg</td>
<td>809</td>
</tr>
<tr>
<td>De Vries, Bauke</td>
<td>559</td>
<td>Hermund, Anders</td>
<td>75</td>
</tr>
<tr>
<td>Del Signore, Marcella</td>
<td>843</td>
<td>Ho, HsinYi</td>
<td>713</td>
</tr>
<tr>
<td>Delaveau, Anne-Sophie</td>
<td>197</td>
<td>Holzer, Dominik</td>
<td>333</td>
</tr>
<tr>
<td>Name</td>
<td>Page Numbers</td>
<td>Name</td>
<td>Page Numbers</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>--------------</td>
<td>-----------------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Horne, Margaret</td>
<td>261</td>
<td>Mueller, Volker</td>
<td>441</td>
</tr>
<tr>
<td>Huang, Jeffrey</td>
<td>491</td>
<td>Mullins, Michael</td>
<td>721</td>
</tr>
<tr>
<td>İlal, Mustafa Emre</td>
<td>89, 129</td>
<td>Narahara, Taro</td>
<td>391</td>
</tr>
<tr>
<td>Jensen, Mads Brath</td>
<td>721</td>
<td>Nircan, Ahmet Kutsi</td>
<td>533</td>
</tr>
<tr>
<td>Joseffson, Kristoffer</td>
<td>385</td>
<td>Noriega, Farid Mokhtar</td>
<td>349</td>
</tr>
<tr>
<td>Juvancic, Matevz</td>
<td>137, 689, 729</td>
<td>Ostwald, Michael</td>
<td></td>
</tr>
<tr>
<td>Kale, Serdar</td>
<td>129</td>
<td>Özkar, Mine</td>
<td>229</td>
</tr>
<tr>
<td>Kalnitz, Paul</td>
<td>161</td>
<td>Özsel Akipek, Fulya</td>
<td>533</td>
</tr>
<tr>
<td>Kang, Min Soo</td>
<td>649</td>
<td>Paio, Alexandra</td>
<td>585</td>
</tr>
<tr>
<td>Karzel, Rüdiger</td>
<td>153</td>
<td>Pakdil, Oya</td>
<td>145</td>
</tr>
<tr>
<td>Kelly, Nick</td>
<td>97</td>
<td>Papadimitriou, Spiros I.</td>
<td>399</td>
</tr>
<tr>
<td>Key, Sora</td>
<td>431</td>
<td>Papapavlou, Aikaterini</td>
<td>173</td>
</tr>
<tr>
<td>Kınayoğlu, Gökçe</td>
<td>515, 639</td>
<td>Petzold, Frank</td>
<td>205</td>
</tr>
<tr>
<td>Kim, Jinman</td>
<td>53</td>
<td>Pratschke, Anja</td>
<td>787</td>
</tr>
<tr>
<td>Kirkegaard, Poul Henning</td>
<td>721</td>
<td>Pusat, S. Emre</td>
<td>803</td>
</tr>
<tr>
<td>Kirschner, Ursula</td>
<td>787</td>
<td>Quasten, Gero</td>
<td>409</td>
</tr>
<tr>
<td>Knight, Michael</td>
<td>191</td>
<td>Razali, Fairuz Reza</td>
<td>181</td>
</tr>
<tr>
<td>Knight, Terry</td>
<td>475</td>
<td>Reis, Martin</td>
<td>323</td>
</tr>
<tr>
<td>Kocatürk, Tuba</td>
<td>61</td>
<td>Richens, Paul</td>
<td>809</td>
</tr>
<tr>
<td>Kontaxakis, Dimitris G.</td>
<td>399</td>
<td>Richter, Christoph</td>
<td>543</td>
</tr>
<tr>
<td>Kozikoğlu, Nilüfer</td>
<td>533</td>
<td>Richter, Katharina</td>
<td>113</td>
</tr>
<tr>
<td>Krijnen, Thomas</td>
<td>559</td>
<td>Rocha, Carlos</td>
<td>83</td>
</tr>
<tr>
<td>Kunze, Antje</td>
<td>507</td>
<td>Roppo, Barbara</td>
<td>843</td>
</tr>
<tr>
<td>Labs, Oliver</td>
<td>455</td>
<td>Rotherford, Peter</td>
<td>795</td>
</tr>
<tr>
<td>Lecourtois, Caroline</td>
<td>197, 475</td>
<td>Sarhan, Ahmed</td>
<td>795</td>
</tr>
<tr>
<td>Li, Andrew I-kang</td>
<td>243</td>
<td>Sass, Larry</td>
<td>475</td>
</tr>
<tr>
<td>Liapi, Katherine</td>
<td>53</td>
<td>Schmiedhofer, Heinz</td>
<td>323</td>
</tr>
<tr>
<td>Loemker, Thorsten Michael</td>
<td>113</td>
<td>Schmitt, Gerhard</td>
<td>279, 507</td>
</tr>
<tr>
<td>Loffreda, Gianluigi</td>
<td>341, 367, 515</td>
<td>Schneider, Sven</td>
<td>205</td>
</tr>
<tr>
<td>Lordick, Daniel</td>
<td>455</td>
<td>Schork, Tim</td>
<td>417</td>
</tr>
<tr>
<td>Lorenz, Wolfgang E.</td>
<td>697</td>
<td>Seo, Ji Hyo</td>
<td>649</td>
</tr>
<tr>
<td>Lyon, Eduardo</td>
<td>565</td>
<td>Shadkhou, Shaghayegh</td>
<td>305</td>
</tr>
<tr>
<td>McDonald-Rissanen, Mary</td>
<td>349</td>
<td>Shepherd, Paul</td>
<td>673</td>
</tr>
<tr>
<td>Mamoli, Myrsini</td>
<td>279</td>
<td>Sigalas, Alexandros</td>
<td>737</td>
</tr>
<tr>
<td>Matcha, Heike</td>
<td>153, 409</td>
<td>Soygeniş, Murat</td>
<td>773</td>
</tr>
<tr>
<td>Meagher, Mark</td>
<td>491</td>
<td>Sökmenoğlu, Ahu</td>
<td>835</td>
</tr>
<tr>
<td>Menges, Achim</td>
<td>289</td>
<td>Sönmez, N. Onur</td>
<td>119</td>
</tr>
<tr>
<td>Minifie, Paul</td>
<td>417</td>
<td>Sprecher, Aaron</td>
<td>161</td>
</tr>
<tr>
<td>Montenegro, Nuno C.</td>
<td>253, 269</td>
<td>Stouffs, Rudi</td>
<td>575</td>
</tr>
<tr>
<td>Mortensen, Henrik Rubæk</td>
<td>721</td>
<td>Sulaiman, Wan Azhar</td>
<td>181</td>
</tr>
<tr>
<td>Name</td>
<td>Page</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------</td>
<td>------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Şener, Sinan Mert</td>
<td>599</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Talašová, Zuzana</td>
<td>705</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tamke, Martin</td>
<td>385</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tarı, Sibel</td>
<td>229</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taşlı Pektaş, Şule</td>
<td>769</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tessmann, Oliver</td>
<td>47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thompson, Emine Mine</td>
<td>261</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thomsen, Mette Ramsgard</td>
<td>385</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tong, Togan</td>
<td>803</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Torus, Belinda</td>
<td>425</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tredinnick, John</td>
<td>623</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trento, Armando</td>
<td>367</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Truchot, Tristan</td>
<td>631</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turan, Bülent Onur</td>
<td>773</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Türkienicz, Benamy</td>
<td>585</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turner, Alasdair</td>
<td>173</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Türkkan, Sevgi</td>
<td>835</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vamvakidis, Simos</td>
<td>313</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Van der Maas, David</td>
<td>491</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Varano, Sandro</td>
<td>631</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vaughan, Josephine</td>
<td>689</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wang, Chung-Yang</td>
<td>497</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wang, Ming-Hung</td>
<td>713</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wang, Yang</td>
<td>243</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wurzer, Gabriel</td>
<td>659</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yalım Keleş, Hacer</td>
<td>229</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yalınay Çinici, Şebnem</td>
<td>105</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yavaş, Altuğ</td>
<td>129</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yazar, Tuğrul</td>
<td>145</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zhou, Yiyi</td>
<td>21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zubir, Syed Sobri</td>
<td>181</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zupancic, Tadeja</td>
<td>137</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
In the field of architecture, computational design has emerged as a sub-discipline having a multidisciplinary nature and using computing methods and capabilities to understand and solve architectural design problems. Computational design is based on computational thinking that includes a range of mental tools in solving problems, designing systems, and understanding human behavior. It has drawn on the concepts of mathematics and computer science.

Computational design elements are derived from both theoretical science and experimental design in such a way that its mechanism relies heavily on mathematical logic, but once built, experimentation is done by varying one parameter at a time to study individual changes. It is a design model, not design itself. Computational design involves applying appropriate computational mechanisms, algorithms, or methods to architecture in order to solve design problems and develop design applications. This process creates systems that can be used as design tools for exploring and forming entirely new design concepts and strategies.