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The Foundation of Architectural, Urban and Construction Engineering Information System

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Abstract- **The Architectural Design (AD), Urban Planning (UP) and Construction Engineering (CE) are three cross-cutting domains that need tight collaboration in order to support the vision, design, environmental issues and the operational support of complex urban artifacts (buildings, urban blocks and cities) construction. Current information technology facilitates the computer supported cooperative work in the complex interoperable development environment design. In this article we present a core conceptual model of data base schema that may support the cooperation of AD, UP and CE stakeholders through the entire life cycle of complex urban artifacts. We plan to use this model as a foundation for AD, UP and CE cooperative information system design.**

Key words: Architectural Design, Blackboard Architecture; Conceptual Data Base Modeling; Computer Supported Cooperative Work; Construction Engineering; Domain Ontology; Information Systems Design; Urban Planning.

I. INTRODUCTION

Particular domain expertise in engineering and scientific fields has emerged demanding more advanced skills and deeper domain knowledge. Information and communication technology development appears like a "big-bang" with the highest impact on overall human activities today. That is why computer supported cooperative work is the challenging discipline that drives the development process of contemporary and future engineering methods, standards and tools.

The essential role of Architectural Design (AD) and Urban Planning (UP) is to enable forward looking approach to the building/facility creation. It uses vide variety of abstractions to represent the building artifact prior to launching the construction phase. The Construction Engineering (CE) is tightly coupled with AD and UP domains and expresses it's routine mainly through the transition phase that transforms the abstract ideas, and their platform independent representations, to the usable physical urban artifacts. It may be seen like the combination of backward and downward looking to the same engineering process or product. All three domains are highly cooperative and run in the context of Environment Engineering (EE).

The contemporary AD, UP and CE are significantly more dependent on the utilization of sophisticated information and communication technology tools. The possibility of creating virtual or augmented reality, based on available software tools and integrated development environments, becomes a challenge to domain experts as well as to the software designers. The special challenges lie in modeling and parametric simulation of space and urban blocks that enables the analysis of existing urban environments in order to gain its potential revitalization, and/or the estimation of future achievements.

Inherent complexity, embedded in real world concepts, promotes modeling and simulations as the unavoidable mechanisms for the preventive evaluation of engineering achievements [1].

A. Doman Dependant Aspects of AD, UP and CE Information System Design

The majority of researchers agree that the most difficult step in engineering any system is a Domain Analysis. It is especially important while concerning the complex problem domains where inherent individual complexity may often discourage both: the information system designers and the problem domain experts to join the adventure of integral information system design. The most challenging approach is the creation of sustainable problem domain mental model that encapsulates relevant stakeholder's expectations [2]. The problem domain mental model creation is highly depend on the deep understanding of stakeholders motivations and thought-processes, along with the emotional and philosophical context in which they are operating. Concentrating on what relevant domain experts want to achieve by the Information Systems Service Layer, rather than on how they perform the everyday activities, may be a promising way to gain the mutual understanding among domain experts and the Information System Designers.

From the engineering point of view it is essential to specify two aspects of any engineering achievement: process and the product. Information system is a system whose mission is to supply other elements of a system under the consideration with data/information packages that are relevant and sufficient to support the decision making process. In order to create a relevant foundation for AD, UP and CE collaborative Information System it is important to clarify product and process impacts to the domain mental model creation that we think is the essential and challenging starting point. Regarding the specification of AD, UP and CE Information System Design Foundation, it is essential to address the combination of design factors that influence both the process and the product [3]. These factors may be divided into two main categories: the environment, that references all the relevant aspects of the artifact surroundings (artifact independent), and the internal (artifact dependent).

B. The Foundation Related Work Analysis

The valuable in-depth study of architectural work in context of ordering, elaborated in [4], fully justifies the concept of Multi-Domain approach to AD, UP, CE Information System design. In the concluding section the authors state that the major challenge to Computer Supported Cooperative Work (CSCW) is the process of cooperative construction of suitable and applicable ordering systems that may aid to the cost reduction and the reliability increase of the distributed cooperative processes of producing and maintaining: classification systems, notations, nomenclatures, procedures, etc.

The results of a 7-month ethnographic field study examining the design coordination process of a building project team is elaborated in [5] focusing on the project team interacting with different types of digital and physical design artifacts in different meeting environments. These observations suggest that a lightweight approach to infrastructure formation is necessary in order to raise the level of usability in meeting scenarios.

The outstanding evaluation of the framework need, while handling the building facility through the entire life cycle, is elaborated in [6]. Considering the Building Information Modeling (BIM) as an emerging technology and procedural shift within the Architecture, Engineering, Construction and Operation (AECO) industry priorities, the author justifies the need for systematic-defined BIM-Framework that extends beyond knowledge inquiry and organization and acts like research and delivery supporting facility.

BIM-based structural framework, specified for optimization and simulation purposes while designing the building facility, is presented in [7]. The authors introduce and follow the concept of a building as a hierarchical structure consisting of building elements and associated data and specify a structural framework that supports dynamic zoning. In the context of referenced article a zoning is a recursively composite conceptual unit used in the organization of building structures or building plans.

In [8], based on a critical review of Building Product Modeling, including the development of standards for the exchange and the features of over 150 Architecture, Engineering, Construction, and Operation (AEC/O) tools and digital models, the author proposed a methodological framework for BIM tools and schemata improvement on top of BIM-SoS (System of Systems) conceptual model. The essential proposition of this study is that via the development of the multi-standpoint framework, it is possible to advance and develop BIM tools and standards towards new, harmonized, innovative solutions.

The [9] paper describes a framework that categorizes and specifies features and technical requirements for a BIM-server to serve as a collaboration platform. The goal of this study is to identify the technical features relevant to a multi-disciplinary collaboration platform, as reflected across the different applications in the AEC industry, belonging to three crosscutting domains: Computer Aided Design (CAD), Building Information Modeling (BIM) and Document Management Systems (DMS).

In the past years, due to the large number of multidisciplinary partners involved in a building project, the AEC industry has been actively developing international and industrial standards [10]. Some of the standards developed are for the design and specification of buildings while others are for interoperability within a specific industry, such as the structural steel industry and the pre-cast concrete industry. Many of these standards share a common technology base with the international standard ISO 10303, known as Standard for the Exchange of Product Model Data.

Our recent researches are particularly focused on the synergy of: AD, UP and CE domains in order to create general, cross domain commonalities that may serve as a foundation for and general Architectural, Urban and Construction Engineering Information System Design.

C. The Role of Domain Ontology in AD, UP and CE Information System Foundation Specification

Understanding of any particular domain of interest is closely related to domain concepts consciousness. The modeling, on the other hand, facilitates a better understanding of the domains and related concepts. The analysis of published researches in the AD, UP and CE domains, joined with the characteristics of real building artifacts, show that several methodology approaches and concepts have raised, lasted and disappeared in the historical frame. By the establishment of set of space and engineering artifact attributes, as the basic elements of urban environment structure, it is possible to simulate and experimentally valorize the different aspects of human-space relationship concerning up to date city building. A common approach to initial domain foundation is to develop a Domain Ontology (DO) whose main role is to capture useful domain semantics and to describe its characteristics as a set of domain rules and functional dependencies [11]. In the following paragraphs we briefly introduce the fundamental aspects of AD, UP and CE domains that governs the ontology development process.

Architectural/Urban/Construction engineering artifacts are always in close relationship to the environment they are located (build) in, transforming the space and establishing the new, extended, environment. The environmental influences range from the artificial to natural ones. In order to raise the quality of leaving, these influences are usually regulated by the set of legislative and formal or informal professional standards and best practices. The main problem is that still they are not integrated and systematized in a form of a foundation that may be referenced and directly used during the entire design process. The modeling and prediction of the space form attributes enable the evaluation of the principles of buildings or urban block construction/reconstruction prior to a physical building, diminishing the risks in the process of decision making.

The Architectural Design (AD) is often defined as a combination of building (being a rational engineering activity predominantly governed by the right brain hemisphere) and art (being an irrational creative activity predominantly governed by the left brain hemisphere) that share the same complexity but from the different perspectives. The challenge to architects is not only an aesthetic one [4] but practical because of the increased number of structural and functional elements of a modern building that has to be integrated in the design and the construction plans making the work of modern architects highly collaborative.

From an Urban Planning (UP) perspective, it is frequently argued that the urban planning is highly specific to each locality defined by: national and local legislative provisions, structural frameworks and procedural requirements that greatly limit the development of common information and communication technology solutions that enhance the plan making and plan implementation process.

From a Construction Engineering (CE) perspective, it is essential to integrate AD and UP aspects over product characteristics, thus enabling the constructors to have deeper insight to the objects they are constructing in the context of everyday operational activities. The design information is usually structured around plans and views that support the designers routine, rather than around products that is a dominant way the constructors work.

The primary aim of The Architectural Design Process is to guarantee that the architecture artifact is designed in such a way to simultaneously satisfy different representational, functional, aesthetic, and emotional needs of organizations and the people who intend to live or work in it [12]. The Architectural Design Process has to be well structured to ensure that stakeholder's needs are satisfied with a predefined priority chain order, thus preventing the case that resulting architecture artifact is the consequence of random collection of unrelated decisions. The authors of [12] introduce the classic model of the seven steps Architectural Design Process encapsulating the following phases: *Pre-Design* (PD); *Schematic Design* (SD);*Design Development* (DD); *Construction Documents* (CD); *Bidding & Negotiation* (BN); *Construction Observation/Contract Administration* (CO/CA) and *Supplemental Services* (SS).

The additional domain expertise is needed in order to complete the "big picture" of an AD. In [13] the author discusses three crucial aspects of the Architecture definition: History, Semiotics (the subject of meaning in architecture) and Theory.

From the History aspect, Architecture has to be considered as one of the earliest professions developed in order to serve the man and his environment. Having this in mind one has to take into the account the temporal characteristics of Architectural Design that, emphasize the ***time dimension*** of architectural artifacts in any domain specific formalism formulation process.

From the Semiotic aspect, architectural artifacts are experienced in terms of their form, structure, aesthetics and usage. According to [13], Architecture has to facilitate not only the user's physical or functional needs, concerning build space, but at the same time it has to satisfy their mental and cultural endeavors. Having this in mind one has to take into the account the ***modal*** characteristics of Architectural Design and, emphasize the ***modal dimensions*** of architectural artifacts.

From the Theory aspect Types of Architectural Design include: *Pragmatic Design* - Concerning the experiments and/or observations performed in order to gain understanding and measure the behavior of the users and designed artifacts; *Typological Design* - Architectural artifact patterns, being the formal description of common structures and behavior that is typically accepted by the domain experts, may help architects to establish a foundation for their design solutions; *Analogical Design* - Assumes creating and using the past experience repository that stimulates the reuse of former solutions in current designs; and *Syntactical Design* - Rule-base thoughts and systems which pertain to designers theoretical perspectives.

Concerning elaborated analysis, we conclude that previously discussed AD process aspects have to be included in Common Ontology Base Models (COBM) and be used as a foundation for interface specification of any usable framework supporting cooperativeness of AD, UP and CE processes. In the next section we focus on Urban Design Process with the same motivation.

Using the results of [3] we have adopted the following artifact independent Architectural /Urban/Construction factors: SPACE AND USER*:* (Organization of a space in accordance to the requirements of the *users*); CLIMATE AND NATURAL FORCES*:* (Natural ventilation*,* Sun angles, temperature, precipitation, earthquake, tornado, hurricane, flood); SOCIAL AND CULTURAL INFLUENCES: (History, religion, culture, arts, aesthetics, thoughts, designer's objectives); MATERIAL AND CONSTRUCTION*:* (Availability, durability, reliability, skills, knowledge); NATURAL ENVIRONMENT*:* (Geography, topography, soil, vegetation); and BUILT ENVIRONMENT*:* (Neighborhood, architectural and urban characteristics, roads and access, utilities and infrastructures); RULES AND REGULATIONS*:* (Country/State/City Building regulations); TIME AND BUDGET: (Investments, interest rates, development opportunities, seasons, work hours).

The artifact dependent factors for Architectural Design mainly concentrate on: BUILDING SYSTEMS*:* The Architectural issues concerning: Structural/ Mechanical/Electrical Engineering; SENSORY SYSTEMS*:* The Architectural issues concerning: Views, noise, feelings, security, privacy, etc.

II. THE STARTING ONTOLOGY MODEL FOR AD, UP AND CE INFORMATION SYSTEM DESIGN FOUNDATION DEVELOPMENT

In Figure 1 we present the starting Generic AD/UP Ontology Model in the form of UML Class Diagram, developed as the consequence of related work analysis and the introductory elaboration [14].

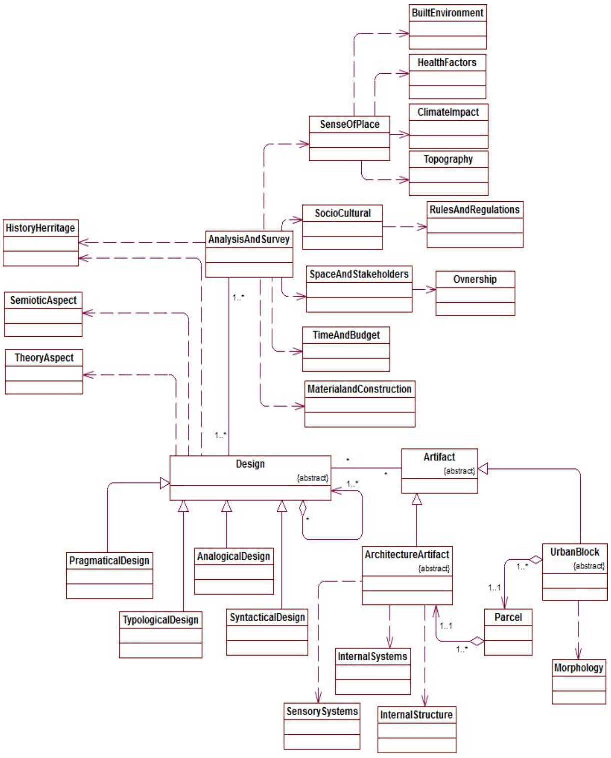

Figure 1. Starting Ontology Model of AD, UP and CE Information System

The elements with the less obvious semantics are briefly discussed below:

- Analysis and Survey – Represents a common concept that clusters: History Heritage, Sense of the Place (Build Environment, Health Factors, Topography and Climate Impact), Socio Cultural Issues (depending on Rules and Regulations), Space and Stakeholders Issues (with particular accent on Ownership aspects), Material and Construction Issues and Time and Budget Constraints. From our opinion, it qualifies as an DSLs orchestrator for encapsulating issues because of the fact that the contemporary approaches usually neglect the associated data objects that may valorize future AD or UP decisions;
- Design – Represents a potentially composite concept that may have four folded appearance (Pragmatic, Typological, Analogical or Syntactical). It is strongly associated with *an Analysis and Survey*, and is also a common concept for AD and UP. From our perspective, it depends on the: History, Heritage, Semiotic and Theory Aspects and is also a candidate for an DSLs orchestrator; and
- Artifact – This concept encapsulates general characteristics of architectural and urban artifacts and is strongly associated with the *Design* concept. It is the generalized concept serving as an abstract declaration that isolates the particular characteristics of Architectural artifacts (mainly buildings) and Urban Artifacts (mainly Urban Blocks). The *Design* manipulates the *Artifact* letting the polymorphism to simplify the artifact handling.

The Information Systems usually follow the Blackboard architecture (Figure 2). The central part is the repository (Repository Schema) wrapped by the Index Structure. The Business Logic layer may be implemented as N-tiered architecture, regarding the concrete infrastructure of AD, UP and CE Information System. The Service Interface Portal is a Facade that hides the Blackboard and enables easy navigation of Clients through the available services.

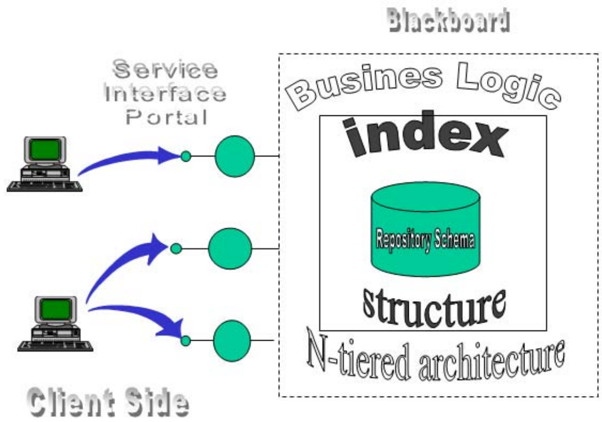

Figure 2. The Generic IS Blackboard Architecture

III. THE ESSENTIAL PARTS OF REPOSITORY SCHEMA CONCEPTUAL MODEL

Regarding the starting ontology model we have created a Conceptual Data Base Model of the Repository Schema that serves as a prototype proposed blackboard architecture. There are several fundamental concepts that constitute the conceptual model: Property and Space. They are modeled as meta-entities that enable, through entity instances (records), data driven description of arbitrary collection of space properties. In Figure 3 there is a part of Property conceptual model presented. The Property is strongly related to Meta Level (Modality) that enables different handling of the same property and Time Modality (Time Stamped Property) that enables different temporal description of the same property. The reflexive relation (Reflex Property) enables modeling of property that is derived from another property. The structure relation (Property Structure) enables recursively polymorphic specification arbitrary property structure (composite properties). The weak Observer signature of any particular Property enables its observer relative personalization. In Figure 4 there is a conceptual model of Space to Property relation presented. It enables data driven specification of arbitrary space (Space) regarding Tim Modality, Meta Level specification, and Observer. The collection of space properties specification is supported by the Property Collection instances. The Space itself is auto-reflexive thereby enabling specification of the space that is derived from another space instance.

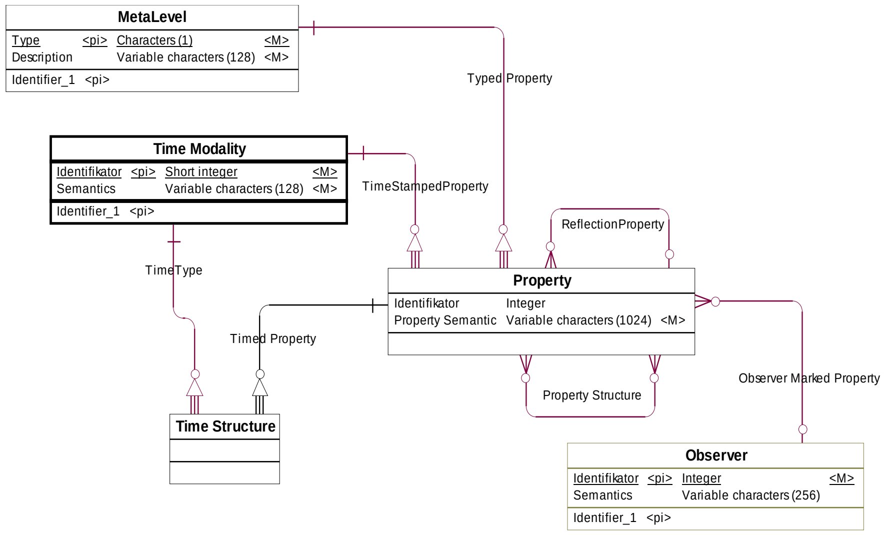

Figure 3. Property Concept Model

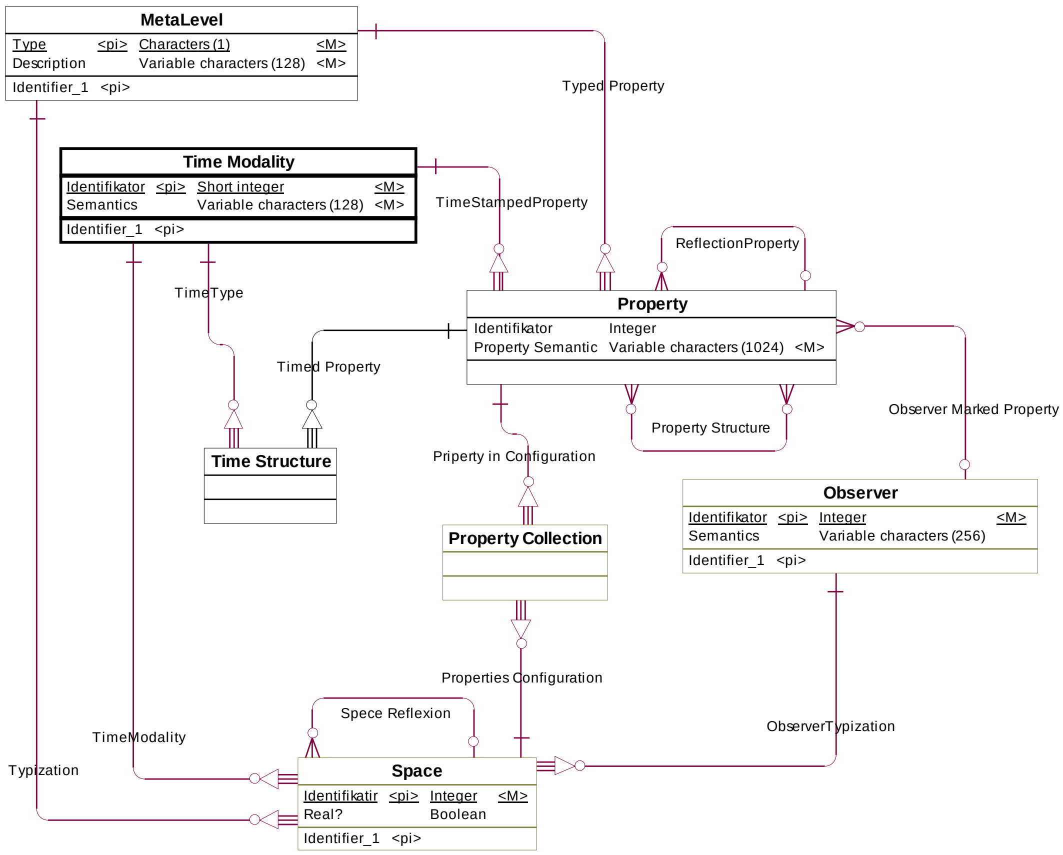

Figure 4. Temporal, Reflexive and Modal aspects of Space Concept Model

IV. CONCLUSION

The contemporary AD, UP and CE are significantly more dependent on the utilization of sophisticated information and communication technology tools. The possibility of creating virtual or augmented reality, based on available software tools and integrated development environments, becomes a challenge to domain experts as well as to the software designers.

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Current information technology facilitates the computer supported cooperative work in the complex interoperable development environment design. In this article we present a core conceptual model of data base schema that may support the cooperation of AD, UP and CE stakeholders through the entire life cycle of complex urban artifacts.

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