Improving Proactive Collaborative Design Through the Integration of BIM and Agent-Based Simulations

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Traditional design paradigms take into account phases as the process were subdivided rigidly in boxes to which pertain specific building entities, actors and LODs. In reality the process of design, a building f.i., it is not so much organized in series, nor designers deal with just a specific LOD. The process is intertwined and actors mix various type entities with different accuracy. To manage these problems, we need a new paradigm and new tools able to take immediately into account satisfied/unsatisfied constraints, to trig on consequences of choices made as far as it is possible and to link fluently and bidirectionally a 2nd layer of building abstraction (BIM) with a 3rd one of knowledge abstraction. An on-the-fly link has been established between BIM and a swarm of agent-based simulations.

Keywords: *Agent-Based Modelling and Simulation, Behavioural Simulation, BIM , Agent-Based Building Modelling*

DESIGN SCENARIO

Huge phenomena have arrived from last century: most population lives in cities from 2008 [1], energy released in the atmosphere increases temperature, pollution is more dangerous that car accidents, connections - any connection - physical and informative ones run more than capacity to understand context and information itself.

That gives huge responsibility to designers: they should understand in deep problems and boundary critical conditions, they can be able to modify event courses and Planet safety and address projects toward success or failure (Meadows 1972, Diamonds 2011).

The building design process has become through the years more and more complex: indeed, it involves a huge amount of information that describes the complexity of the process and the context, in the wide means of the term. Furthermore, this complexity is evident in case of interventions on historical buildings and buildings of our current digital era are said to be more complex by information structure because of the complexity of shapes and the difficult to conduct the process in a coherent integrated way.

As other industrial sector, AEC sector presents a growing complexity, following the even higher performances required by users, the urgent need is to optimize design choices avoiding unexpected delays and cost-dangerous project variations (Dehghan et al., 2015).

Designers, in addition, need to untangle this intertwined complexity due to an increasingly extensive and detailed regulatory framework, related also with a parallel increase of requirements express by users. Finally, the designer itself is involved in a deep transformation, in favour of large design companies with hundreds of designers, belonging to specific different domain, often spread in different parts of the world (Chen and Hou, 2014) that often even work concurrently on the same entities.

In a changing world - in nature and humans needs - we need very clever tools to speed up the design, all types of design - architectural design this case, as W. Morris stated.

Managing these extreme problems means "designing". In our CAAD world, we should adhere to strategies nature did, particularly one of most successful example of adaptation: the human behaviour.

What humans do? Optimise. Optimizing thinking especially. The following study reports how a new paradigm can support architects making their choices more aware - and satisfying - in a proactive way.

STATE OF THE ART

From the outset of the Informatics Era, designers felt the need to use informatics tools to satisfy their necessities. Thus, the attempt envisioned by Nicholas Negroponte to replace the Designer (Negroponte, 1973) regarded as a "elitist middlemen" (Llach 2015) appears today differently achieved, at least partially, in practice.

Starting from the Sixties, when the digitalisation started to make its way, many tries were made toward the definition of support tools for the design activity. The experiments developed to this aim belong essentially to the set marked by two methodological opposite approaches, which have characterized CAD tools development starting from first times. These were carried out when the vision of Yona Friedman and Nicholas Negroponte were opposed to Skidmore, Owings and Merrill (SOM) approach based on Building Optimization Program (BOP) or, in other words, the "Perfect Slave" approach. (Llach 2015).

Friedman and Negroponte, in different but conceptually close studies, hypothesized a cohabitation between two intelligent species in a symbiotic relationship among them. Following the Friedman and Negroponte's perspectives, complex support systems have been developed in order to simulate the behaviour and performances achieved by building objects (and systems), allowing designers to choose design solutions to be adopted among those that match the stated requirements. That time onward, research has applied to two different challenges: to improve performance of a singular aspect of design, the "tools by tools" approach; or to have an "overall vision" of design process. Obviously, these two philosophies have had in times different outcomes, and that the edge between them has been blurred, as well as the "singular aspect", the "limited scope", is relative to a certain extent.

Another aspect to be taken into consideration since the birth of the early CAD systems, technologies and instruments is that designers act in two distinct phases: "mechanical" and "creative" ones. The former has evolved radically until to the current BIM systems, causing a radical transformation of operating methods of the design activity. The latter, in contrast, today appears practically negligible as the number and effectiveness of tools conceived. Some difficulties in giving to computer systems human-like attributes, such as curiosity and judgment, and due to the belief that fundamental design parameters escape from an objective definition hence they are hard to be represented and managed.

Nevertheless, all of these experiences are based, more or less explicitly, on the Coons paradigm (1966) were design was considered as an iterative process that alternates a creative stage" to a "mechanical stage," in which design choices are tested with respect of "performance metrics"(Llach 2015).

This lack is mainly due to the undervaluation of several aspects that, instead, were central since the early experiments developed in the 70's: the flexibility, defined as the ability of a system to cope with problems of any size within a specific domain and adaptability, defined as the ability of a system to deal with problems pertaining to different domains.

The challenge to provide designers support systems with the required flexibility and adaptability became clear from the beginning. "Each designer is creating His Own library of services out of the problem-oriented language. Once created, note that these operations are no less rigid than the predefined package of design commodities."(Negroponte 1973).

Some experimental systems have already shown the possibility to create advanced representations of building objects flexible and adaptable, based on the knowledge engineering, allowing the design choices verification against a system of constraints. In this way, only acceptable solutions are guaranteed. These experimental systems and, even more, the current support tools offered to designers by the market, cannot assume proactively behaviour modifications and, consequently, integrating autonomously the designer choices in order to identify solutions that can optimize the performance achieved compared with stated requirements.

CURRENT SOLUTION FOR AN ANCIENT PROBLEM

To deal with these tasks designers and researchers extensively explored the collaborative design paradigm (Kvan 2000, Carrara et al. 2009, Achten and Beetz 2009) and turned out that to be effective it should be overcome: inconsistent data by means of BIM tools, incoherent semantic entities by means of representation of Ontologies (OWL), and the missing relationship between them by a "bridge" that links these two layers (Fioravanti and Loffreda 2015, Beetz et al.2006).

The inconsistent database management problem has been treated by J. Gray the Google Earth inventor and now it is no more a taboo to deal with inconsistent entities, f.i. different interpretations of an archaeological site entities by means of ontologies belonging to different archaeologists (Cursi et al. 2015), or putting together ontologies and shape grammars (de Klerk and Beirao 2016).

We already explored in a previous study the possibility to realize a partial "proactive" design tool (Carrara et al. 2013), but with traditional ontologies it is possible to treat only entity property incoherencies (2nd layer) not to treat fuzzy entities.

Although the current BIMs provided a multidisciplinary platform, and the possibility to develop the design phase in a concurrent way among different-located work set, the design activity request a real software environment, composed by a huge number of digital tools, often with lack of interoperability (Miettinen and Paavola 2014), forcing designers making many data-transfer operations among different forms and tools. Consequently, this intricate process results time-consuming and error-prone. Evidently, the envisioned mutual complementary improving, and role interchanges between computer and designer that, nowadays, are getting closer to the dream of human-computer co-operation.

To attain these aims, the DaaDgroup at Sapienza University of Rome, is developing some experiences aimed at overcome present days' paradigm and building design systems by an Agent-Based development environment integrated with current BIM systems system to link the 2nd layer (building abstraction - BIM) with the 3rd one (knowledge abstraction). This solution is capable to offer the required flexibility and adaptability, taking a proactive role able to complement 2nd with 3rd reasoning layer, respecting to the "first-order logic" [2] and leverage the designer activity through the identification of near optimal design solutions.

INTEGRATING BIM AND AGENT-BASED SIMULATIONS

To smooth the design process, we addressed to the agents' representation that can dynamically adapt solution (if any) to an ever-changing context (physical and cultural). Other two important assumptions are: a frame representation able to change its superclass and to structuring its entities in subset; an adjacency network that takes into account not only spatial relations (rooms, loggias, etc.) but also proximity of preferred orientations or links (cultural sites, sightseeing, panoramas) or, in a closer Project Management point of view, the viability and related time and costs related to building realization at construction phase.

We have a quite powerful paradigm as the Collaborative design one that has proven to deal with these aspects, but nothing regarding intelligent classes or subclasses of entities we can group for a goal. Moreover, if we changed the orientation of a building, these tools (BIMs and ontologies) can rotate the building and just put in evidence not satisfied requirements.

The proposed system is founded on a new paradigm by means of an Agent-based Model approach (Novembri et. al. 2015) with two fundamental assumptions: modularity and flexibility ones. This system can effectively be achieved by adopting an on-demand concurrent-computing technique. The agent swarms, indeed, are highly modular as numerous the technical domains (architecture, HVAC, structures, etc.) are; and the system is so flexible as allows swarms of agents (or a single agent of them) to hot-swap when they are required at the moment. These agents can be distributed (also geographically) and can operate concurrently. However, this process is normally avoided by BIM systems because a concurrent access to the instance of the model can easily generate situations where designer choices and the proposed systems actions can cause rat race condition conflicts. A rat race, however, is an endless, self-defeating, or pointless pursuit. It brings to mind the image of lab rats racing through a maze to get the "cheese" much like the single project domains tries to get an optimal design solution but, when integrated with other domains, is useless.

These agents can be modelled by means of an old-new language (Lisp) linked to the lower ontologies layer. This way we are free to customize agents according to our needs and allow them to call libraries, different languages, external functions, ontologies and BIM programs at will. Another interesting characteristic is its nature of the interpreted language that can trig immediately consequences on related entities.

Thus, an interesting development environment called BIM Work-Bench (BWB) can match desired synchronous characteristics with BIMs limit need by means of an embedded communication mechanism. There, every project change, (f.i. updating or adding components, characteristics, spaces, etc.) made by designer into the BIM environment gets Actors (in terms of messages to be executed), that is transferred immediately to the correspondent Agents. Consequently, this 'intelligent' system uses the event-input to elaborate action(s) to realise choices into the BIM system. This is made possible by means of modelling Actors (Hewitt 1973) that manages effectively communication among them. The system has been implemented by AKKA.net tool, that improves the actors' effectively modelling through a message-based and asynchronous process, avoiding involving a huge quantity of computational power. Furthermore, this tool provides a hierarchic structure with the creation of a Supervisor-Actor, that can manage several data belonging to different domains. Another challenge to be dealt with is the simulation of a cluster organization of actors, like the human approach to create task-groups for complex problems.

To deal with these objectives we applied two ideas: a very large use of default values even if on jeopardized knowledge at different abstraction layers; an extensive use of adjacency in different domains, not only on i.e. climate, public infrastructure,

So these agents (Mei et al. 2015) should be coupled with Graph theory and complexity models, as like is for IoT to suggest the designer which is the proper windows to choose in respect with the several constraints that characterize a project as the suitable path for a car that takes into account traffic status in an automotive navigation system.

Going back to the example of changing building orientation, in a façade modelled by Agents differently that previous situation it reacts to that event, trigs for an adaptation of former solution to a newer suitable for new context. Context in a broader sense like we explored in a previous research (Gargaro and Fioravanti 2014). That in turn trigs other agents in the agent's network as far as possible with information system has.

PROACTIVE DESIGN SYSTEM AS A COLLABORATOR OF THE ARCHITECT

The system we are developing is a "design partner" able to dialogue with humans as, like humans, concurrently thinks at different abstraction layers and takes into account different partial solutions of different design phases. The usefulness of this approach is that agent-based systems have a complementary ability compared whit humans,

If they change an element all the reasoning network is activated as far as it will be possible. That means they extensively use their defaults (architectural components, plants, details, shapes, context conditions, etc.).

So, we are developing a system able to take into account heterogeneous entities of different knowledge abstraction layers (each of these ones with several levels of detail) in domains full of default entities, that in real time explores entity networks and puts in evidence consequences and side effects. That can be considered a true pro-active design system.

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