

Dynamic Coordination of Distributed Intelligence in Design

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Abstract: *Recent introduction and coupling of digitally mediated design and production environments facilitated a radical deviation from the traditional ways of using representations, knowledge assets, organizational forms and standards. Consequently, we observe an abundance of the traditional views of design and the emergence of new cognitive models/constructs based on the emerging relationships between the designer, the design object (artefact), the design tools/systems and the organizational network of the various actors and their activities in building design & production. The paper reports on the initial findings of an ongoing research which aims to uncover the ways in which digitalization and digital tools have recently been adopted to the work practices of multidisciplinary firms and the evolving socio-technical networks and organizational infrastructures within architectural practice.*

Keywords: *Distributed intelligence; coordination of digital design; socio-technical change; building information modelling; parametric design.*

Introduction

Recent introduction and coupling of digitally mediated design and production environments facilitated a radical deviation from the traditional ways of using representations, knowledge assets, organizational forms and standards. Architectural and Engineering design is becoming more and more a digitally-networked practice, and an outcome of distributed activities within/across disciplines and involves embedding intelligence into the formation, organization, performance and actualization of spaces. The increasing use of advanced 3D knowledge-rich parametric/generative design media, combined with increasingly sophisticated information modelling systems and digital prototyping technologies are already enabling radically new ways of designing and

coordination among the many actors in Architectural Design and production. These technologies act as innovation infrastructures which has the potential to affect the core processes and products of Architectural Design, as well as a having a “revolutionary” effect on the profession and the discipline of architecture (Kalay, 2006). Design is becoming more and more an enterprise which requires a continuous and dynamic coordination of cross-disciplinary intelligence that is distributed across digital tools/systems, people, and organizations in a social context.

The generative, representational and collaborative potentials of various digital media, mass customization, embedded computing and the factors inhibiting the full adoption of building information models in Architectural practice are already well documented (Bernstein and Pittman, 2005;

Seletsky, 2005; Lyon, 2006; Terzidis, 2006; Boland, Lyytinen et al., 2007). Among the various publications on Architectural design theory and practice, the focus has been on: formulations of a theoretical discourse in digital architectural design (Lynn, 1999; Oosterhuis, 2002), changing theoretical and methodological directions (Oxman, 2006), episodes of digital design practice with emerging forms and processes (Kolarevic, 2003; Bollinger and Grohmann, 2004; Schodek, Bechthold et al., 2005). Despite the large body of available literature and the high level of theoretical and methodological content, socio-technical and organizational distinctions related to the different media and the influence of heterogeneous media on the formation of both product and process innovations are not yet formulated (Boland, Lyytinen et al., 2007).

In this paper, we introduce the concept of “Distributed Intelligence” which we define as the cross-disciplinary design intelligence that is distributed across various design media, people, modules of knowledge and the various representations of the design artefact. The paper will report on the initial analysis and findings of an ongoing research which focuses on the socio-technical transformation of architectural practice due to technology adoption. The concept of “Distributed Intelligence” is used as a theoretical framework to identify, analyze, and characterize the different forms of mechanisms developed to structure and coordinate design intelligence in current practice.

The potentials of technology and its instrumentalization

At the core of technological innovation as applied to design and construction lie advanced Building Information Modelling (BIM) and Parametric Modelling (PM) tools and systems. These systems offer radically new methodologies to merge design with execution. While Parametric Modelling tracks and integrates design parameters set by the user; building information modelling (BIM) integrates schedules,

and databases into 3-D modelling. With parametric modelling, design, engineering and fabrication intentions can be expressed independent of the geometry and late-stage decisions can be potentially fed back into the design iteration without the inherent cost of the conventional generate-test-discard model (Shelden, 2006). Similarly, intelligent building information models serve to bring various aspects of building design and construction into a set of integrated digital models, each of which represents different aspects of a building design (architectural & structural design, electrical & mechanical engineering, etc.). Potentially, this suggests that the intelligence of various specialists can be embedded into the generation, formation, performance and production of spaces. Such a capability also suggests a reversal of the conventional notions of the linearity of design process by changing the sequencing of how and when design information is developed and consumed (Shelden, 2006).

Recent studies have focused on the technological aspects of collaborative design and innovation. A common standpoint of a mere technology focus is the view of information technology mediating between humans (Paiho, Ahlqvist et al., 2008). This view is supported by the recent descriptions of the role of technology as a mediator between practices (or stakeholders), which often imply that the intrinsic diversity of these practices can somehow be homogenized (Kellogg, Orlikowski et al., 2006). However, this is usually not the case in highly dynamic and innovative environments such as architectural design and production. Our research support the idea that technology is indeed a critical enabler of integrated design and production in highly dynamic and innovative environments such as architectural design and production. However, emergent human networks and work practices, in turn, facilitate the emergence of new methods to deal with the emerging knowledge and complexity affecting the ways in which the technology is instrumentalized. This instrumentalization entails the ways in which humans mediate between different media, facilitating new

coordination mechanisms across various interdisciplinary actors and representations.

Co-evolution of technological, social and organizational change

Yet it would be fair to say that although the potentials are huge and endless, the technological transformation the architectural profession is going through at present time has not been as smooth as one would hope it would be. The institutional and social structures of the building industry, as well as the high variation in its technical systems and practices (e.g. construction technologies, fabrication tools, computing software, etc.) build up multiple barriers to fully utilizing the collaborative potential of new digital environments (Shelden, 2006). Moreover, different digital media and collaboration styles offer radically new and, most often, varying methodologies to merge design with execution. Similarly, the interaction of the architect(s) with different project participants through different media at different stages of the design process and the extent to which this interaction contributes to product and process innovation vary. However, there is not yet any formulated method or theory on how to choose the best possible tools and organizational structures that will suit the architect's preferred design methodology or preferred set of media. Moreover, there are fundamental issues in the utilization of these diverse set of digital media. For example, although BIM advocates its usefulness in bringing design intelligence across disciplines from pre-design to operation, in current practice, its usefulness has been limited to better data transfer and integration. It currently does not entirely encompass and link with processes that occur in the creative and conceptual design stages. Similarly, there is a computational limitation in the design aspects that cannot be addressed parametrically with current computational capabilities of various parametric software.

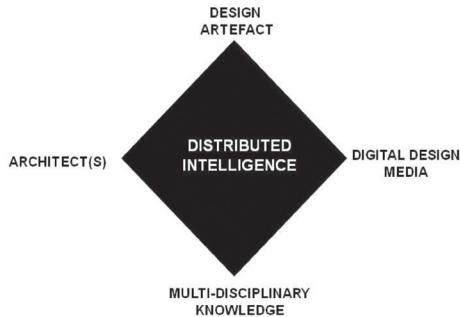
Another issue is the coordination and transfer of meaningful (semantic) data, which is usually lost when the geometry is transferred between different

applications. In current architectural practice, some innovative firms have been able to change the structure of their organizational network and processes and mechanisms of design coordination. Changes in the organization and architecture of such network structures bring changes to the form of coordination of complementary activities and competencies. Consequently, technological change and structural change co-evolve and reinforce each other along a process that can be depicted as a "creative destruction" (Schumpeter, 1942) where new actors, new forces and new coordination forms emerge. Similarly, organizational changes mirror reconfigurations in the knowledge structure, therein including knowledge possessed by individuals as well as the relational structure on which their activities rely (Metcalf and Ramlogan, 2005). Recent studies emphasize the criticality of understanding the socio-technical transformation of the architectural practice due to technology adoption. However, this transformation is not a homogeneous one and the use of technology is rather opportunistic and dependent on various factors (contractual frameworks, software skills, etc) on a project specific basis and the culture of the design firm which affects how technology is instrumentalized and embedded into the overall design process (Holzer 2007). Consequently, we observe the spontaneous emergence of highly complex socio-technical systems where both the human/organizational structures and the IT capabilities are distributed, diverse and heterogeneous (Boland, Lyytinen et al., 2007).

Distributed intelligence: A theoretical framework for analyzing socio-technical networks

We introduce the concept of "Distributed Intelligence" which we define as the cross-disciplinary network of design intelligence that is distributed across various design media, people, modules of knowledge and the various representations of the design artefact (Figure 1). Our research uses this concept as

Figure 1
Distributed intelligence



a theoretical framework to explore and identify the ways in which distributed intelligence is structured and coordinated between different stages of the creative design process.

The following sections will describe and illustrate the 4 main components of our theoretical framework (internal representations, external representations, collective creativity, and coordinated production) each of which refer to a generic set of relationships between the 3 nodes in the diagram where the 4th node is represented as a variable.

Internal and external representations

While design problem structuring was earlier a very implicit process, mainly taking place in the head of the designers, advanced design media offer tools to explicitly represent these problem structures, build

and communicate alternative structures. In other words, digitally mediated design tools and systems offer alternative ways pertaining to how to mentally construct designs - internal representations of the design idea - and how to communicate information about these designs within the design team - as external representations.

The first component, *internal representations*, refers to the interaction of the architect with the digital media to mentally construct, generate and model the design artefact. At this stage, the extent to which multidisciplinary knowledge is embedded in the evolution of the design artefact is a dependent variable (Figure 2a).

The second component, *external representations*, refers to the interaction of the architect with the digital media in order to communicate/exchange design information with the other stakeholders, for the subsequent engineering and production processes. At this stage, the extent to which the design artefact/model carries the embedded information is a variable (Figure 2b).

The third component, *collective creativity*, refers to embedding multi-disciplinary knowledge into the formation of the design artefact. At this stage, the extent to which the digital media facilitates/supports this process is a dependent variable (Figure 3a). Finally, the fourth component, *coordinated production*, refers to the incorporation of constructability information into the design artefact (model)

Figure 2
(a) -left -
Internal Representations

(b) -right-
External Representations

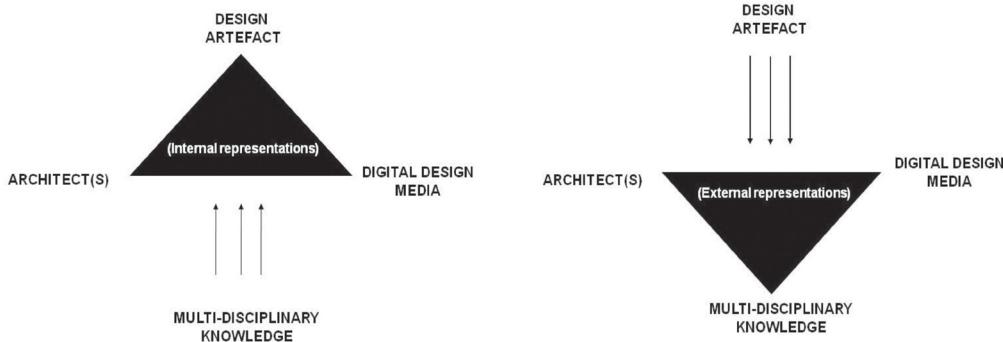
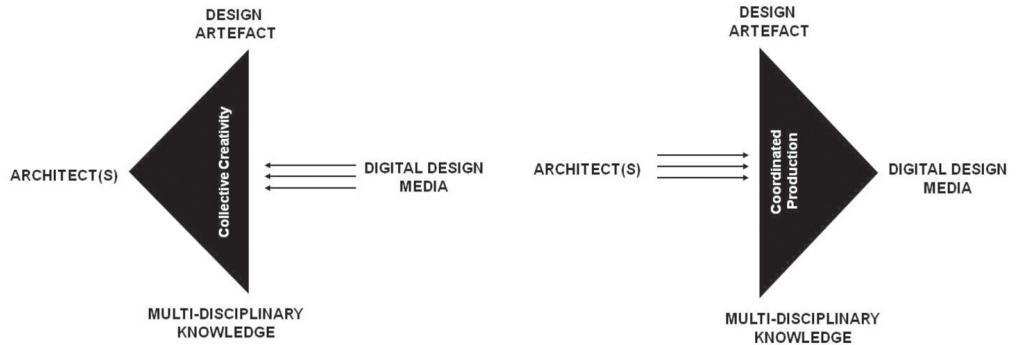


Figure 3
(a) -left -
Collective Creativity

(b) -right-
Coordinated Production



for the actual production (Figure 3b). The extent to which the architect interacts with this process is a variable. Similarly, the relationship between the various stakeholders and various media at different stages of the design process and the extent to which this interaction contributes to innovation vary.

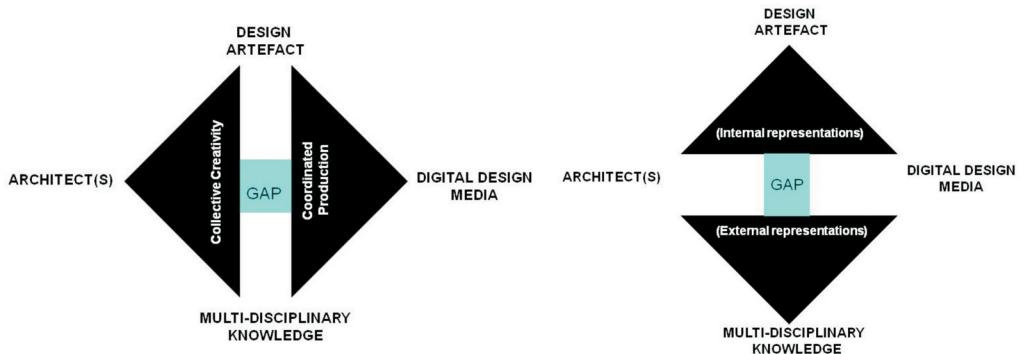
Unlike traditional hierarchies and linear project progression, the coordination of these components follows a network structure by facilitating the emergence of new actors, new processes and new coordination mechanisms. In this framework, coordination does not only refer to the choice of appropriate media and organizational structure, but also to the formulation of innovative methods to bridge the gaps that currently exists between these components and their associated processes (Figure 4).

Emerging coordination mechanisms

In current practice, innovative firms are characterized and distinguished by the ways in which they bridge the gaps presented in the previous section (see Figure 4). However, we found that these firms do not necessarily innovate by merely using technology, or a specific tool per se, but by finding innovative mechanisms to structure and coordinate their design intelligence through various media, customized workflows, organizational structures and complementary activities. The emergent mechanisms of such coordination is either fully resourced within the company and/or outsourced as an alternative.

At Foster and Partners, for example, the Specialist Modelling Group provides in-house consultancy to project teams at all stages from concept design

Figure 4
Innovation bridges the Gaps
between components



to detailed fabrication. Huge Whitehead, Director of the Specialist Modelling Group, points out that many problems they face at Fosters are problems of language rather than technology and the main limitation lies in finding the effective means to communicate and coordinate such communication (Hensel, Menges et al., 2006). Although the group provides tools, techniques and workflow, they are developed in reverse order. Starting from the formulation of the problem, the first step is to propose an appropriate workflow. At this point, a very peculiar observation in the firm's activities and work flow is the centrality of the "people" as opposed to the centrality of a "3D model" which is a generic assumption of any BIM methodology. Although the firm uses BIM, the activities and workflows do not follow the methodology suggested or envisaged by the creators of this technology. Within the proposed workflow, suitable techniques are experimented in different combinations. The result forms the brief for the development of customized tools that are tested by the design team in a continuing dialogue. Customized tool building is an integral part of the firms design process and ensures that a rationale becomes an integral part of the design concept and allows the generation and control of building geometries.

In Swiss Re building, for instance, the problems related to how to design and produce details that are programmed (rather than drawn) were investigated. The building stands as a classic example of an associative framework providing a context for adaptive parametric components. In this way, fabrication follows a consistent dialogue between structural and cladding geometry (Hensel, Menges et al., 2006). In such a coordination mechanism, the designer becomes in charge of the process by providing necessary external representations to bridge the gap between *collective design* and *coordinated production* whereas the responsibility for the performance lies with the contractor. The design approach is usually to create a parametric model which provides high degree of geometric control and ability to generate variation in design. At the same time, the parametric

models entail the versatility in providing the relevant information for digital performance tests which are carried out in collaboration with external consultants (Hensel, Menges et al., 2006). This involves the incorporation of various different software applications and operating systems each of which require a simplified representation of the model as the input to their analysis. For example, while structural analysis requires central lines, thermal analysis requires volumes, and daylight analysis requires meshes and so on.

Not every firm can provide in-house expertise to integrate design ideas with that of actual realization. At this point, a specialist knowledge from various fields need to be integrated to bridge the gap between *internal* and *external representations*, especially when the architectural forms are challenging and an average CAD technician wouldn't be able to model/draw and the contractor wouldn't be able to generate a realistic cost estimate. "Design to Production", a specialist consultancy firm (founded by Fabian Scheurer and Arnold Walz) is one of the most prominent examples of this emergent niche of service in building industry. The firm (team) devises parametric models for the interface between rendering and realization. Fabian Scheurer describes their role as: "*We are deliberately in the middle of everyone. We are a relay station, we help them coordinate....There is no software for that. Fifty percent of our job is just sitting down and talking to the different people*" (Peters, 2009). The firm is to be credited for the coordination of design and production teams for the fabrication of 18km of unique doubly curved, timber roof beams of the Centre Pompidou Metz gallery (by Shigeru Ban), accurately, on time and on budget. Their role was to communicate the complicated geometry of the 90m-wide, 40m-long fluid structure and enable its fabrication. The timber girders had to be broken down into components so that they could be fabricated and correctly priced, and put in the right place. The challenge was to communicate this information with the contractors and fabricators for correct pricing and fabrication.

In the EPFL in Lausanne (by SANAA), although the curvy surface was very well described (mathematically) by the engineers, the firm still needed to extract the rules and geometries from this surface to design the temporary wood formwork. In this commission, they worked for the general contractor for the tender process. After tender, they worked for the formwork contractor to optimize the fabrication by building a detailed parametric model and delivered all the components as machine-ready code, ready to be fabricated.

Conclusion and discussion

We introduced the concept of “Distributed Intelligence” which we define as the cross-disciplinary network of design intelligence that is distributed across various design media, people, modules of knowledge and the various representations of the design artefact. Our research uses this concept as a theoretical framework to analyze design practice and to explore the ways in which distributed intelligence is structured and coordinated between different stages of the creative design process.

We reported on the initial findings of our research which aims to uncover the ways in which digitalization and digital tools have recently been adopted within work practices of multidisciplinary firms and the evolving socio-technical networks and organizational infrastructures in architectural practice. Our research support the idea that technology is indeed a critical enabler of integrated design and production in highly dynamic and innovative environments such as architectural design and production. However, new human networks and work practices, in turn, facilitate the emergence of new methods to deal with the emerging knowledge and complexity affecting the ways in which the technology is instrumentalized. This instrumentalization entails the ways in which humans mediate between different media, facilitating new coordination mechanisms across various interdisciplinary actors and representations.

It is essential to acknowledge the merits of

technology adoption, however, it's equally important to realize that this adoption does not necessarily take place as anticipated or envisaged by the very people who have created that technology. The ways in which architectural practice responds, in its own unique ways, to the possibilities offered by different design and modelling tools provide crucial hints for the development of next generation technologies which might offer a better transition by taking into account the dynamics of the architectural practice as a social network of people and knowledge modules.

References

- Bernstein, P. G. and Pittman, J. H.: 2005, Barriers to the Adoption of Building Information Modeling in the Building Industry, Autodesk Building Solutions Whitepaper, Autodesk Inc., CA.
- Boland, R. J., Lyytinen, K., et al.: 2007, Wakes of innovation in project networks: The case of digital 3-D representations in architecture, engineering and construction, *Organization Science* 18(4), pp. 631-647.
- Bollinger, K. and Grohmann, M.: 2004, *Workflow architecture - engineering*, Basel, Birkhauser.
- Hensel, M., Menges, A., et al.: 2006, *Techniques and technologies in morphogenetic design*, London, Wiley-Academy.
- Holzer, D.: 2007, Are you talking to me? Why BIM alone is not the answer, Association of Architecture Schools Australasia Conference.
- Kalay, Y. E.: 2006, The impact of information technology on design methods, products and practices, *Design Studies* 27, pp. 357-380.
- Kellogg, K., Orlikowski, W., et al.: 2006, Life in the Trading Zone: Structuring Coordination Across Boundaries in Postbureaucratic Organizations, *Organization Science* 17(1), pp. 22.
- Kolarevic, B.: 2003, *Architecture in the digital age : design and manufacturing*, New York, NY, Spon Press.
- Lynn, G.: 1999, *Animate Form*, New York, Princeton Architectural Press.
- Lyon, E.: 2006, *Design Process Taxonomy: Notes on Design Theories, Methods and Instruments*, SIGraDi

- 2006 Proceedings of the 10th Iberoamerican Congress of Digital Graphics 21-23 November, Santiago de Chile - Chile.
- Metcalfe, J. S. and Ramlogan, R.: 2005, Limits to the economy of knowledge and knowledge of the economy, *Futures* 37, pp. 655-674.
- Oosterhuis, K.: 2002, *Architecture Goes Wild*, Rotterdam, NAI Publishers.
- Oxman, R. E.: 2006, Theory and Design in the First Digital Age, *Design Studies* 27(3), pp. 229-265.
- Paiho, S., Ahlqvist, T., et al.: 2008, *Roadmap for ICTbased Opportunities in the Development of the Built Environment*. Helsinki, VTT.
- Peters, T.: 2009, Design to Production, *Mark* 19(April-May), pp. 200-205.
- Schodek, D., Bechthold, M., et al.: 2005, *Digital Design and Manufacturing: CAD/CAM Applications in Architecture and Design*, NJ, John Wiley & Sons.
- Schumpeter, J. A.: 1942, *Capitalism, socialism, and democracy*, New York, London,, Harper & Brothers.
- Seletsky, P.: 2005, 31 October 2005), *Digital Design and the Age of Building Simulation*, *AECbytes* Retrieved 20 November 2006, from http://www.aecbytes.com/viewpoint/2005/issue_19.html.
- Shelden, D.: 2006, Tectonics, economics and the reconfiguration of practice: the case for process change by digital means, *Architectural Design* 76(4), pp. 82-87
- Terzidis, K.: 2006, *Algorithmic Architecture*, Oxford, Elsevier.