Creation of an Evolutive Conceptual Know-how Framework for Integrative Building Design

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Abstract. Low productivity of the building sector today is attributed to the fragmentation of tasks, disciplines and responsibilities, as well as to the resistance to adopt integrative work processes and digital means. The increased complexity of architectural projects and the aroused social consciousness for sustainable environment calls for integrative design collaboration. Thus, there is need for a Conceptual Framework combining work processes, technological means, normative aspects and domain knowledge. This paper defines such a framework combining Integrated Design Process (IDP) and Building Information Modeling (BIM) with the purpose to contribute for sustainable built environment. Its theoretical background lays on studies in social learning (activity theory and situated action theories). These theories suggest that learning and knowledge generation occurs mainly within a social process defined as an activity. This corresponds to the context in which the IDP-BIM framework will be used, its final objective being the transformation of building design practices. Various layers of knowledge information are present in the Conceptual Framework, namely, on the design process, on the integrated digital environment and on the roles of the actors in the design process, depending on the project-delivery method. Two validation scenarios are under development and observation: one is concerning the assistance provided by the Conceptual Framework in creating a common language between different building specialists, and a second one is regarding the ergonomics of the digital interface.
1. Introduction

Low productivity of the building sector today is attributed to the fragmentation of tasks, disciplines and responsibilities, as well as to the resistance to adopt integrative work processes and digital means. The increased complexity of architectural projects and the aroused social consciousness for sustainable environment calls for integrative design collaboration. Based on recent research, we can propose that sustainable buildings can be designed through an integrative design process (IDP) which is best supported by Building Information Modeling (BIM)[1, 3].

However, our ongoing research program and consultations with advanced practitioners in Canada underscore a number of limitations. For example, a large portion of the interviewed professionals and construction stakeholders do not necessarily see a link between sustainable building, integrative design process and BIM, while their joint use augments the power of each of these approaches taken separately [2]. Thus, there is an urgent necessity for the definition of an IDP-BIM framework, which could guide the building industry to sustainable results and better productivity. It will combine work processes, technological means, normative aspects and domain know-how. Through this Conceptual Framework, we aim at multiple objectives of training, support and process-organization. These can be, among others:

- Provide support for an Integrated Design Process;
- Facilitate the creation of common language and narrowing the "culture" gaps between the actors in the design process;
- Propose various technological workflows (and dataflow) and their place in the design process;
- Offer standards for various deliverables;
- Assist owners and other actors in the verification process.

The paper will firstly present the state of the art in Integrated Design Process (IDP) and Building Information Modeling (BIM) internationally and in Canada (with more detail for Quebec). Secondly, arguments on the need and the timing of support for the industry will be discussed. Then, we will expose the methodology used for the definition of the Framework, followed by a description of its structure, contents and digital implementation. Some scenarios for the validation of the Framework will be shown. Finally, future work will be outlined.

We are aware that some aspects of the paper, like implementation of BIM technology in the industry, are regionally limited, while others, like helping the organisational change supported by technology change are not. Moreover, other regions of the world are in a simulation similar to ours and the research presented in this paper could be of practical importance for them. The research on the
situation in the industry, though, is regionalized, as this gives some specificity to the proposed Conceptual Framework and influences its timing.

2. State of the art in IDP and BIM

According to the literature, integrative multidisciplinary design is a strategy resulting in high performance buildings, nurturing sustainable way of living [3, 4]. Responding to the increased technological complexity of our built environment, as well as to the objective of meeting multiple criteria of quality, both necessitating multidisciplinary collaboration during design, intelligent building behaviour modeling is seen as a powerful means for fostering quality, augmenting productivity and decreasing loss in construction.

2.1. On IDP

IDP process is well formalized in the "Roadmap for the Integrated Design Process" [4] which is widely used as a guideline for collaborative integrative design by innovating practices in USA and Canada. In his publications, as well as in the interviews held with him during the qualitative study, Bill Reed underlined the importance of charrettes involving all the project stakeholders, as well as their span in time - starting from the very beginning of a project and continuing through the whole life cycle of the facility. A well prepared, structured and managed charrette is a prerequisite for its good results. According to the same author, architecture should be ecologically "integrative" and help the regeneration of its environment.

Kolarevic [5] uses the term "integrative design process" to indicate a process open to a large range of specialists and stakeholders who can contribute to a sustainable project (like psychologist, biologist, social worker, etc.). The vision of this author implies flexibility and dynamic configuration of the "integrative" team as well as of the process.

Importance to change the way of work, supported by technology, is underlined in research concerning the relatively new concept of "Integrated Design and Delivery Solutions" where collaborative work processes and enhanced skills, together with integrated data, information and knowledge management are seen as means "to minimize structural and process inefficiencies and to enhance the value delivered during design, build, operation, and across projects" [6].

In the context of this paper, Integrative Design Process means a design process involving all stakeholders, taking into account the whole life cycle of the project, and supported by information technologies, with the purpose to create a sustainable facility helping the revitalisation and the regeneration of its
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environment. Having in mind the whole lifecycle of a building, we focus our research only on the initial phases of a project design.

2.2. On BIM

The National Building Information Modeling Standard (NBIMS) of the USA is putting enormous efforts in creating a BIM standard, but BIM ontology is still under development [7]. Many documents are being prepared and from different viewpoints. Even though this is considered normal for a process in its "childhood", it creates confusion among the professionals and lowers their productivity. Thus, the desire and the need to have a unified reference on the subject are getting stronger.

The maturity of adoption of new methods of work and new technologies can be measured through a maturity matrix. Succar [8] recently proposed a conceptual framework for BIM, including process, technology and policy aspects. On this basis, he also developed a maturity matrix for BIM adoption.

Based on numerous available definitions of BIM [3, 9], and trying to differentiate our comprehension of BIM from a stripped one levelling it to a modeling software tool, we define BIM as a modeling technology and associated set of processes to produce, communicate, and analyze building models containing coordinated, consistent, computable information about a building project in design. The parametric information in the intelligent digital model can be used for design decision making, production of high-quality construction documents, prediction of building performance, cost estimating, construction planning and even space management.

The full potential of BIM can only be realized when used in collaboration and through the building’s lifecycle. In most cases, though, this is still a distant objective, given the immaturity of the industry.

3. Situation in the industry

The level of adoption of IDP and BIM by the Canadian industry, the perception about them and the challenges facing the transition process were the subject of recent joint qualitative and quantitative studies that we realized together with "Extract Recherche Marketing" and in collaboration with Professional Orders and the Agency for Energy Efficiency of Quebec. The results from the quantitative study (performed through on-line questionnaires) and from the qualitative one (where data was gathered through semi-directed interviews) were first separately analysed, and common conclusions were drawn afterwards. They are not the topic of this paper, but we will mention them briefly in order to explain some decisions on the definition of the proposed Conceptual Framework.
3.1. Perception and challenges

Judging from the results from the study on IDP and BIM in the industry, the perception of the IDP is positive and there are already examples of early adopters, especially for "suitable" projects, or under owner’s requirement. The situation is different concerning the comprehension, perception and level of adoption of BIM. This concept is often wrongly identified with only one BIM enabling software. The perception is dominated by fear from the risks in terms of needed investments and change of the work process. Moreover, BIM is not seen as a method helping sustainable design, which on its turn, is mainly led by sustainability certification tools (like LEED). This might be due to the order of adoption of LEED, IDP and BIM in Quebec, respectively 1st, 2nd and 3rd. Given that LEED is often used as a "shopping list" during the design process, it is important to bring to the professionals the knowledge about the potential of the IDP accompanied by BIM enabling tools.

A recurring concern was demonstrated in the interviews concerning the difficulties to work collaboratively due to the different professional "cultures" of the design specialists and actors in the design process (architects, engineers, contractors, etc.). It was pointed out that there is urgent need to foster each-others understanding of the respective work, as well as to establish a common language during the IDP.

Generally, the industry is interested to adopt an IDP method of work, but the "how-to" remains mostly unknown. Compared to the situation in other parts of the world [10], we experience a heavy lag and urgent measures are needed.

3.2. Support for the transition process

According to research on the introduction of new technologies [11, 12], the most difficult moment is after the initial "hype" period, when the steep learning curve brings deception and a moment of decision comes : to continue the adoption of the tool or to abandon it. On the Figure 1, the two curves of the graphic intersect at this point (also called the "adoption gap").
In our understanding it is crucial to provide support to the stakeholders at this moment. According to the questionnaires and the interviews, our regional industry is approaching this moment, so the creation of a Conceptual Framework comes just in time. At this stage, our research focuses on the initial design phases of the project, given their proven strong impact on the final result.

4. **Theoretical bases and methodology for definition of the Conceptual Framework**

This research defines a Conceptual Framework, whose theoretical background is in social learning (activity theory and situated action theories) as well as in the theory of "boundary objects". Social learning theories suggest that learning and knowledge generation occurs mainly within a social process defined as an activity. "The activity itself is the context. What takes place in an activity system composed of object, actions, and operation, is the context. Context is constituted through the enactment of an activity involving people and artifacts" [13]. This corresponds to the context in which the IDP-BIM framework will be used, its final objective being the transformation of building design practices. Boundary objects are tools or artefacts that promote new methods or processes as a consequence of users interacting with the object and among them [14, 15].

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**Fig. 1.** The “Innovation adoption curve” of Rogers [11] (in red) gives the number of technology adopters with time, and the "Hype cycle curve" used by Garter [12] (in blue) represents the fluctuation of interest to the new technology with time.
The process of the project is also bound to gating reviews [2], inspired from software development processes. An iterative process of this kind was found to be successful in the context of multidisciplinary design studios [2, 16]. The feedback from this study allowed for modifications and adjustments included in the present proposal. The gating process assures the good quality of the project and its compliance to the client’s requirements.

5. Proposal of a Conceptual Framework

The proposed IDP-BIM framework is based on previous research and developments. As main references are taken:

- For the life-cycle process: the Road Map developed by Bill Reed, Cascadia and Busby, Perkins & Will [4].
- For the design process and quality insurance: iterative design process bound to gating reviews [2].
- For the technological support and BIM standards: the NBIM Standard and the GSA documentation [9].
- For the data workflow: the interoperability scheme combining different aspects of a BIM model and used in previous studies [16].
- For the BIM project execution planning: the Guide developed by Computer-Integrated Construction and Penn State University [17].

One of the challenges of this research is to map the above mentioned approaches, processes and technologies into the design process, thus creating an integrated framework supporting and nurturing sustainable design. This represents the specificity and the uniqueness of the proposed Conceptual Framework.

5.1. Structure

The IDP-BIM framework can be represented by a multidimensional matrix linked to a knowledge base:

- the axes of the matrix are the project timeline, the design process actors and building stakeholders (architect, engineers, client, contractor, environmental biologist, etc.), or different aspects of building performance (environmental, functional, social, interior environment quality, cost, etc.); and
- the knowledge base provides multiple layers of semantic support in terms of process, domain knowledge, technology and workflow at a given moment of the project and for a given actor or building aspect.
The structure of the Conceptual IDP-BIM Framework allows two different ways of use:

- **general use**: each actor in the design or construction process can find out the tasks and the methods of work of all the other actors;
- **specific use**: a given actor can find out what is a possible or a recommended task, and/or method, and/or software, etc. in the process, depending on his speciality and role in the IDP, as well as on the stage of development of the project.

The intent of the "general use" is to enhance teamwork by learning terminology and concepts from the domain of other specialists a given actor has to work with. The "specific use" of the Framework is intended to support the collaborative process and the integrated model dataflow by providing specific information depending on context and timing. It is also aiming at the adequate preparation to the process "events" (charrettes, topic workshops, gates, etc.) and at assuring the quality of the deliverables at each "gate".

Beside the structured contents aiming at training and supporting the design professionals and the construction stakeholders, a large amount of other relevant information can be accessed through links to external resources of domain knowledge, best practices and others.

### 5.2. Contents

Various layers of knowledge and process information are present in the Conceptual Framework. A committee of experts will be in charge of keeping the contents up to date and provide examples of best practices for each subject.

#### 5.2.1. On the process

The process is structured on the basis of Bill Reed’s Road Map for IDP [4] and integrates a quality assuring iterations-and-gating process for the initial phases of design. Accordingly, the Framework contains information on each item in these processes, as well as on their relations in terms of time, actors and project models.

The process begins by the owner’s brief. A "visionary charrette" is a recommended start for the integrated project team at this moment. After the definition of a first common vision and a "chart" of the project, an iterative conceptual process begins. Some topic workshops can be held, involving some of the concerned actors in the design process.

Depending on the nature and the scale of the project, various numbers of iterations and charrettes can be held. It is important that each charrette is well
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prepared and structured in order to give optimal results. The role of a Facilitator is presented in the part of the Framework dedicated on the actors in the design process.

The iterations taking place between each quality-control "gate" are aiming, each following one, at a more and more "integrative" solution. The recommended criteria for the quality of the model presented at each “gate” are described in the Framework.

Each "gate" implies verification of the quality by the owner. Tools for assisting this evaluation are proposed.

5.2.2. On the digital environment

The content concerning the digital environment of the IDP is rich in graphics, multimedia demonstrations and reference documents.

Dataflow between various software tools and digital environments are illustrated by graphics, file formats are specified for the different purposes, and methods for converting files are explained. Having in mind the possible dataflow, workflows (tested in practice) are recommended.

Workflows can be suggested in general, for the whole project and all actors, or for a specific aspect (like energy efficiency or cost estimation, for example), and for a specific actor (like energy efficiency for architect or for MEP engineer). These will be prepared in the basic version of the Conceptual Framework, but should be regularly updated.

Workflows may vary depending on the nature of the project and its way of realization. Building containing digitally fabricated parts, for example, may be conceived through workflows which might differ from a workflow of traditionally constructed facility.

Software features and their modes of use are presented depending on the phase of the project. Recommendations are made on the use which each actor can make of a given software tool or environment, depending on his discipline or role in the design process.

Having in mind the constant changes in the digital tools, this part will be subject of regular technological watch and updating.

5.2.3. On the actors in the design process

In this part are defined the roles of the actors in the integrative design process. The first version of the Framework includes Architect, BIM Manager, Client, Constructor, MEP Engineer, Structural Engineer, Facilitator, Estimator, Landscape Architect, Interior Architect, LEED AP Project Manager and Urban Planner.

Special attention is paid to the roles of the "non-traditional" members of the design team like owner and constructor. Emerging new roles (and even specialities) are described, namely Facilitator and BIM-Manager.
The Facilitator is ideally a professional who is not directly a designer of the project for which he acts as facilitator. He organises and facilitates the charrettes, typically remaining impartial, and assures the participation of all team members in the discussions.

The BIM-Manager is a professional who organises the workflow around the BIM model and assures its coherence and quality. This implies the establishment of a server and a network for the project, creation of protocols for model synchronization, and adoption of a plan for information management. Some of these tasks can be shared with the Project Manager or a computer-support specialist, but for larger projects (or at a company level), the role of a BIM Manager is essential.

5.3. Interactive digital implementation

The IDP-BIM framework was first created as an "unfolded" prototype, where all the necessary information for the "structured contents" is included. The final interactive version is being created as an evolutive digital environment for know-how providing schematic or detailed views, general or filtered information depending on the moment, the user requesting the information and/or the nature of requested information.

As seen on Figure 2, the interface is based on the Process component of the Framework, thus underlying its importance. All additional information is integrated into the process representation. Each "event" and item has documentation for itself attached to it (and accessible to everybody). Thus, the multidimensional matrix linked to a knowledge base "feeds" the items accessible through the process interface.

Various filters are constructed depending on the chosen perspective for representing the information. The filters are still in a process of development, but here are some examples:

- architect looking for a workflow concerning the energy simulation at the schematic stage of design;
- owner questioning the criteria for quality evaluation of the design at the schematic stage;
- contractor or project manager searching for a way to see the impact of prefabrication on the construction time of the building;
- facilitator preparing a charrette before the beginning of the development stage of a design project, etc.
Fig. 2. One of the proposed interfaces for the interactive digital implementation of the Conceptual Framework (adapted from the image of Bill Reed of Integrated Design Collaborative, Doug Pierce of Perkins+Will and Busby Perkins+Will)[4].

The Conceptual Framework, as conceived, plays the role of a common knowledge base for Integrated Design Process and acts as a boundary object, which is essential for collaboration [2, 18]. The domain knowledge present in the interactive implementation of the Framework will be organized through a semantic network and play the role of a teaching tool. As a special case, it could also serve as a common environment during collaboration on a given project.

Given the complexity of the domain, the large amount of information which needs to be addressed, as well as the permanent evolution of the field, the Conceptual Framework is first created at a base level. It will remain open for future additions and restructuring. It will have an established protocol for regular updates.

6. Validation scenarios

Two validation scenarios are under development and observation: one is concerning the ergonomics of the digital interface, and a second one is regarding the assistance provided by the Conceptual Framework in creating a common
language between different building specialists. Both of them take footing on the boundary object literature [14, 15].

In the first scenario, subject matter experts (SME; including but not limited to architects, engineers, urban planners, and pedagogical advisors) will provide feedback on the digital interface’s ergonomics in order to determine the extent to which the Conceptual Framework facilitates interactions and collaboration between users. In a first step, an in-depth presentation of the framework and its intended effect will be made to SME. Focus group methodology [19] will follow. Questions will include:

- What elements of the framework increase user interactions? Why?
- What elements of the framework hinder interactions? Why?
- What elements should be added in order to maximise user interactions? Why?

One researcher will moderate the focus group and two research assistants will record comments, suggestions, and issues raised by SME. After the focus group, the research team will convey and based on methods developed by Brannick et al. [20], will rate each element raised by SME on three criteria: contributions to design practice and/or process, relevance based on current knowledge and research on design, and feasibility of inclusion. These criteria will facilitate rank ordering of most pertinent improvements which will then be added to the framework by our team.

The second validation scenario involves an empirical demonstration of the framework’s impact on creating a common understanding of the design process and outcome among members of a team working collaboratively. Based on our previous research [16, 21], and psychological aspects of teamwork [18, 22] we will proceed with a pre-post measure of cross-disciplinary knowledge and perceived self-efficacy. Knowledge of others’ contribution and expertise is a predictor of team performance [23]. Self-efficacy is an individual’s beliefs in his/her capabilities to produce given attainments [24] and is a strong predictor of performance [25, 26].

Before a multi-professional collaborative design session based on the framework, team members will be presented with the design task and the goal of the session. In terms of knowledge, they will write down what they know of other disciplines’ contribution in reaching the goal. In terms of self-efficacy, they will rate the confidence with which their interactions with cross-disciplinary team members would help the team reach its goals. The same knowledge and self-efficacy exercise will be repeated after the design session. A positive difference between pre- and post-teamwork on knowledge and self-efficacy measures will indicate that the framework acts as an effective boundary object increasing knowledge and self-efficacy in reaching collaborative goals.
The Conceptual Framework will be introduced to the professional community through conferences and educational hands-on sessions. Then, it will be accessible on the Internet (according to modalities which are not determined yet).

7. Future development

The Conceptual Framework for IDP and BIM offers to the design teams meta-knowledge on processes and events, as well as domain knowledge regarding various aspects of sustainable buildings. The Framework is unique in its character as it brings information on processes, technology and sustainability into one integrated environment, thus inviting the design teams to use them together and in this way, increase the impact of each of them taken separately.

The future work will start by validating the Conceptual Framework and its interactive implementation through the above described scenarios. Then, modifications will be made, according to the results. Finally, the process of diffusion for the industry will start through introduction courses and publication on the digital implementation of the Framework.

Through some additional development, the interactive implementation of the IDP-BIM Conceptual Framework could also serve as a project repository or as a company’s sharing environment. Moreover, and again through supplementary development, it could be converted into a project managing tool: the general timeline can be customized and “scaled” for any process (number of gates, charrettes, ateliers, etc.) or left flexible in order to accommodate projects of different nature and scale.

8. Acknowledgements

This research project, with Project leader Professor Daniel Forgues, was made possible thanks to a grant from the Agence de l’efficacité énergétique du Québec and with the collaboration of the Quebec Order of Architects in Private Practice and the Quebec Order of Engineers.

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