«Bauhaus 101. Intercultural Dialogue Books» è una collana interdisciplinare che affonda le proprie radici nei paradigmi culturali e nelle finalità espresse dalla scuola voluta da Walter Gropius nel 1919.

La collana si basa sui principi fondativi della scuola Bauhaus. Avanguardia, innovazione, contatto con la realtà, sperimentazione, ricerca e formazione, libertà di espressione creativa e mentale, dialogo, collaborazione e contaminazione tra discipline umanistiche e scientifiche, nel rispetto di una visione innovatrice fondamentale per ristabilire un equilibrato rapporto tra tecnologie, arti creative, scienza e cultura, favorendo processi di connessione e condivisione fondamentali per lo sviluppo delle attività umane.

I testi esprimono in maniera chiara e costruttiva questa forte connettività interdisciplinare, favorendo la creazione di punti di tangenza nei differenti ambiti culturali, ossia lì dove avvengono interessanti conflitti creativi che costruttivamente rimettono in discussione regole e codici per esplorare nuovi e interessanti paradigmi.

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Towards the reactive building process management

BIM and AI techniques to improve time and cost optimisation in construction sites

preface by Gabriele Novembri

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Preface

To increase productivity of the construction sector close to the levels of the manufacturing industry is now a mandatory goal.

The optimisation of times and costs of the sector's performance appears to be linked to a general evolution that involves all aspects of the construction industry, among which the site management and organisation must be included.

The development of software technologies now available for the sector, research activities and ongoing experiments show that, thanks to BIM modelling tools, the application of artificial intelligence techniques, project management, and production control systems it is possible to achieve appreciable results.

However, we face with a high fragmentation of construction companies and professional firms, and a regulatory framework that encompasses a high number of laws and bodies in charge of control and approval, that limits the extensive application of some techniques available today. These conditions evidently cause delays and the fragmentation of resources throughout the construction process.

For a long time, we have based the search for improving productivity on product innovation through many studies and experiments centred on the adoption of prefabrication and industrialisation.

Although product innovation has profoundly altered building construction methods and techniques, it now shows all its limits in the light of the very low productivity advances in the sector, as recorded in recent studies. In addition, this approach was not always well combined with the quality of the built environment, which was often characterised by light and shadows (*eg.* Corviale, the 'Khrushchyovka blocks' of the Soviet era, etc.).

For some time now, research and investigation activities have shifted from product innovation that we might define as *hardware* approach, to the search for a rationalisation, formalisation and optimisation of the process management, as is for the *software* approach.

The result of this significant paradigm led to major innovations such as the recognition, in the early 1990s, of the importance of Project Management combined with the extensive application of *Just InTime* and *Lean Production* Manufacturing techniques (Womack *et al.*, 1990).

Here too, however, we face many difficulties. While product innovation relies on mechanical-application experiments conducted in the laboratory or on limited portions of the element, research into building digital tools requires a holistic approach that considers the entire design, production and construction processes. It is within this complex framework that the research activity described in this publication fits. Its aim is to present a series of experiments in which certain design processes are formalised and modelled to optimise the resources, costs and construction times required. The models developed are aimed at organising the construction phases. Starting from the information base created through this type of modelling, the WBS is analysed as the definition of the work to be carried out, the location as the areas and context in which the activities must be carried out and the crews are the operating teams employed.

An Agency represents each of these three components. It represents a group of intelligent agents. Starting from the WBS, the definition of the locations and the assignment of the tasks to be carried out to the crews. The proposed simulative model allows the determination, starting from the information in possession, of a reciprocal balance to satisfy the objectives of each agent, which allows the definition of a satisficing progression (Simon, 1955) both respecting the safety of the workers employed and the spaces that the various operational teams can occupy.

The proposed methodology can allow the simulation of the construction process from the early design phases. This approach allows the designer to analyse the feasibility of the design choices regarding an important aspect that is often completely delegated to other actors during the construction phases. The decomposition of the text makes it easy to read, and the re-proposition of the codes and procedures of visual programming help in the comprehension and repeatability of the experiments, all of which were confirmed in the actual construction sites.

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Chapter 1

Introduction, general framework and vision of the research*

The construction sector satisfies one of human's basic needs, fulfilling a contingent need, and characterising the culture of a people or even an era, thanks to the power of the message they convey[1]. The data available prior to the recent pandemic show that the construction industry accounts for around 6% of GDP (Aa.V., 2018) and, in fact, represents one of the most important components of a nation's gross domestic product. Considering the development of emerging economies, such as China and India, they estimated the development of the sector by 2030 at 14.7% of GDP.

We need to consider that the improvement of the sector's productivity by only the 1%, would cause savings of about $100 Billion per year, to which we must add the important and beneficial effects on employment that an increase in the sector's productivity could trigger. The most recent literature shows how the quality and quantity of construction can affect the livability and economic attractiveness of cities and

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1. Is explicative in this sense the concept of the Weltanschauung (Adorno, 1985).

the well-being perceived by the population (De Boeck *et al.*, 2019), while also highlighting its important social role. Construction also plays a strategic role because this sector realises and guarantees fundamental services to the life and the development of a Country such as infrastructure, telecommunications, health and education. Despite its fundamental role, a serious lack of formalisation and optimisation of processes, still characterises the sector. We need to consider that while the manufacturing sector for twenty years improved productivity of about 2.6% per year, the construction registers now a loss of productivity estimated of about 25%.

This delay of innovations and related productivity issues affects many aspects of a nation's life. From a purely econometric point of view (Barbosa *et al.*, 2017), the factors originating the lack of productivity growth linked to technical and legislative aspects were analytically determined. It is interesting to note that the study also considers factors related to the legislative framework, which today appear to be backward regarding the development of digital techniques, often inadequate to ensure proper management of orders. In this sense, the research line of reshape regulation is active today in relation to introducing digital techniques in the management of contracts such as blockchain technology (Kiu, 2020). From a purely technical point of view, the factors responsible for low productivity can be summarized:

– low-tech construction and procurement processes, still relying on craft-based methods, characterised by a poor performance and quality (Al-Qutaifi *et al.*, 2018);
– limited use of automation and supply chain optimisation systems, as is the case, for example, in the

e-commerce sector. This leads to a lack of coordination between the progress of construction phases and the supply chain (The Scape Group, 2018);
- inadequate training of workers, which also affects safety management on the construction site (Dey *et al.*, 2017);
- limited formalisation, standardisation and simulation of construction processes;
- limited use of project management and lean construction methodologies.

Evidently, a key-challenge that will be determinant is the pervasive introduction of digital technologies into construction, considering the capability of digital processes to avoid human errors and to automatise procedures.

This process has been ongoing for many years, mostly for design tasks, but the introduction of hi-tech solutions was hampered by some typical features of the building sector. Considering the specific case of the Italian market, both of Design and Construction companies are mostly small or medium-sized, and there is an inner difficulty to take the wave of innovation, due to the impossibility to exploit economies of scale for amortising the investments in equipment, education, and training of personnel. Otherwise, also from the Client point of view, the implementation of digitalisation in their organisation needs a complete re-organisation of skills, tools, and procedures.

To catalogue and overcome these difficulties, we have firstly to better individuate issues and list them in two main categories, divided by the materiality of the impact of solutions. We can categorise as 'hard' them who refers to digitally improved tools and machineries to be employed in the construction process, with the aim to improve productivity by improving the physical capabilities of the involved manpower using tangible elements.

For example, we could include in this group all the wearable technologies starting from the augmented reality glasses till to the exoskeletons.

With the future spreading of the use of these tools, we can imagine how the manual tasks of construction could became less strenuous and, at the same time, shift the workers' energies and efforts from a purely physical level to a qualitative one, transforming in experts in tools management and construction quality control. However, this study focused on methodologies of improvement and optimisation of building process management, conceptually following the Systems Engineering approach (Mencarelli *et al.*, 2020), so we can categorize them as 'soft' because they act in organisational field.

The need to focus on these aspects arise also by considering that the development of Information Technology applied to the construction sector has led, in recent years, to the introduction of powerful approaches like the FEM and BIM modelling, which have had a great impact in the design sector. From the specific point of view of Construction management, the integration between Project Management techniques and BIM models (*eg.* Navisworks, Synchro etc.) led the way to the spreading of *Decision Support Systems* but, in current practice, they did not trigger a general process of re-thinking and rigorous formalisation of the building process.

One of the causes that limits the development of an innovative formalisation of techniques and procedures for the construction management is due to the tendency to use simple tools, often improperly such as the Gantt chart, which is appreciated above all for its immediacy of reading. Despite its clarity and immediacy, this simple technique, which is widely used in the sector, is ineffective in analysing situations where activities overlap. The technique makes it possible to show how many and which activities interfere in a work phase but does not make it possible to identify where this occurs on the site. Nowadays, this tendency makes it difficult to apply advanced project management techniques and, specifically, the full use of the Lean construction approach which, although known since the end of the 21st century (Green, 2002), is still applied to a limited extent in the construction sector. If it were possible to overcome the criticalities outlined above, what have been defined as productivity boosters would be activated, which are now indispensable for the construction sector (Barbosa *et al.*, 2017). The immediate consequence of the extensive application of the previously mentioned techniques would be the formalisation and optimisation of the processes, which would have a positive impact in terms of environmental protection, reduction of polluting emissions, raw materials used and a lower impact on the environment due to the reduction of execution times. It should be considered that the impact could be significant because the construction sector absorbs about 50% of global steel production and handles 30% of global pollutant gas emissions (Craveiro *et al.*, 2019). The activation of productivity boosters, however, requires a greater formalisation of processes, which now appear to be linked to the ability to coordinate and manage the tools available to operators through an orchestration of processes in construction carried out in a simulative environment, aimed at creating a single database no longer only of the properties and geometries of the elements (*ie* Building Information Modeling – BIM) but inclusive of the preferences and automatic evaluation of proposals, based on choice criteria imposed by the user or automatically deduced from previous experience, through a machine learning approach.

The study propose a way in defining this process of formalisation and management, through the use of advanced ICT tools directly usable by design ers, thanks to the possibilities given by Visual Programming. In fact, as predicted by Negroponte, the *Augmented Architect* needs to create their own digital tools and libraries of objects for increasing its design capabilities. Nowadays, this is possible thanks to the Application Program Interface (API) and generally with the Visual programming applications directly imbedded in digital design tools of current use. In this study, therefore, it was important to analyse the state-of-the art and test the capabilities of Reactive Programming (Ghannad *et al.*, 2019) to assess the feasibility of the project in terms of time and costs through a continuous and iterative exchange between tools of the so called 'software constellation'. The results, tested on actual construction sites, show how organisational measures can support both design choices from the outset to optimise resources, and the most convenient operational measures during the construction site.