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Editorial

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Keywords: tooling, automation, data-driven construction, contextual knowledge, modeling methods

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In the history of archiDOCT, data is the first topic that is taking up two volumes, a proof of the appeal of data as an extraordinary topic. This is a further confirmation of our speculations that the doctoral research oriented towards the world of data is paramount and seeks more fora to broadcast its several variants.

ArchiDOCT 17th “DATA - ii” differs from “DATA - i” as it focuses on a different object of inquiry. The first issue contained essays on the theoretical aspects of *Data, the technologies involved, and the relevant applications*, whilst “DATA - ii” contains essays on tooling, automation, and data-driven construction and modelling methods. An exceptional good-practice example is the prelude to the work of five doctoral researchers on the topic.

More specifically, ‘DATA - i’ focused more on the theoretical implications of the implementation of data in the fields of architecture, while exploring the ontological consequences within this entanglement, an on their reification into the broader field of the pedagogy of the discipline, the second one is based upon the premise that data is intangible entities continuously fluctuating in our environment but as a proper design material that can be used at different scales to address heterogeneous issues, with the capacity to lead the design process and circulate meaningful information. Whether we refer to the object, the building, or the city/territory, the implementation of data in architecture is intrinsically contextual and leads to inevitable connections with other domains, demonstrating at the same time the challenge to frame this topic from a single perspective.

The equivalent of the Vitruvian triad for what concerns data (collection, processing, analysis) does not directly apply to architecture considering its innate characteristic of being at the same time a discipline swaying between the sciences and humanities where relations are not linear, unilateral, or forethought. If in pure IoT and ICT, data is by definition ‘structured’, meaning that it adheres to a pre-defined data model and is therefore straightforward to an-

alyze, with a strict connection between ‘columns and rows’ (Excel spreadsheet or SQL database), in architecture the assumption to investigate is quite different.

Data in architecture is a form of unstructured or semi-structured data where, in most cases, individual components or boundaries are not directly related to a rigid scheme or organized patterns following predetermined manner, as it happens in software such as Apache Grid, optimized to maintain and store multiple relations between nodes. As architectural practice is exposed to multiple and simultaneous influences, unstructured information may contain, at the same time, data such as dates, numbers, and facts. If properly detected and catalyzed, these could interpret as proper system ‘glitches’ through which the design process moves forward as it evolves.

Bearing this distinction in mind, the research gathered in this issue aims to investigate data from an applied perspective and focusses on specific objects of inquiry. DATA - ii contains essays on Data Software and Building Technology and Data and the Cities where topics such as automated production technologies, data retrieval methods and implementation in urban morphology, data assessment for building information modeling methodologies are presented and discussed.

Computational Intelligence: The Grid as a Post-Human Network, is good-practice example by **Phillippe Morel**, architect, founder of EZCT studio, and scholar-educator at eminent architecture schools worldwide. Morel’s essay addresses the entanglement between the notions of technology and intelligence and their implications on production and its socio-economic and ethical context. As technology is itself a reflection of a particular intelligence, especially of the one that created it, it can offer insights into ‘intelligence’, no longer, as a specific character within a situated body in a determined space/time. According to the author, the current ‘distributed paradigm’ is where the concept of collective intelligence is fully expressed by grid com-

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puting, formally known as a group of networked computers, to reach a common goal. Different from cluster systems, each node can perform independently and perform simultaneous tasks. These post-human networks, defined as (a)-spatial and (a)-social, allow a new genre of complex (mass) production where the role of the human is limited to conceptual work. Such premises are exemplified in the work of the EZCT Architecture & Design Research studio, where attempts of moving towards the grid of design conceptualization and production have been made over the years. These experiments have also been the reason to reflect on the concept of collaborative practice not just as a human-exclusive prerogative.

The first essay, delivered from PhD **Fani Kistorou**, Bartlett UCL, is entitled **Visualising Change in 4D: Bridging larger- and smaller-scale data in architectural and urban morphology**.

The author explores the connection between data and urban morphology from both a quantitative and a qualitative perspective. Firstly, she discusses the possibility to collect and relate a series of 'un-structured' sets of information coming from heterogeneous means such as field surveys, historical maps, building permits, photos, text-view, and recordings. Secondly, she argues for the comparability of such datasets through their manipulation, organization, cleansing, and modeling throughout multiple tools such as NURBS Modeling, Geographic Information Systems, and Visual Programming Languages. Using an accurate three-dimensional model for the housing scheme of Cité Ouvrière in Mulhouse (France) as a case study, Fani presents an integrated operative framework to map and measure all the different changes that have been taking place either at an architectural or an urban morphology scale. The essay demonstrates how previous limitations can be overcome through enhancing spatial analytical models by producing and analyzing new meaningful dataset combinations through a proposed qualitative framework.

A geo-data collection strategy to assess undergraduate students' housing: A social, environmental, and spatial approach, is a choral effort of a group from the University of A Coruña (UDC) composed by **David Pereira-Martínez** (PhD Candidate), **Vicente López-Chao**, **Plácido Lizancos**, and **Virgílio Borges Pereira**, from the University of Porto (Porto). Their work focuses on the production of a spatial and analytical database to assess students' location and change of residency according to their study needs and university position, considering at the same time the modification of such dwelling over time. Their multifaceted analysis is conducted by gathering a sensitive amount of data led by a 'non-intrusive' philosophy towards the user's intimacy. The specific methods and tools described are intended to propose a new and efficient workflow in architecture and urban studies to implement social, environmental, and spatial features from a geo-data collection procedure. The group has used this holistic strategy to realize visual and qualitative outcomes to describe the students' housing phenomena and further propose urban requalification and performance-driven interventions.

The damage survey forms for Cultural Heritage between simplified procedures and needs for implementation: a critical analysis of data collected for the ceme-

tery type after the "2012 Emilia" Earthquake, authored by **Veronica Vona**, PhD Candidate at the University of Ferrara, points out some of the criticalities emerging from the implementation of current damage survey tools for Cultural Heritage for cemeteries following the severe Emilia Romagna Earthquake (Italy). After a disquisition regarding the specific typology of the cemetery, both from a historical and an urban point of view, the essay focuses on how the existing tools cannot offer a proper operative framework to proficiently use the data recorded to produce meaningful analysis and elaborate effective intervention strategies. By identifying a series of criticalities about different categories (damage index calculation; experimental form introduction; macro-elements identification, etc.) the author presents part of her research-oriented towards more suitable frameworks and data acquisition methods for the field of damage evaluation.

Structural Expertise through BIM, delivered by **Víctor Fernández-Mora**, Department of Construction Engineering, Universitat Politècnica de Valencia, and **Víctor Yepes**, Institute of Concrete Science and Technology (SCITECH), Universitat Politècnica de Valencia, attempt to combine two identified trends in the Architecture, Engineering and Construction Industry (AEC Industry): Building Information Modeling (BIM) and the rehabilitation of existing and not efficient buildings. Specifically, the authors propose Building Performance Simulation Tools (BPS) to enhance structure expertise in architectural renovation, exploiting the possibilities of the BIM environment. The plug-in they developed extracts the data from the BIM Model (downstream moment), performs the analysis, and introduces the result back into the software (upstream moment) while informing the professional of the suitability of the element to support the new demands. Software interoperability and data exchange is the main feature of this integrated approach where problems related to uncertainties in structural behaviour, materials, and design of elements, can be addressed by offering professionals new tools at hand.

The last essay by **Bianca Andaloro**, PhD Candidate at the University of Palermo, is entitled **Data matters: two pioneering projects of interactivity in architecture**, focuses on the analysis of two pioneering projects to create an attractive binomial couple to highlight the importance of physical and virtual interaction between buildings, data, and environment.

Two projects, the Saltwater Pavilion by Kas Oosterhuis and Blur by Diller Scofidio, are described as useful examples where the exploitation of data and its consequential implementation in architectural design can lead to 'make the invisible visible' and suggest new relationships with the external environment and its continuous modifications.

The essay follows a research path that proposes interactivity as the catalyst of the so-called 'Information Technology Revolution in Architecture' and pictures a scenario of a renewed sensibility towards the definition of new connections between the building, the user, and the broader context.

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Computational Intelligence: The Grid as a Post-Human Network

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Keywords: genetic algorithms, postindustrial knowledge, collective intelligence, grid-computing, post-human collaborative practices

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Research and design collaborative EZCT Architecture & Design Research has adopted grid computing to produce a series of furniture systems and other small-scale prototypes using genetic algorithms in combination with automated fabrication technologies. Here, cofounder Philippe Morel relates this design practice to the broader technical and social implications of various grid-computing projects, such as the online organisation Folding@Home, which utilises grid computing and distributed communities for the production and exchange of postindustrial knowledge. He argues that these ‘knowledge farms’ which create an ‘ambient factory’, are perhaps the ultimate form of social-economic production, transforming not only the evolution of design but of the communities that produce and eventually consume its products.

Indeed, today, it has sadly become very fashionable to reject, in an obscurantist way, many more things in the sub-conscious than is necessary: it is much nicer to adore the ‘primitives’ and to note, happily, a ‘bankruptcy of the rationalist mind’ ... than to realize, once and for all, without equivocation, that the age of physics, far from becoming extinct, is just beginning!

Arno Schmidt (1959), *Calculus I*

The scientific man is the ulterior development of the artistic man.

Friedrich Nietzsche (1994), *Human, All Too Human*

1. ‘Distributed’ Paradigm

During the past five years, most of my (post-) ‘critical-political time’ has been spent dealing with a new idea of collective intelligence that replaces the one implicitly defined, a century ago, by Gabriel Tarde (1890) or, explicitly, 10 years ago, by Pierre Lévy (1997). This intelligence first evolved from communication networks ranging from the newspaper to the telephone, the fax to the Internet. Today, it finds its fullest expression in grid computing, the distributed computing paradigm *par excellence*. Grid computing is a protocol for linking discrete but geographically dispersed

machines into a distributed parallel processing network. Grid computation has given rise to a distributed computational intelligence that renders the classical concept of singular and autonomous intelligence obsolete.

As important as the technology itself are the consequences of this phenomenon, namely the rise of a new kind of people – geographically isolated scientific farmers who exchange their postpolitical concepts in symposia¹ – and the rise of a posturban environment that I call the ‘Ambient Factory’. What are the constituents of this factory? An early example, SETI@home, participated in deciphering extraterrestrial radio signals for signs of extraterrestrial intelligence. And this experiment has recently been transformed into a new model of industrial production with projects such as Folding@Home, Evolutionary@Home, XPulsar@Home, FightAids@Home, Genome@Home, Models@Home and HIWTNI (Home is where the network is).²

All these examples of grid computing use the downtime of geographically dispersed PCs (at the moment often running as screensavers, but there is no doubt that computation power per se will become a global market – take, for example, the polluting rights market and the recently created Powernext Carbon)³ to process the immense amounts of

^a **Philippe Morel** is an architect and theorist, co-founder of EZCT Architecture & Design Research (2000) and initiator and founding CEO of the large-scale 3D-printing corporation XtreeE (2015). He is currently a Visiting Professor at UCL Bartlett and an Associate Professor at the École nationale supérieure d’architecture Paris-Malaquais, where he headed the Digital Knowledge department (co-founded with Pr. Girard). He was previously an invited Research Cluster and MArch Diploma Unit Master at the Bartlett School of Architecture, UCL. Prior to this he taught at the Berlage Institute in the Netherlands (seminar and studio) and at the AA (HTS Seminar and AADRL Studio). His long-lasting interest in the elaboration of a theory of computational architecture is well expressed in his numerous essays, projects and lectures.

¹ Those who are not scientists, who are, by implication, in marketing or business, exchange their ideas in trade shows or technology conferences, places where, following Nietzsche’s sublime prediction, our whole civilisation affords ‘buying or selling as a luxury of our sensibility’ (Nietzsche, 1882).

² I used this HIWTNI abbreviation, developed by the McKinsey quarterly, in Morel (2002), which is an explicit theorisation of what I only evoke in the present article.

³ Due to the Kyoto Protocol, companies and countries now trade polluting rights on this dedicated marketplace (Powernext Carbon).

data involved in investigating a scientific research problem. Through a home PC, which becomes a piece of e-laboratory equipment, any user therefore participates in a community of scientists and nonscientists in producing knowledge. This effectively creates a carpet constructed of autonomous but interconnected 'farms': computer farms, energy farms and so on. The term 'farm' may seem anachronistic, but it is appropriate because it connotes the sorts of new living practices these networks produce.

The questions such projects raise for (a-)spatial and (a-)social organisations of production for the present are as significant as Ludwig Hilberseimer's recognition of the electrical power grid in 1955 as 'the real force toward [urban]decentralization', since 'even the smallest settlement can be supplied with water, electricity, heat and light' (Hilberseimer, 1955).⁴ Today, grid-computing networks not only allow the multitudes to communicate and to give an existence to the 'world brain', they allow computers to communicate in autonomous ways as a pure infrastructure that is at once global, abstract and standardised. This infrastructure allows a new kind of distributed computational and linguistic production, revealing what previously was called human production⁵ as what it truly was all along: reproduction. Indeed, because of the growing complexity of all production (for example, in biotechnology, material science, pharmaceuticals and computer sciences), all that is left for human labour is conceptual work. Everything else, in any field, is done by computers or numerically controlled machines.

2. 'Distributed' Paradigm

Why use ideas of industrial production, post-human networks or disappearing cities in reference to bionetworks and the multitude? Contemporary production seems to be driven by scientific rather than social forces. If so, understanding science means understanding real characteristics of our civilisation driven by 'quantitative concepts' such as numbers, statistics, approximation tools and methods, and mathematical precision. Quantity sounds abstract if, in the field of architecture, we consider Hilberseimer's diagram

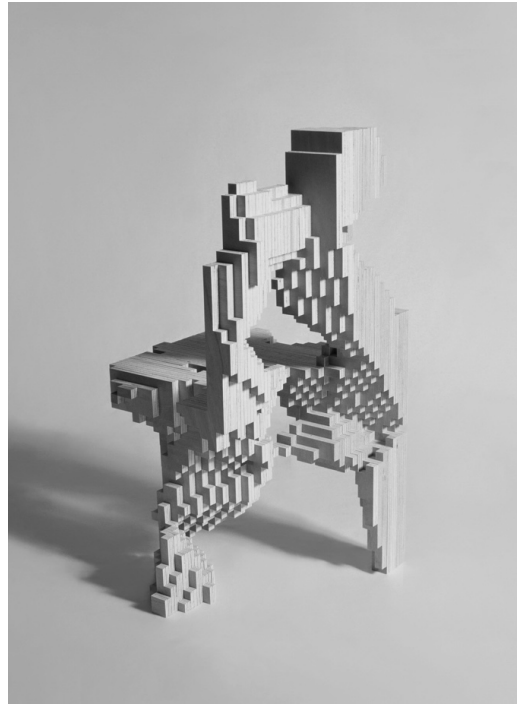


Figure 1. Chair 'Model T1-M', after 860 generations (86,000 structural evaluations)

H Bomb on Chicago, dated 1946, but it also appears as a very practical concept if we listen to Max Planck's comment on the same nuclear power problem (1947): 'An appropriate calculation has shown that the quantity of energy liberated in this way in a cubic meter of uranium oxide pulverized in a hundredth of a second would be enough to raise a load of a billion metric tons to a height of some 18,000 meters. Such a quantity of energy could replace the combined production of all the world's most powerful plants for a good many years' (Planck, 1947).

⁴ The Ambient Factory concept actualises not only Hilberseimer's but also Mies' parallel comment: 'There are no cities, in fact, any more. It goes on like a forest. That is the reason why we cannot have the old cities anymore; that is gone forever, planned cities and so on. We should think about the means that we have to live in a jungle, and maybe we do well with that' (van der Rohe, 2001).

⁵ The classical one theorised by Adam Smith then Karl Marx

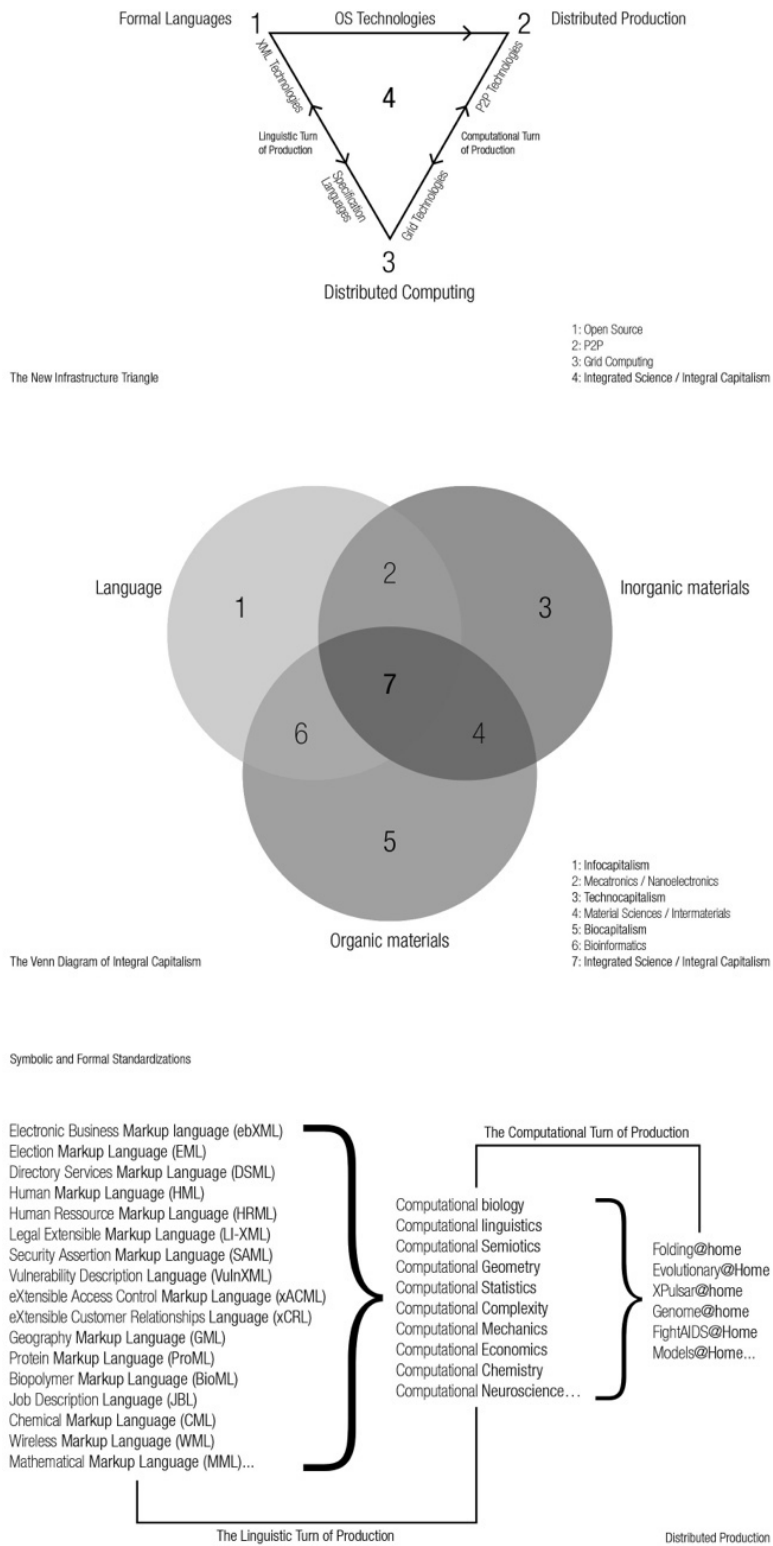


Figure 2. The diagrams are part of a global analysis of contemporary science-based capitalism – through the linguistic/computational turn of contemporary production – developed by Philippe Morel over the past four and a half years. This study insists on the merging of three inseparable forms of capitalisms (infocapitalism, technocapitalism and biocapitalism) into an integrative economy: the Integral Capitalism. The study has to be considered as a post- Koolhaas (as well as postSassen) analysis of globalisation

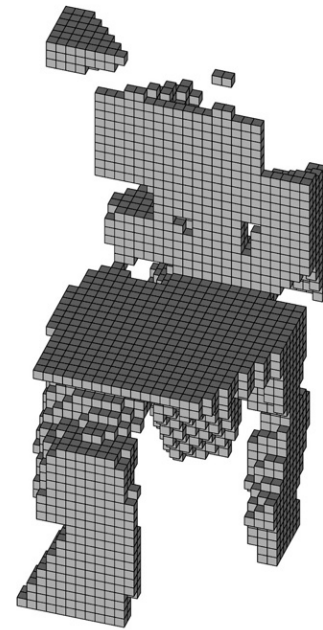
Source: Morel and EZCT Architecture & Design Research (2002)

Here, quantity is a concrete problem, as concrete as Robert Musil's definition of the traditional newspaper – 'filled with a measureless opacity' that 'goes far beyond the intellectual capacity of a Leibniz' (Musil, 1930) – a definition often envisioned for our contemporary information overload. In this respect, thinking about collective intelligence means thinking about the way it works and the way problems are solved. Quantitative questions in fact pose their problems and their solutions simultaneously. Algorithms solve searching problems, peer-to-peer storage problems, open-source collaborative practices' problems⁶ and open technologies standardisation and communication problems. An answer to a technological problem is always a technological answer. Then, what is grid computing if not an appropriation, for industrial purpose,⁷ of a new kind of productive paradigm? Is not SETI@home, which processes each year the equivalent of 400,000 years of computing time by a single processor, the new paradigm for industrial production, for 'collaborative computational practice' in any field, including architecture? It seems that corporations have already answered positively to this with their employment of the SETI@home model,⁸ and I believe that grid computing is the next step for collective intelligence – an infrastructure-based computational intelligence.

3. Tools and Concepts

The integration of concepts like distributed partial machine intelligence within the design process is an integral component of EZCT Architecture & Design Research's work. However, the practice not only refers to ideas of technology and science in their analyses of technology, but makes use of them. Architects should not metaphorically depict technology but use it, in a flat model, beyond any representation. Finally, because EZCT is part of the multitudes whose work concerns the 'ultimate production of human imagination' – that is, concepts – the practice also builds proofs for these concepts as design projects constructed through computers and programming languages.

For example, the practice has recently moved towards a grid model of design conceptualisation and production, extending its long-standing use of Mathematica, software normally oriented towards scientific communities, as a design tool, by using its grid-computing variant. GridMathematica leads to more efficient collaborative practice while alleviating the constraints of a single computer's calculation power. Its use has allowed EZCT to reinforce its long-term collaboration with physicist Bruno Autin (author of the Geometrica software package, formerly of CERN) and mathematician Maryvonne Teissier (Paris VII University). Of course, GridMathematica is not the only way to achieve



TestBolivar-320 Generations

Figure 3. The 'Bolivar' model is evaluated for a multiple load strategy (it is always stable, whatever way the seat is positioned)

This model (prototype and drawings) is part of the Centre Pompidou Architecture Collection

Source: EZCT Architecture & Design Research, Hamda, and Schoenauer (2004)

distributed computing. During the summer of 2004, EZCT led a project wherein a series of chairs were computed using genetic algorithms for optimisation using a cluster of 12 computers from the École Polytechnique in Paris. They were controlled by Hatem Hamda, from a geographically distinct lab (INRIA), using a Linux platform and open-source libraries and software including Evolving Objects (an evolutionary computation library) and xd3d (a scientific visualisation tool). In this process, first a human collaborative practice was evidently implied in the previous development of the open-source libraries, software and so on, and second a computational and 'post-human' collaborative practice became the paradigm since a very limited number of people were able to appropriate a vast amount of computational resources.

Thus we should not underestimate the fact that collaborative practice does not necessarily mean a human collaborative practice, and take into account newly emerging concepts; for example, that of productive autonomy.

⁶ Open source is an answer from contemporary capitalism to itself: 'I've worked for IBM in Linux for more than six years, and it has become big business for us, it's a fundamental part of IBM's business. We're not into Linux and open source because it's cool. It's nice that it's cool, but it's good business. We're making billions' (Frye, 2005).

⁷ Keep in mind that everything is industrial – it is pharmaceuticals, high-energy physics experiments, education, and so on – and that some distinctions between laboratories on one side and transnational corporations on the other do not really hold any more.

⁸ Arcelor or AstraZeneca: 'Large-scale clusters allow us to manage and share computing resources across the entire Discovery Function, accelerating drug discovery, design and time-to-market, and realize our investment in hardware. Platform LSF has more than proved itself so far and is now the preferred solution for managing compute farms in AstraZeneca' (McLaughlin, 2002).

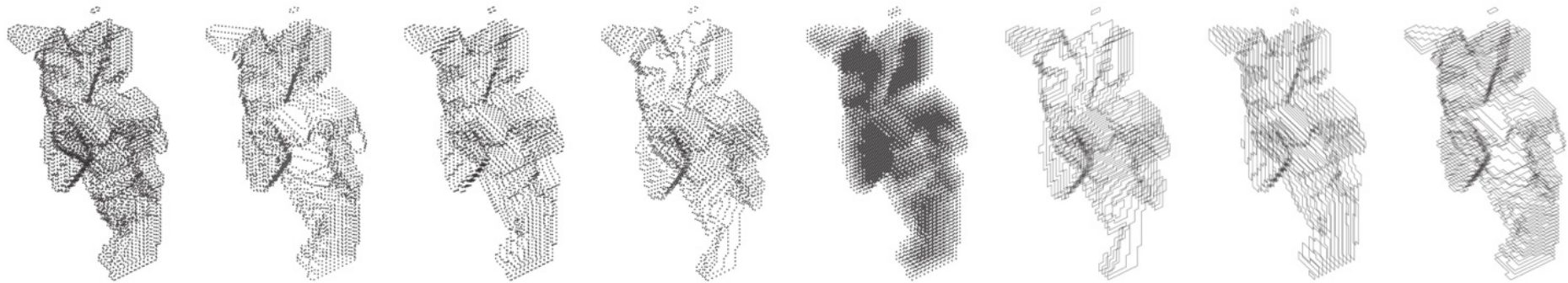


Figure 4. Data analysis, 'Bolivar' model, Mathematica drawings

Because the data was structured for mutations and evaluation via finite element methods, it needed to be rearranged for fabrication. Mathematica was therefore used for writing different algorithms in order to ease pricing, cutting and assembling. The drawings are part of the Centre Pompidou Architecture Collection.

Source: EZCT Architecture & Design Research, Hamda, and Schoenauer (2004)



Figure 5. The process sheet shows seven chairs optimised through a mono-objective optimisation strategy, two chairs optimised through a multi-objectives strategy, and the optimisation process for Model 'Test2'. The sheet shows the crossing-over internal representation based on Voronoi diagrams. This high-level representation strategy, developed by Marc Schoenauer, allows for a better correspondence between the genotype representation and the phenotype of the real chairs

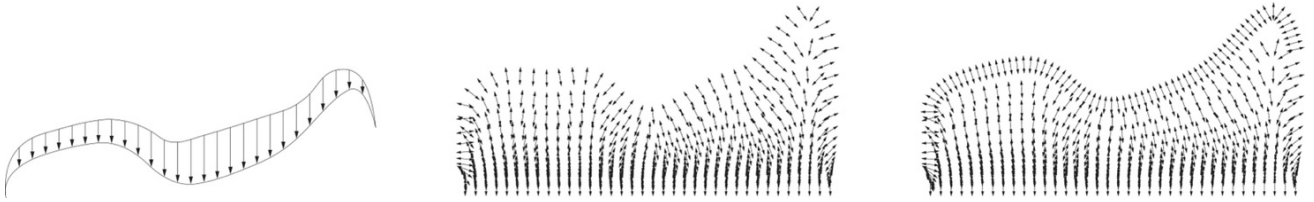



Figure 6. Preliminary structural studies for a lounging chair (unrealised)

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Visualising Change in 4D: Working With Quantitative and Qualitative Data in Cartographic Studies

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Keywords: cartography, archival research, 3d modelling, statistical computing, GIS information

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This paper discusses the methodologies and datasets used in the cartographic study of morphological change in a 19th century residential scheme in Mulhouse, France. It examines (1) the availability and comparability of existing datasets (spatial, historical and archival), (2) the collection of new data from field surveys to historical maps, building permits, photographs, and planning documents by means of visual mapping, drawing, text review, and recording, and (3) their pre-processing including their transformation, cleansing, and integration using specialised tools, such as GIS, Rhino, Grasshopper, and RStudio.

The final outcome is a detailed and georeferenced three-dimensional model for the entire housing scheme of Cité Ouvrière that includes all 1,253 buildings (in volumes) and plots (in polygons) in their original (circa 1897) and current state. The produced model combines the accuracy of smaller-size data with the extent of bigger-size data. Its extent, level of aggregation and detail make it possible to use for cartographic research and spatial analysis at different scales and link it to available geographic information employed for municipal and national planning. Specifically, the model has already been proven valuable in revealing patterns of change and measuring the impact of the building densification process at the microlevel (Kostourou, 2021). This is because it can support a granular, longitudinal historical study that spans over 150 years and cover different spatial scales (from the neighbourhood to the building) while serving as a tool to systematically document transformations in the built form across scales and illustrating how local individual processes contribute to the formation and transformation of the larger whole.

The paper introduces an integrated framework for mapping physical changes of buildings and plots, by joining historical research, spatial analytics, and architectural modelling. Proposed as a solution to the inadequacy of current frameworks and datasets, the new methodology is able to collect and combine available information from online sources, archival documents, and field work; create and process high resolution and aggregate data; overcome limitations of current cartographic studies and open up possibilities for researchers to exploit two-dimensional and three-dimensional, categorical and numerical data for the analysis of spatial structures.

1. Introduction

This paper discusses the methodology used in the study of morphological changes of buildings and plots in the Cité Ouvrière in Mulhouse in eastern France. Cité Ouvrière is a nineteenth century working-class settlement originally

built for the workers of the DMC textile factory. It comprises of 1,253 single-family houses, which over the course of 165 years, have been transformed. The inhabitants have incrementally expanded their houses, altered their roofs and facades, added sheds, garages, shops, and workshops, and rented out parts of them for income (Kostourou, 2020b).

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The whole scheme has changed from a designed industrial housing development to domestic vernacular based on an extensive system of bottom-up and top-down adaptations and greater socio-economic changes.

In the process of studying Cité's transformation, the main challenge was how to *map* the physical changes both *synchronically* and *diachronically* in order to measure them both individually as well as aggregately as a phenomenon of a larger neighbourhood. The two temporal dimensions mentioned, synchronic and diachronic, derive from the concept of 'description retrieval' in space syntax theory (Hillier & Hanson, 1984), according to which at any given time and for any given description of space, there are both synchronic and diachronic relations, that can be captured in a single frame or over time respectively (Griffiths, 2009; Hanson, 1989). In other words, apart from a static way of looking at the built environment, there is also a fundamental need to trace its description as a sequence in time because it assists the understanding of historicity (Griffiths, 2011) and of processes of growth and change in societies (Connerton, 1989), cities (Moudon, 1986; Psarra, 2018), and buildings (Brand, 1994; Steadman, 2008, 2014). Hence, mapping both the synchronic and diachronic descriptions of space in this study would provide a more thorough, systematic, and multi-scalar understanding of the capacity of different elements of the built environment to change with time.

In what follows, I present all the analytical steps and decisions taken to map changes in volume and shape at both an architectural and an urban scale, ultimately proposing a methodological workflow that joins historical research, spatial analytics, and architectural modelling (section 4). A first part discusses the availability and comparability of existing datasets (geographical, historical, and archival), exposing their current shortcomings (section 3). The next parts discuss quantitative and qualitative data separately. First, section 5 describes the creation of a synchronic 3D model based on available GIS data and historical drawings and images, and then, section 6 explains the collection and handling of categorical data from field surveys and historical building permits found in the municipal archives by means of visual observation, sampling, content review, and analysis. The last part explores the preparation, transformation, and combination of the datasets produced in the previous steps to create an original and comprehensive geospatial dataset that carries spatio-temporal attributes and features vector and three-dimensional forms, and which can be used to trace the evolution of the built form over time (section 7).

The paper proposes a new methodological workflow to collect and combine larger- and smaller-scale information from available online sources, archival research, and field survey whilst turning them comparable in terms of their level of detail, georeferencing and processing ability with the help of advanced analytical tools. This approach overcomes limitations of previous studies and helps researchers in the fields of urban studies, historical geography, cartography, and architecture to document past and present development patterns, visualise the dynamics of growth in the built environment, and predict future trends. It is also particularly useful for architects, planners, and data scien-

tists who work with two- and three-dimensional data for the analysis of the built form.

2. The Field of Urban Morphology

Urban morphology is the field that investigates the formal elements of streets, buildings, and plots. In its classical form, there are several schools of thought: the Italian (process typological), the British (historic-geographical), the French (historiographical), the German (morphogenesis) and the North American (geographical). I will make no attempt here to explain the ideas and lines of inquiry behind each school, on the one side because excellent summaries have already been provided by Cataldi (2003), Marzot (2002), Whitehand (2001), Larkham (2006), Darin (1998), Hofmeister (2004) and Conzen (2001), and on the other, because a number of papers (e.g., Gauthier & Gilliland, 2006; Kropf, 2009; Moudon, 1997; Pinho & Oliveira, 2009; Scheer, 2015 to name a few) have already discussed the differences between them. What is of interest here though is that although the schools' approaches seem to be fragmented and lack a coherent universal systematisation (Fleischmann, 2017), they share an epistemological overlap. This is concisely summarised by Scheer (2015, p. 3): "Epistemologically, all the urban morphology schools of thought share certain methods of acquiring knowledge, analysing it, and validating it. These are (1) collection of formal data about the study area; (2) recognition of common patterns in the study area and across study areas; (3) developing and testing theories of change; and (4) linking the results of the physical analysis to conditions not directly related to urban form".

2.1. Existing Methods

In this common epistemological inquiry, there are two important caveats to note; the first refers to the type, extent, and resolution of formal data, and the second to the methods used for recognising patterns. On the one hand, classical morphologists gather data from historical maps, surveys, field measurements, photographs, and documentary records in a rather laborious and time-consuming way. Even though the produced datasets are very detailed and provide a fine-grained understanding of the ground conditions (see for example some of the earliest works of Muratori, 1959, M. R. G. Conzen, 1960 and Whitehand et al., 1999), they are limited in volume and extent—a problem often identified when dealing with *small-scale data*. On the other hand, analysts rely heavily on visual observations and verbal descriptions to recognise patterns from the gathered data; an approach which lacks systematisation and quantification, and depends on the resolution of the study and its context (Whitehand, 2012). Indeed, Serra (2013) flags this is a common and important problem in the classical field and calls evidence that stems from visual observation ill-defined, non-reproducible, and impossible to falsify.

After the 1970s, technological developments in the field of GIS and the availability of larger volumes of geospatial data made it possible to overcome some of these limitations. This saw the rise of quantitative urban morphology, which allowed for the cartographic representation of wider areas in the urban fabric and the analysis of the topological,

dimensional, and geometrical relations of their formal elements at a larger scale (Erin et al., 2017). Few of the most distinctive methodological advancements include the mathematical models introduced by Martin & March (1972); the graph theories of Krüger (1977) and Steadman (1983); the *Space Syntax* theory and methods by Hillier & Hanson (1984); the *Shape Grammar* by Stiny (1980); the fractal geometries by Batty & Longley (1994); the *Spacematrix* density model by Berghauer Pont & Haupt (2004); the street patterns descriptor by Marshall (2005); the *Multiple Centrality Assessment* by Porta et al (2006); the *architectural morphospace* by Steadman & Mitchell (2010); and the *Urban Network Analysis* by Sevtsuk & Mekonnen (2012). However, these approaches have so far focused more on the analysis of spatial datasets rather than the creation of new ones, that may combine the resolution of small-scale data and the volume of larger-scale data.

3. Types of Data

In the present study, to measure morphological changes via one of the abovementioned tools of quantitative urban morphology, new spatial data had to be created suitable for further processing and analysis. For the case of Cité OUVRIÈRE, three kinds of data were necessary and available:

- Geographical data, that is two-dimensional georeferenced data, which included –but did not stay limited to– contemporary cadastral plans in CAD and GIS format acquired by the local municipality (*Ville de Mulhouse*), the *Institut National de l'Information Géographique et Forestière* (IGN), and the *Agence d'Urbanisme de la Région Mulhousienne* (AURM). Although the data came from different sources they had a certain degree of consistency and served as the base to which primary data from field observations were added manually.. They also had measurable properties were indexical, and therefore reliable, verifiable, and robust for analytical research.
- Historical data, which were essential given the longitudinal aspect of the research. The study relied on both quantitative and qualitative historical data for example old photos and plans from the municipal records (*Service des Archives municipales*), and the digital platforms of the city (mulhouse.fr) and of the region (mulhouse-alsace.fr). Some historical data were only available in hardcopy form due to their age, requiring considerable effort to collect (often in situ), digitise and synthesise. Yet, their value was unique for they enriched and extended the informa-

tion available to present; provided well-grounded evidence to support a longitudinal study of patterns of continuity and change in spatial structures; and revealed the dynamic relationship of the social and spatial issues, which are hardly vested in a single moment in time.

- Archival data, a sub-category of historical data, referring to original heritage documents, currently without use, that have been made, received or maintained by public administration organisations. The study used archived maps and building permits for individual houses issued by the municipality before 2000¹. Most of these data had to be retrieved manually from the local *Service des Archives de Mulhouse* due to copyright issues². Despite the laborious nature of that process, this data offered to the study a much more vivid understanding of the decisions made by different actors at any particular time in history (Kostourou, 2022) and painted a graphic picture of the order and sequence of changes between synchronic descriptions of the built environment.

3.1. The Problem of Existing Large-Scale Data

Nonetheless, the historical or archival data did not come in a vectorised format and the existing large-scale geographical data fell short of capturing the three-dimensional built form at the micro level. Available geographical data like the BD TOPO®³ covered only 95% of the building information. This was because of the way the data had been collected from photogrammetric restitution⁴ from an aerial photography (precision between 0.5-1.5m). [Figure 1](#) summarises the modelling constraints in a graphic way.

Firstly, according to the descriptions provided by IGN (2014, p. 70-72), buildings smaller than 20m² were missing from the dataset, while buildings between 20m² and 50m² were disregarded depending on their location and appearance. This meant that volumes such as small annexes, workshops or garages were excluded. Secondly, inner courtyards with a width of less than 10m were not represented as a hole in the built-up area; affecting thus any typological understanding of the built form. Thirdly, adjacent or superimposed buildings with the same land use were generally considered as one and the same object (having only the outer contour marked), if their height difference was less than 10m (or 3 storeys) and the surface area of each building was smaller than 400m². Last, the building geometries did not match the geometries of the plots (BD PARCELLAIRE®), whose outlines were directly obtained from the cadastre.

1 Documents produced after 2000 are not kept in the *Service des Archives de Mulhouse*. For the sake of convenience and consistency, the analysis only relied on archival data found in this building.

2 Some data are accessible online in webpages operated by the Ville de Mulhouse, Mulhouse Alsace Agglomération (m2A), Bibliothèque nationale de France (BnF), Centre Régional de Documentation Pédagogique de l'Académie de Strasbourg (CRDP) etc.

3 BD TOPO® is a 3D vectorial geographic description of territorial objects and infrastructural elements, in metric precision and at scales ranging from 1: 2,000 to 1: 50,000. The edition referred here is from April 2016.

4 Science and art whose subject of study is photography in the intention to collect data leading to dimensional restitutions and to determine the shape and position of an object in space.

So, without a complete integration of the two data sources, the formal elements were not superimposable in the GIS platform.

In terms of buildings' height, micro differences and roof details were lost, although the received dataset covered the entire city. The height of the buildings was calculated as the difference between Z_{max} (altitude of the contour, that is the upper edge of the buildings, usually the height of gutters) and the ground level elevation. Z_{max} was calculated by interpolation as the median roof altitudes, considering the altitudes of the contours of the directly contiguous buildings. So, heights between adjacent buildings with small height difference were averaged and unified, and buildings lower than 3m (Z_{min}) were not captured at all.

4. A New Methodological Framework for the Built Form

So, there was a clear need to create a new dataset, comprised of a detailed georeferenced three-dimensional model of Cité Ouvrière, that could overcome all the above limitations and document the historical development of the boundaries, shapes and volumes of its plots and houses at the micro level. [Figure 2](#) shows the proposed workflow process for that task, visualising the sequencing of steps, and the tools and methods associated with each of them.

The first set of methods and tools (secondary data processing) concerned the advanced 3D modelling of the built form. Specialised tools, such as GIS, Rhino and Grasshopper, were used to create two detailed and georeferenced 3D models for the entire housing scheme of Cité Ouvrière including all 1,253 buildings and plots in their original (circa 1897) and current state (circa 2018). The final data (larger-scale) was extensive in volume, carried detailed information about the built form, and could be linked to the georeferenced geometries received from the municipal and national institutions.

The second set of methods and tools (primary data processing) aided to gather new data by means of visual observation, classical mapping, drawing, text review, and coding. These data (smaller-scale) were limited in volume and format, and slow to collect; still, they were more detailed, easy to comprehend and synthesise. Their qualitative analysis was mainly descriptive, yet provided insightful information on the local context.

Both data handling processes yielded datasets in tabular forms, which were then combined and further analysed in the RStudio software. Further analysis on the joined dataset was able to reveal patterns of change at various scales, trace the densification process at the micro level, and measure its impact on the open space consumption in a statistically sound manner (Kostourou, 2021); however, a presentation of these results extend beyond the scope of this paper. What is important to note here is that the R programming language was instrumental in combining and analysing large sets of both categorical and numerical data.

The above process establishes a methodological workflow for a high-resolution multi-scalar quantitative and qualitative analytical approach to study morphological changes over time. It is a smooth workflow between different tools, datasets, and representation modes to ensure

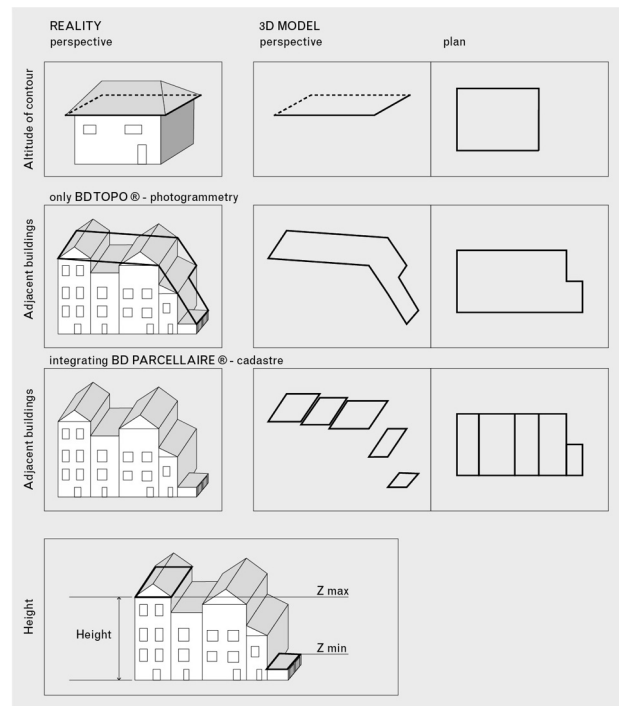


Figure 1. Modelling constraints as presented by IGN (2014, p. 71-72) and edited by the author.

the consistency in the resolution and precision of data, the coherence and systematisation of the analytical steps, and the reproducibility of findings. Also, it deals successfully with both the synchronic and diachronic processes of urban transformation and the microscopic and macroscopic scales of spatial investigation.

4.1. Limitations

Despite its comprehensiveness, the workflow features certain limitations. Firstly, the creation of the datasets is a slow and laborious process, and its necessity depends on the research objectives. Secondly, the produced models are simplified representations of the built form, namely volumes for buildings, and polygons for plots. Geometrical and architectural details like facades and interior layouts are not captured, and subsequently, not considered in the analysis. Nonetheless, simplification is a standard part of modelling, and helps focusing on the properties of the object under investigation. Thirdly, important factors that affect the formation and transformation of the built form are not quantified, such as planning controls, zoning, fire codes etc. Although the study looks at building regulations through history, it does not represent them numerically or visually as such thing would be very difficult to do. Of course, some of the above limitations as well as the labour-intensiveness of key stages could potentially be managed by a wider team of researchers. In that case, strict rules need to be set in advance not to compromise the consistency and accuracy of the process.

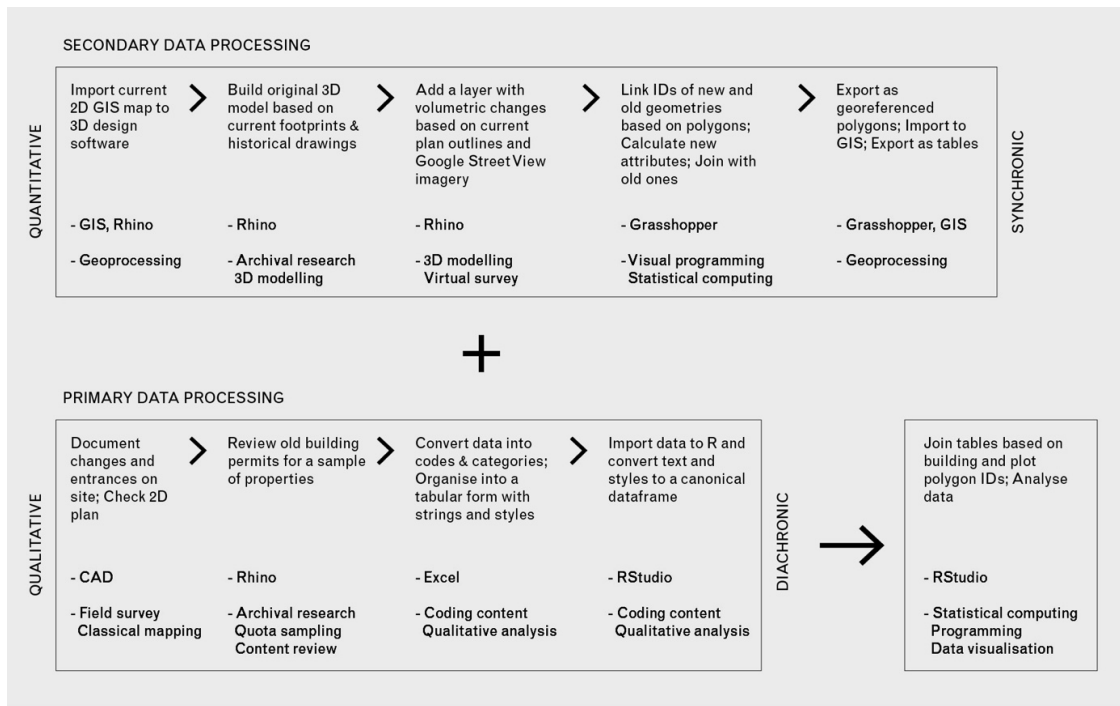


Figure 2. Overview diagram of the proposed methodological workflow

5. 3D Modelling for Two Chronological Dates (Synchronic Description)

The process started with the building and plot geometries (BD PARCELLAIRE ®) provided by the cadastre. I imported the plan in Rhino software and constructed a 3D model of the original layout as it was designed by the architect Emile Müller between 1853 and 1897. With the help of archival sources, namely the drawings of the original typologies found in the catalogue of the *Exposition Universelle* of 1889 (Müller & Cacheux, 1889), and historical studies like the one conducted by the sociologist Stéphane Jonas (2003), I was able to retrieve the original three-dimensional description of Cité Ouvrière at the time of its completion in 1897. The first model included 1,253 buildings and plots, their exact dimensions, and roof details. It was composed of four main typologies arrayed in a repetitive layout: 38 terraced (T), 190 back-to-back row houses (BtB), 998 quarter-detached (QD) and 27 semi-detached houses (SD).⁵

I then used this model as a basis to build the second 3D model of the current situation by adding volumes to (or subtracting them from) the exterior of buildings based on the cadastral outlines, and heights estimated from 3D Google View. It should be noted here that no facade details were mapped as they have zero volumetric cost and were thus not relevant for the built density analysis that followed. Also, while the dimensions, heights, and roof details of the new volumes were recorded, this was done approximately in re-

lation to the original measured buildings. However, the 3D version of Google Maps provides effective zoom-in and orbit capabilities that allow an unobstructed view of the geometrical and configurational relations of the volumes and ensure a similar precision range between 0.5-1.5m.

Figure 3 presents the four available representations: (a) the initial model generated from the data received by IGN, the national GIS service; (b) the Google 3D view of the same area; (c) the first Rhino 3D model created for the original Cité Ouvrière in 1897; and (d) the second model where both the original envelopes (white) and their transformations (highlighted in black) exist—and could be measured—separately. It becomes evident now the striking difference between the initial and the final model and how essential was the construction of a more detailed model that carries detailed building-plot information at two chronological dates and responds to the core inquiries of the study.

As a final step, I used Rhino's plugin, Grasshopper, to perform a series of actions: identify the new projected geometries; link the volumes of transformations to the source building and plot geometries; label the formal objects and add new attributes (typology, date of construction, height, area, volume, etc); join these with the initial IGN attributes; and export the entire dataset as georeferenced polygons that could be re-imported to GIS and analysed in R studio. These are only the minimum actions required to complete the modelling task. However, once the Rhino model is created, the processing possibilities within

⁵ These numbers are based on the three-dimensional modelling constructed by the author. Jonas (2003, p. 289) counts 28 terraced (T), 190 back-to-back row houses (BtB), 998 quarter-detached (QD) and 27 semi-detached (SD).

Grasshopper are endless, and include among others descriptive statistics, unsupervised classification based on rules, composite mapping, and generative modelling. [Figure 4](#) is a screenshot of the Grasshopper canvas, showing the basic interrelated components and their functions.

The final output, both in 2D, 3D, and tabular form, was a unique dataset of approximately 9,700 entries, covering the original and current geometries of plots, buildings, and their transformations. And although further analysis followed, it is important to acknowledge that the digital models ([Figure 5](#)) could already visualise morphological changes in a simple and straightforward way, making formal patterns easy to recognise through observation. In other words, the process itself carries its own analytical value. It expands on the “representation framework of urban-form evolution”⁶ (Pinho & Oliveira, 2009, p. 122), namely a set of maps that allow the registration, comparison, interaction, and rectification of multiple georeferenced data layers. – Whilst the authors discuss this in relation to street network maps, the present study suggests further a set of 3D cartographies that can interact with the georeferenced plane data layers, and allow the registration, comparison, and interaction of non-aggregated building information at the micro level.

6. Collecting Data for the Interim Period (Diachronic Description)

While the 3D models helped in creating a space-time description for the analysis of the built form, they stayed limited to two chronological periods, the original and the current one. What happened between these two dates remained unknown, obscuring any understanding of the piecemeal evolution of the built form from the beginning till the present. Hence, the next step focused on the collection of formal data for the intervening period. The process was divided into three steps: (1) field survey, (2) sampling, and (3) content review and analysis.

6.1. Field Survey

I started by conducting a field survey on site. I observed physical changes on the exterior of the houses, their distribution and configuration around the plot. I recorded entry points to the plot and buildings and detected some initial types of change. Field survey was meaningful because it offered familiarity with the context and the spatial culture of the neighbourhood. It also helped to understand the exact type of information needed for the subsequent steps, and to direct the archival research.

Next step was to test and refine these observations by collecting further evidence. While some of the historical maps featured the footprints of certain volumetric changes (mainly horizontal extensions), they did not provide any information about the third dimension. Therefore, I resorted to the *Permis de Construire* (building permits) issued for in-



Figure 3. Four representations of the same part of Cité Ouvrière: (a) built volumes extruded according to the heights obtained by the photogrammetry, (b) Google 3D View, (c) built volumes of the area in 1897; and (d) final model integrating the original CO built volumes and their subsequent densifications.

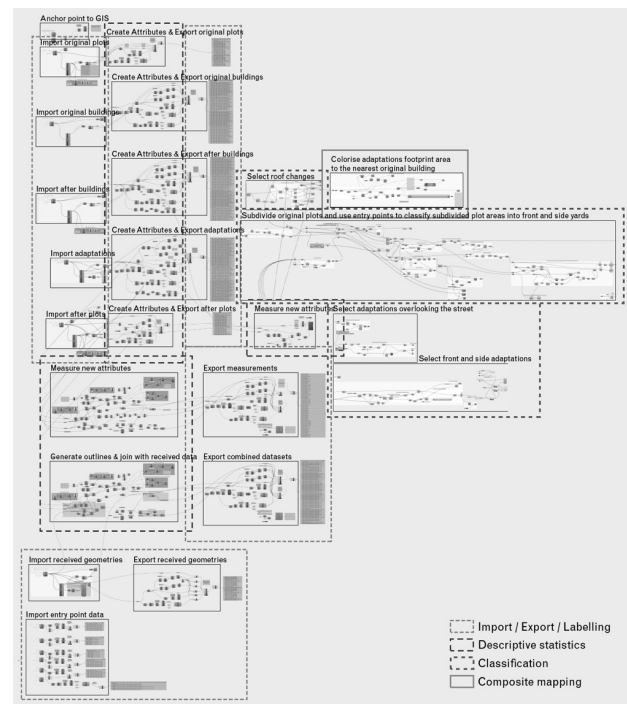


Figure 4. Excerpt of Grasshopper 3D canvas, showing the necessary (highlighted in red and blue) and few possible (green and yellow squares) processing functions for the two 3D models.

⁶ The authors mainly refer to street network maps.

dividual properties between the end of 19th century and 2000.

6.2. Sampling

The challenge at this stage was that there were more than 1,240 addresses and each address had multiple files to review. The files of building permits were split into ancient (JIE) covering the period 1900-1970 and post-war (1257W) for the period 1970-2000 with another sub-division for the period 1947-1979 (1132W); all of which were held by the municipal *Service des Archives*. In addition to this, no archival file could be taken out of the building so the reviewing had to be done during office hours. All these challenges led to the idea of sampling, namely selecting a subset of individual building-plot compounds to focus on, instead of going through the files of all the houses in Cité Ouvrière. This sample had to be representative of the wider population in terms of building typologies and built forms, and large enough to ensure that the results would be reliable estimates of the true characteristics of the population as a whole.

The sample was determined through a standard statistical sampling method called *quota sampling*. This is a non-probability sampling technique that relies on the ability of the researcher to select elements depending on the existence of sub-groups among the data and the size of these sub-groups so that the sample remains representative of the population proportions within the sub-groups. With regards to the built landscape of Cité Ouvrière, there were several sub-groups: 4 building typologies, 64 statistical blocks in terms of census data (*îlots*), 102 urban blocks, and 3 construction phases (Figure 6 top).

Sampling was also based on four additional criteria: first, to collect information for houses that fall within the same statistical block (*îlot* 1990/1999)⁷ so that for example subsequent data aggregation to census boundaries could be possible; second, to select statistical blocks that overlook streets with similar centrality values (this came from space syntax analysis on street network), so that the effect of street-facing could be somehow cancelled out as a contributor to physical changes; third, to distribute the sample across the neighbourhood so that it covers both the periphery as well as its centre; and fourth, to select houses in adjacent blocks in order to test the impact of visual and spatial proximity of neighbours on their decisions to carry out modifications. Figure 6 (bottom) illustrates all the sub-groups within Cité Ouvrière, the overlay of different statistical boundaries (see footnote) and highlights the selected sample in black.

From a total of 64 *îlots*, 27 were selected for the archival research. The sample contained 520 original building-plot

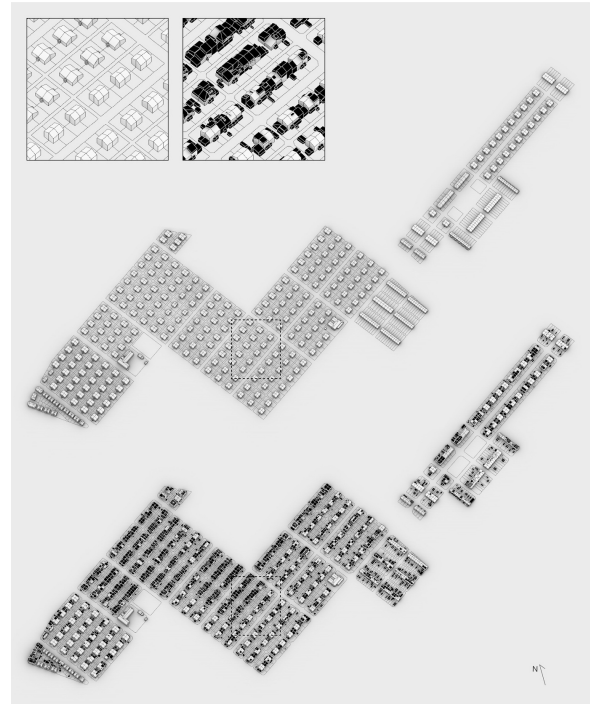


Figure 5. The two 3D models of Cité Ouvrière at its original (top) and current (bottom) state. There are 3,477 volumes added to the original model (highlighted in black), an increase of 68% in the total built volume.

compounds—or 498 current ones—and 46 street blocks⁸. The proportions of different sub-groups within the wider population were almost entirely preserved. The percentages in the sample did not deviate more than 5% from those for the entire population and the sample was large enough to ensure that the findings lied within a low margin of error (3% for the total population of houses). In other words, quota sampling was effective in selecting a subset of addresses to focus on that was representative of the building-plot population in Cité Ouvrière.

6.3. Content Review and Analysis

The third step was to review the folders of the 520 selected addresses, wading through official documents and taking photos of any plans attached. The publicly accessible legal documents found therein including building control applications, photos and formal complaints, consisted of extensive and descriptive texts that had to be *analysed while reading* them. Content analysis⁹ is an organisational and analytical approach to evaluate and code textual material

⁷ Between 1900 and 2000, there were archived census data for the following dates: 1968, 1975, 1982, 1990, and 1999. Each of these studies was based on different statistical boundaries (INSEE, 2016). For the sampling, I selected the smallest unit of all, the *îlot* 1990/1999. The analysis on census data is not presented here.

⁸ More on the calculations for quota sampling, see Kostourou (2020a, p. 168-171).

⁹ In fact, content analysis describes a broad family of methods and practices (Cavanagh, 1997) and their use is rather flexible in the sense that it depends on the research questions and objectives, the data, the researcher, and the boundaries of the analysis.

in order to extract the essence of its information and help to interpret the meaning of its content (Hsieh & Shannon, 2005). While it is normally used by sociologists to interpret theoretical texts or interviews, here it was employed during the fieldwork to facilitate the data collection.

The content analysis of the archival folders was directed by the initial findings of the earlier field survey. Before visiting the municipal archives, I had already defined a list of volumetric changes that needed validation and refinement. While reviewing the archival material, I would first scan through each document, search for terms related to morphological changes, and then write down the information as labels so that once I was off-site these could be categorised and turned into processable data. The information recorded for each transformation comprised of the year, the owner, the type of change, the reason or context behind it, the dimensions of the volume, its use, the number of prescriptions the construction had to follow, its cost (or level of fine in case of unauthorised changes), any relevant regulations, and the outcome of application—whether successful, executed, or not. Additional information was recorded too, such as the status of ownership, the condition of the building i.e. inhabitable, and transactions like sales or rents. The documents also included informal stories, personal testimonies, complaints, and other anecdotal information, which even if they were not considered as hard facts, provided a rich background for the study. These were transferred as short notes (instead of codes) to shed light on the relationships between neighbours, on the spatial cultures, political regimes, and prevailing societal opinions.

There were several limitations in this process. Firstly, the data collection was not always possible, either because some house addresses had no records or because some of the above-mentioned information were missing. Indeed, the level of detail was not the same among all applications. Secondly, many of the documents were handwritten in stylised letters in French or German, since Mulhouse had been twice under the German occupation; and the terminology was changing from one year to the next, arousing doubt regarding the original meaning. Especially in the ancient building permits, one could find archaic words, which are no longer in everyday use or have lost their particular meaning in current usage. For instance, the German word *Wirtschaft* could mean a range of things, from restaurant, bar, pub, bistro, business, café, farm to guesthouse, and the French *gloriette* could be translated to summerhouse, kiosk, gazebo or garden house.

Meanwhile, the process was time consuming and laborious. It could not be reproduced nor automated with regards to archival documents, and hence, the collected data could not be falsified. Instead, it was based on human labour, and was therefore subject to error, particularly when interpreting foreign terms or coding textual material. This was minimised by consulting the archivists and online translation services, and by maintaining consistency in the labelling, predefining most of the categories, and looking at many different types of data in order to synthesise a broader perspective on the topic. Still, the coding was inherently reductive, and a certain loss of information compared to the original content needs to be acknowledged. Although this influenced the level of accuracy for the subsequent analy-

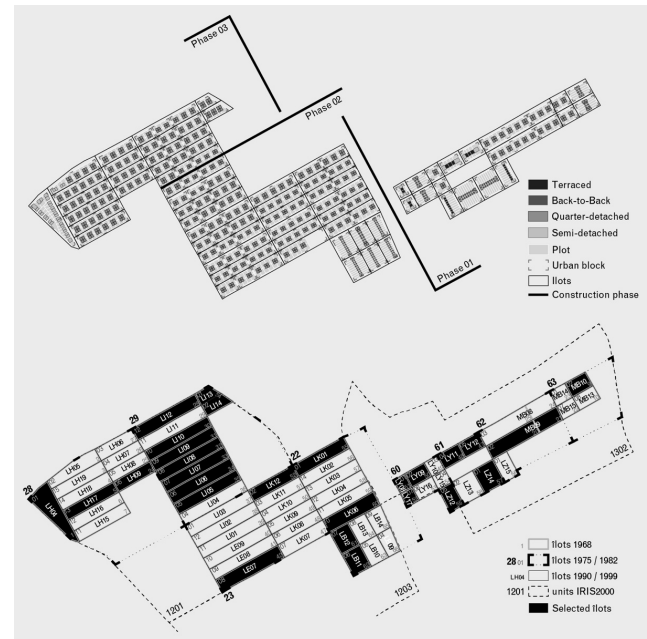


Figure 6. Top: Sub-groups among the data in Cité Ouvrière. Bottom: Overlay of different census boundaries, their geometries and code names. The selected statistical sample (highlighted in black) is based on the smallest available aggregated units for statistical information, the ilots 1990 / 1999. Base map and data source: INSEE and Archives de Mulhouse

ses, the sample was large enough to consider such deficits negligible.

Instead, this process allowed a certain closeness to data, which in combination with evidence from photos and plans, offered valuable historical and cultural insights. All of the three steps helped gaining an in-depth knowledge of the case study, recognising the emergence of physical transformation, and understanding the role of different actors in the process. Specifically, the content analysis was very useful for it translated textual material into qualitative data of categorical variables, which were in turn converted into statistically analysable data.

7. Pre-processing: Joining Datasets

The last step of the workflow was to combine the information collected from the archival research with the georeferenced data produced by the 3D modelling; in other words, convert the paper-based notes into countable attributes and join them to the vector-based georeferenced geometries.

This was carried out by shortening the notes to single words—for example types of changes were coded as extension, extrusion, roof etc—, entering them manually into Excel, and organising them into a tabular form (Figure 7). Each row corresponded to one house address, the first columns contained information from the spatial dataset, such as the code of the statistical block or the ID of the building geometry, while the following columns covered each year from

1853 to 2000. Strings (character-based data) were inserted into the cells, describing all the changes taking place in a particular address on a specific date. Border styles were used to indicate the status of ownership, while drop shadows were added to indicate the condition of the building or financial transaction. The table was then imported to RStudio. The text and styles were converted to a canonical dataframe, which had one row for every single type of change. The new ‘molten’ dataframe was further widened by attaching to it the rest of the gathered information, like the construction cost or the owner’s profession. The final dataset was mostly consisted of nominal data, namely qualitative labels which could not be ordered or measured, but could be statistically analysed in terms of clustering, frequency, counts, or percentages. Eventually, the table was joined to the vector-based spatial dataset based on the matching fields—the ID of the various building and plot geometries—and statistically analysed in R.

8. Conclusions

The paper presented a new methodological workflow for the creation and analysis of detailed data at the building and neighbourhood scale, combining both qualitative data from archival research and quantitative data from geoprocessing and modelling. The process revealed the complexities of the micro morphology which would have been otherwise missed, should available large-scale data and quantitative experiments have been used. By doing so, it provided an insightful understanding of the subjects and objects under investigation.

The main output of the whole process was the production of an entirely new dataset, which records the three-dimensional description of the built form through time. Firstly, a realistic model of the entire housing scheme was built to capture two chronological stages of its morphological evolution (synchronic descriptions). This was made in a way that the original volumes were separated from the subsequent additions and adaptations attached to them, and that each structure was an independent object whose area and volume could be measured. Secondly, the archival work contributed to the creation of a comprehensive set of qualitative data for a sample of 520 houses and a period of 147 years (diachronic description). By looking at the data, the drawings, and the photos, it was possible to re-trace and visualise in 3D the piecemeal trajectory of growth between the original and the current form (see for example Kostourou, 2021, p. 64).

The workflow integrated more traditional with more advanced techniques from the fields of architecture, urban morphology, geography and computer science to map the synchronic and diachronic process of physical change in the built form. It employed existing historical, archival and geographical data, created new qualitative and quantitative data, and processed and combined them to visualise change in 4D, overcoming limitations of handling and combining larger- and smaller-scale data in the abovementioned fields.

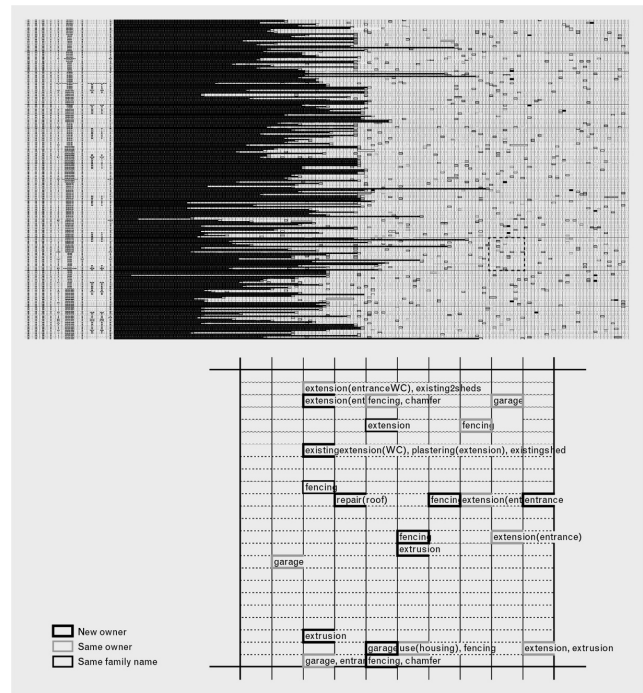


Figure 7. Top: Screenshot from the Excel spreadsheet. The cells highlighted in colour track physical changes in time, showing different statuses of ownership. The cells in black indicate the period of time for which we have no information because either the building had not been built yet or there was no record of physical change in the archives. Bottom: Zoom into one decade for one statistical block. Each column represents one year from 1951 to 1960, and each row one house/address from the block.

However, its main contribution was the production of *detailed longitudinal* data, which could systematically document microlevel changes in the built environment for over 150 years and explain how local individual processes may contribute to aggregate phenomena of transformation in our neighbourhoods and cities. It also addressed critical points identified by authors such as Batty and Xie (1997), Stanilov and Batty (2011) and Stanilov (2002) regarding the access, vectorisation, and verification of historical data. As Stanilov (2002, p. 174) argues, “documentation on historical development patterns is scarce and sporadic yet it is an invaluable tool in reconstructing our past and predicting our future. [...] a detailed set of historical records of past development patterns can be used as a powerful educational and analytical tool for visualizing the dynamics of growth and the identification of development trends.”

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A Geo-data Collection Strategy to Assess Housing in Its Social, Environmental, and Spatial Aspects

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Blocks of flats are the most abundant built element in many cities and their quality is an important issue. Undergraduate students often occupy these accommodations and this group describes a wide range of housing situations that makes it possible to assess their quality. This research aims to describe the data collection strategy in an ongoing research project in the city of A Coruña (Spain), oriented towards assessing the ordinary blocks of flats where the students live (shared flats, apartments). The method uses several sources (a questionnaire, cartographic viewers, the cadastre, and municipal historical archives) and a sophisticated strategy to be non-intrusive, efficient, and user-friendly. This information would allow an understanding of both students' changes of residence and their locations within the city. Formal methods are applied to estimate ordinary interior designs based on external configurations and consequently verify them with users and public archives. This holistic strategy creates a georeferenced database by adopting efficient procedures, thus reducing user inquiries.

The case of A Coruña confirms the variability of housing conditions and the complex phenomena involved, including possible correlations between housing quality and economic/social parameters, which can be studied with the developed database.

1. Introduction to Housing Quality and Dynamics Through Students' Accommodation

This paper is framed in doctoral research about ordinary housing quality, with special attention paid to the case of blocks of flats (apartments). Literature has used the term

ordinary housing to describe those places where a person usually lives and, in this approach, the term highlights its abundance and focusses on a series of shared patterns that would allow research to deal with this built heritage using advanced techniques, taking advantage of their repetitive patterns. Blocks of flats are the main residential typology

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in many cities and include rented housing, some of which is occupied by students. These self-contained housing units are private, so collecting information is complex and intrusive. Although it is essential to ensure the quality of people's flats, an efficient method to collect the necessary information about private housing units is unknown.

In cities with a large university community, students live in their parents' houses, in halls of residence, or rented shared flats. A Coruña (Galicia) is the home of the Universidade da Coruña, which has more than 17,000 students and is a city without public university residences. Therefore, it is common for students to live in rented apartments, which have very different conditions according to the students' purchasing power, economic effort, contacts, and the supply and dynamics in the property market. For these reasons, undergraduate students' housing can describe the highly varied situations of other groups in society and its study can contribute to the understanding of the built environment in general. In addition, students demand short-term rentals and many obtain poor housing conditions, which can illustrate problematic dynamics in the city. Nevertheless, students with greater purchasing power and/or economic effort occupy good locations in the city and contribute to real estate speculation (French et al., 2018).

Regarding the social approach, previous research in A Coruña found a correlation between housing dynamics and the sociology of their inhabitants (Rodríguez-Barcón, 2016, 2020) and the same hypothesis for the case of the student population needs attention. Students are in social transition (towards their position in society) and during their studies their social position is derived from their family's position, according to in Spain (Barañano & Finkel, 2010) and abroad (Almeida et al., 1988; François & Poupeau, 2009), so the students who rent a flat also represent a wide range of social situations. In addition, due to the precarious conditions of some students and their temporary situation, undergraduate students tend to respond to questions about their housing conditions without prejudice. Students' family houses also reflect the different housing situations in society, taking into account the existence of underrepresented groups in the university system (Barañano & Finkel, 2010). Thus, the student population exemplifies many variable housing situations (Abubakar Ghani et al., 2018; Alamel, 2020) and describes different social groups with their capacities – sociological *capitals* (Lamela, 2014; Pereira, 2018). These studies about groups and the social aspects of housing normally use anonymous questionnaires (Almeida et al., 1988; François & Poupeau, 2009) on the one hand, and/or personal interviews and visits to the buildings on the other (Abubakar Ghani et al., 2018), resulting in a lack of detail in the former case and being quite invasive in

the latter.

The environmental approach focuses on the characteristics and indoor quality of the building. This approach suggests that the building must provide quality in terms of health and well-being to its inhabitants, beyond solving minimum needs. Edward White (1989) and Pinson (1993) contributed to this theory through the Post-Occupancy Evaluation that sought to know the real use of the building and the users' perceptions. Pinson pointed out the need to understand this approach in 'trivial' buildings, in contrast to some methods instituted in the architectural avant-garde, a critical position also shared by sociologists like Léger (2010). For this reason, this research focuses on the quality of the ordinary blocks of flats according to the advantages they offer to their inhabitants and can be divided into the *material quality* and *cultural-symbolic quality*, as explained and applied in previous work (Pereira-Martínez, Borges Pereira, et al., 2020)¹. This approach to quality in ordinary buildings differs partially from others used in the analysis of artistic works, such as the *Baukultur (Davos Declaration, 2018)* or the three Vitruvian qualities. Nevertheless, the aforementioned analysis matrix allows the study of ordinary quality as a two-dimensional field² and has the potential to reveal the correlations between residences' quality and users' social status (Pereira, 2018), which is one of the purposes of the data collection. These environmental methods that analyse built spaces and people's reactions require detailed drawing and interviewing work (Léger, 2010; Pinson, 1993) and it is difficult to find a relationship between the studied buildings and others with the results of the cases are not repetitive.

Finally, the spatial approach to the phenomenon deals with the geographical distribution of student residences and their origins. On the one hand, the residences' locations help researchers to understand the dynamics between territorial interest and building quality since it is difficult to access a good combination in an affordable flat (Dang et al., 2014). Good accommodation in a peripheral area has a different value and provides different conditions for a student compared to one in the city centre. In the previous work (Pereira-Martínez, Borges Pereira, et al., 2020), the existence of geographical, economic, and social peripheries was shown based on buildings' qualities, and these features were related to users' capitals. On the other hand, different geographical origins (i.e. rural vs. urban areas) could affect the students' choice and their opinion about their accommodation (Rodríguez-Barcón, 2016). In spatial studies, obtaining a precise location that can be related to specific housing units is problematic and they usually work on a wider scale using areas (districts, neighbourhoods), thus it is difficult to integrate with the information on a building

1 A complete study of these quality components was carried out in a previous article (Pereira-Martínez, Borges Pereira, et al., 2020). The quality of housing buildings can be subdivided into their *material quality*, *cultural-symbolic quality*, and *centrality* (location). These features can be related through Bourdieu's distinction with the *economic*, *cultural*, *symbolic* and *social* types of capitals of their inhabitants (Pereira, 2018).

2 The notion of *positions* (levels of quality) and *vectors* (requalification, improvement of qualities) can be used in this quality field, with the advantages of these methodological tools for analysis, comparison, and projections.

scale. Nevertheless, some studies were able to relate spatial and building information in individual cases (Alamel, 2020) and this approach has great potential to explore.

Despite the existence of the aforementioned studies, there is still a gap in the literature to cover a global vision of these three aspects (interdisciplinarity) and consequently to allow them to be correlated. In addition, a less intrusive workflow is sought, friendlier to people and that can be applied in any housing building or urban area. The case of the undergraduate students' housing is highly representative of other cases due to the aforementioned social, environmental, and spatial reasons. The theoretical framework explained in this introduction lays the foundations for the following sections about the necessity of a geo-data collection strategy and the specific design of the strategy developed for this case, including an example of its preliminary results using the pilot group of the survey.

2. Necessity and Requirements for a Geo-data Collection Strategy

The multifaceted analysis necessary to study this complex reality requires a strategy to collect many different types of sensitive information in a less-intrusive and efficient way:

- First, the social approach presents parameters related to the economic and cultural capitals of the students' families and other social-demographic data (age, gender).
- Then, the environmental analysis requires a description and students' opinions about the buildings, housing units, bedrooms, and neighbourhood features.
- Finally, the spatial approach needs the location of the accommodation and the geographical origin of the student.

The amount and different types of data required for this survey threaten its feasibility, integrity, sample size, and the privacy of the studied specimens. This would be the case if a microanalysis were performed, like in Post-Occupancy Evaluations (Léger, 2010; Pinson, 1993). The methods of asking the students to draw their bedrooms/accommodations or personal visits are discarded, due to the lack of standardisation of the former and the effort and intrusiveness of the latter (particularly during the Covid-19 pandemic). Other macro and urban techniques would be too general for this study. Therefore, an efficient strategy to collect a large amount of sensitive and graphic information is proposed, because there is a lack of use of medium (neither micro nor macro) techniques in architecture. In addition,

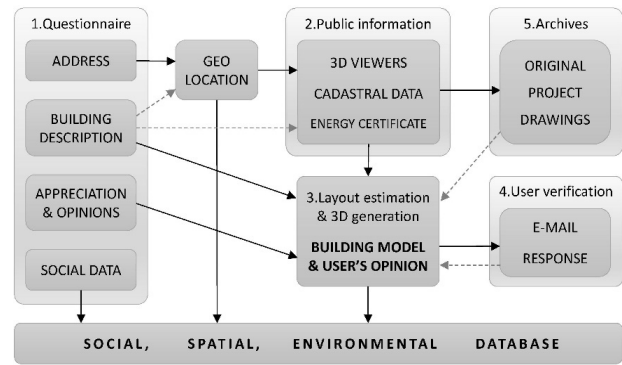


Figure 1. Information collection strategy: sources of information, steps (strategy sections), and main/verification workflow

tion, in the case of ordinary blocks of flats, it is possible to take advantage of their cultural spatial model and common repetitive patterns³, which allow the use of non-intrusive and technological techniques. Thus, the strategy to collect information, which is developed in the following section, even if it collects valid information for the students at home and in halls of residence.

3. Design of the Information Collection Strategy and the Tools of the Survey

Thus, the survey proposes a strategy that uses several sources of information (a questionnaire, public services, individual verification, and consultation in archives) and advanced techniques (GIS, non-intrusive internal estimation, automated 3D generation, and probabilistic methods) to be efficient and user-friendly to reduce student inquiries. [Figure 1](#) relates the sources and steps for obtaining information with the three aspects under investigation.

Firstly, a short questionnaire asks about the data that it is not possible to obtain through other means: building characterisation, appraisals, social origin, images, addresses, and contact. This requires the processing of private information and the anonymisation of results in a second step. Nevertheless, with the address, the researcher can geo-locate the building, study the external configuration, access public information, estimate the internal configuration (Pereira-Martínez, Lameira, et al., 2020; Yue et al., 2012), and consult information in archives. The procedure of requesting the address (Alamel, 2020) could be controversial and pose risks – fewer or lower quality responses –, but, if it is clearly explained, students do not mind giving

³ In the context of the ongoing thesis, a previous paper studied the spatial model and common patterns in ordinary blocks of flats in Porto, Portugal (Pereira-Martínez, Lameira, et al., 2020). A shape grammar for the general configuration of these buildings was developed, programmed, validated, and prepared for a large number of cases. The empirical research of the thesis found the same spatial model in buildings in the city of A Coruña and other municipalities in the Galicia-North Portugal Euroregion Literature and it explains other ordinary patterns in other places – i.e. studies in the USA by Yue, Krishnamurti, Grobler (2012) – that would invalidate the notion of a 'generic' model applicable anywhere. This understanding of the spatial model of this cultural-technical context allows the use of non-intrusive methods, reducing detailed manual analysis, which is an interesting and necessary line of research in architecture.

information about this if those are in their favour. The following epigraphs describe each part of the strategy and open up to a general discussion about data collection and processing.

3.1. Questionnaire

The questionnaire is a traditional tool to study social groups (Almeida et al., 1988; Pereira, 2018) and this instrument should balance extension, clarity, depth, and intrusiveness. In this research, the design includes two main constructs: the student's accommodation and the social status of the family.

In the first section, there is the question about the address, a Likert scale (1-7) to assess their satisfaction with and the quality of the flat and the room (comfort, light, aesthetics, furniture, equipment, views, etc.), and finally, multiple-choices and writing space to describe the building features. Examples are included to obtain more homogenous responses about the address and other issues. Additionally, the student is invited to share photographs of the flat/room. In another section, the questionnaire is comprised of sociodemographic items (age, gender, geographical origin) and questions about the parents, to know their social status. For this, multiple-choice questions include information about their housing tenancy and job situation (partial indicators of economic capital) and their level of studies (part of their cultural capital). Moreover, students are invited to give the full address of their family, to compare their accommodation in A Coruña and their family house.

The questionnaire is designed to be applied online during class time and to be completed integrally, but students can indicate the non-applicability of certain questions or their refusal to answer. The questionnaire was validated by several methods: a verification by the Research Ethical Committee of the PhD program in the University of A Coruña, an external validation by experts (architects and sociologists), a focus group of professors and students, and finally, by the internal coherence of data. The questionnaire was also tested with a pilot group in a class of 10 second-year architecture students. This served to prove the feasibility of the strategy and produced the examples shown in the figures.

3.2. Public Information (Cartographic Viewers, Cadastre, and Energy Certificates)

The address that the students provide allows access to the public information about the building, as shown in the left section of [Figure 2](#). This is theoretically simple, but its implementation implies some practical problems in contemporary research that should be discussed. In this case, the questionnaire requests a non-structured address from the respondent (following an example) because it is the most user-friendly method: there are problems with structured address collectors (especially in rural areas and foreign countries) and integration difficulties in web services (in this case, Microsoft Forms).

The address is verified on GoogleMaps and the coordinates are identified, as well as for the responses that only name the street or neighbourhood, which allow an approx-

imate geographical location. Search engines are especially adequate for non-structured information, but addresses must be introduced manually; therefore, improvements in address processing could be very profitable, especially if carried out by public services (i.e. cadastral and post addresses). Then, the geo-location of both student and family residences are manually typed to create the multi-type database with the alphanumeric information and files (photographs). Automatic routines can use the GIS coordinates to add orthophotos and oblique views of every building to the database.

The address is also related to the cadastral reference to access detailed information manually, such as the CAD/GIS external shape, façade photo and horizontal division drawings. In addition, alphanumeric data can be automatically downloaded, such as the construction date, the number of floors, the typology, the number and area of residences, and the areas dedicated to different uses.

Energy consumption and emissions certificates are mandatory for rented flats and then available using the address. This would allow researchers to assess the housing units and verify this information with the user's description, but more detailed data would be preferable, and some students' flats are rented in a precarious situation without a certificate. The energy certificates are checked manually because, despite bulk downloading being previewed in Galicia, it is only available for the most recent cases and, once again, addresses structures are not standardised.

In the previous explanation, the manual and automatic tasks are emphasised to highlight the difficulties, current advances, and potentials found in this case for an integrated, non-intrusive workflow in architecture and urban studies. On the one hand, descriptive technologies – raster, orthophotos, viewers, photogrammetry including Google Earth 3D – are useful to manually consult information; nevertheless, their integration in an efficient workflow is difficult and/or complex. On the other hand, vector easy-link spatial information – such as CAD, BIM, GIS, and simplified BIM (Jabi, 2016) – could have the biggest potential to be included in an integrated, efficient workflow. An example of this is the Spanish Cadastre with normalised exterior drawings and indoor information in vector interoperable formats (but variable in quality, detail, and reliability) which are used in the following section to develop layout estimations that are linkable to the database and communicative for the students.

3.3. Methods of Layout Estimation and 3D Generation in an Integrated, Efficient Workflow

The estimation techniques are useful for blocks of flats in this context because their housing units follow a repetitive model: an internal layout highly determined by the outer perimeter, restrictive common patterns, and a predefined spatial model (Pereira-Martínez, Lameira, et al., 2020). They are adequate for the case of the students' flats but do not work for cases not limited by their external configuration, such as the detached houses of the students' families, with many spatial possibilities and different typologies.

A previous paper⁴ designed a shape grammar methodology to estimate the positions of the main rooms (kitchens,

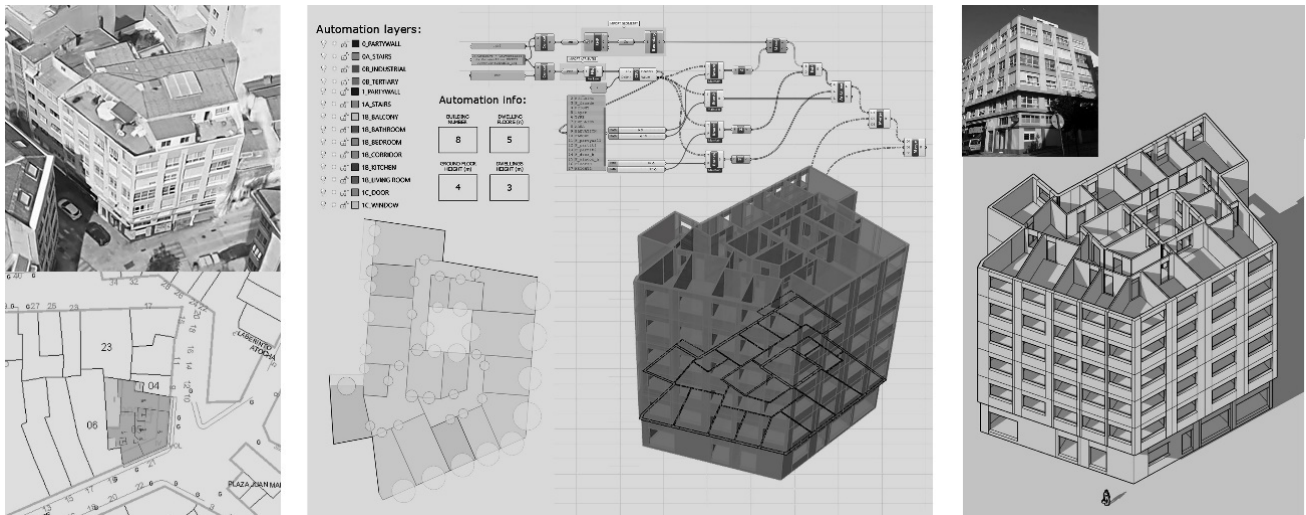


Figure 2. Strategy steps 2-4: public information, 2D estimation and subsequent 3D generation, and final verification with users

living rooms, and bedrooms) and the common stairs. In this study, the methodology was manually applied and complemented with the strategy developed by Yue, Krishnamurti, Grobler (2012) that estimates the internal layout based on windows and roof information (kitchen extraction and bathrooms/toilet air exhaust pipes). [Figure 2](#) displays the application of these techniques using the vector perimeter and the descriptive information (left section), to form a simple 2D scheme (middle-left), able to be automatically processed to build a detailed thickness-included 3D model (middle-right). The estimations of the main and ground floor are drawn in CAD using the notion of lightBIM – focussed on spaces and spatial relations (Jabi, 2016) –, with polygons for spaces (without wall thickness) and circles (representing points) for doors/windows. A certain layer structure and template allows its automatic processing by GIS (ArcGIS) and by parametric 3D modellers (GrassHopper-AutoCAD-SketchUp) to form a 3D model for analysis and respondent verification.

According to the verification of the following sections (users' feedback and drawings in archives), there is a quite high level of accuracy in the number, position, size, and even shape of the main rooms – especially high for kitchens and living rooms. There are sometimes differences with bedrooms, mainly if they are precarious (without windows). There is less accuracy in secondary spaces – corridors, bathrooms, storage spaces, etc, especially if they are internal and have no façade – and the shape of spaces often differs. There is then a variable but controlled uncertainty, which is considered.

Layout generation and automatic 3D modelling is also a field of research in progress which has made great development in recent years (Guo & Li, 2017; Keshavarzi & Rah-

mani-Asl, 2021; Merrel et al., 2010; Silva et al., 2015; Yue et al., 2012) and has potential for the future, including its integration in BIM workflow. It is necessary to highlight that the proposed estimation methodology and software application (Pereira-Martínez, Lameira, et al., 2020) can process both orthogonal and irregular layouts ([Figure 2](#)), necessary to apply these methods to reality, and this constitutes a great asset in comparison with other studies, based on and limited to Cartesian geometry. This application illustrates the potential of formal methods to advance in an efficient, integrated workflow because they work with geometry and structured data. These possibilities will increase with probable improvements in vector information (cadastre) and new AI techniques for window recognition and 3D location on façades. Nevertheless, some integration problems remain or can appear between different software and these issues multiply the work of professionals and researchers.

3.4. Verification of the Building Information with Users

The questionnaire obtains respondents' e-mail addresses to verify the previous public information and layout estimations. To do this, the respondents received a standardised e-mail explaining the aims and procedures of the study with the alphanumeric data obtained (construction date, description, etc), graphic information consisting of the public cadastre photo, and, if applicable and in the case of architecture students, the files of the simplified CAD layout and the 3D model (middle and right part of [Figure 2](#)).

Thus, it is possible to verify non-intrusively with respondents if the address and the building are correct, the internal configuration is accurate (or what the errors are),

⁴ A study of ordinary spatial patterns in ordinary blocks of flats was done in Pereira-Martínez, Borges Pereira, et al. (2020). A shape grammar was developed for estimating the position of rooms of a certain size in contact with the façade and the possible position of the common stairs at the centre of gravity of the rest of the floor.

and receive more information from students: descriptions or even files, because the architecture students can modify the drawings and models. It is only a minority of students who respond to this second step, but their feedback is qualitatively very valuable to verify the accuracy of the information and the methods. This non-intrusive strategy of a short questionnaire with a second statistical verification has the advantage of normalising database information and reducing respondents' efforts.

3.5. Verification with Historical Archives

A second verification is based on the historical archives in the municipality of A Coruña, which gathered building projects and construction licenses until the 1970s. This is adequate for this research because student flats are usually old (Figure 3) and in these cases, the Spanish Cadastre is less complete and reliable. This second method of verification reduces uncertainty due to the lack of responses by e-mail, gives good material for comparison, and adds more information about the buildings' designs and quality. Some buildings' projects are not found and others could have been transformed during construction or been renovated, so all the cases are studied with a certain level of uncertainty.

This building in Figure 3 is an example of an old building occupied by students. It was designed for the middle class with similar repetitive bedrooms and spaces, which are precisely what students normally seek in their accommodation. The shape and geometry are complex, following the design trends of a bourgeois building from the '40s with a carefully designed façade, but the spatial order and patterns are simple and repetitive, following the ordinary model described in previous research (Pereira-Martínez, Lameira, et al., 2020). The fact that examples like this can become obsolete for the original target population and be occupied by students illustrates the complexity of building dynamics and the potential of students' flats analyses to unveil them.

3.6. Integration in a Social, Spatial, Environmental Database

The data from the previous sections are integrated into a multi-type geo-database that allows researchers to analyse detailed dynamics in complex phenomena, like the case of undergraduate students' housing. The social, spatial, and quality implications of the accommodations are analysed, taking into account the variability of users' appraisals, also included in the database. Thus, this analysis can interrelate the results of each specimen in the different aspects, using the analytical fields presented in this case: student's housing location, appreciation, accommodation's quality, parents' social status, parents' house quality, and student's geographical origin. An example of the database information in these analytical fields is shown in Figure 4 using the results of the pilot group (10 specimens) in the form of a graph.

On the left, the quality of the students' accommodation, family residences, and their parents' social status are interrelated; in the middle, the students' appreciation is shown; and on the right, the locations of the students' homes in

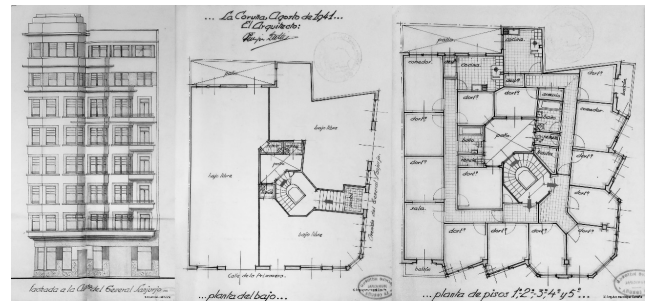


Figure 3. Step 5: verification with original drawings, i.e. a building with ordinary patterns

Source: Arquivo Municipal da Coruña

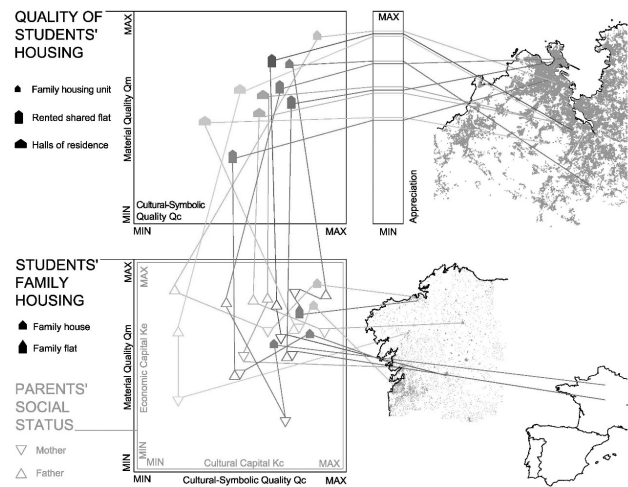


Figure 4. Pilot group results: a social, environmental, and spatial database, able to relate housing quality to users' capitals

the city (upper picture) and their geographical origin (lower picture) are arranged. The housing geolocation and student origin are related to the characteristics of the buildings and social data on the left. This graph provides an overview of the study and the database with the three-factor approach: social, environmental, and spatial. Preliminary quality and capital synthetic indices were used for this representation and are still under development and validation. Under these reservations, Figure 4 illustrates the variability and differences in housing qualities (generally lower in student shared flats than in family homes, but not always) and possible correlations between the individual variables or the general position in each field of analysis. Furthermore, this can be used as a basis for many other questions and hypotheses.

This survey is in progress and the growing sample is not easy to represent and analyse individually at this level of detail; nevertheless, these examples serve to understand the procedures and expected type of results of this data collection strategy and the eventual analyses that can be applied to the database.

4. Discussion of the Students' Housing Case and the Data Collection Strategy

After explaining the strategy design, the procedures, and the type of data collected in the previous sections, the case of students' housing can be better understood in its heterogeneity and the complexity of the dynamics involved. An example of this is [Figure 4](#). The complexity of these analyses needs to be explained in future dissemination, but the case of A Coruña illustrates the variability of the conditions of their undergraduate student housing and the complex phenomena involved.

The discussion about the necessity of a data collection strategy and its specific design should consider the different aspects of the problem, the phenomenon characteristics, and the available sources of information, as explained in the introduction. The adequacy of the strategy to the group of informers is a key factor in this study as, undergraduate students were especially targeted groups for their greater accessibility, openness, and capacity to represent other housing dynamics. Thus, an advanced collection of data could be implemented. It would be desirable to introduce more detailed information and techniques in further studies about the subject and apply typestyle of strategies – with the necessary adaptations – in other groups and the general population.

Regarding the data collection strategy, in previous sections, certain methods and tools were specifically discussed regarding their advantages and disadvantages, but the underlying topics are the new advances and possibilities offered and how to integrate them into an efficient workflow in architecture and urban studies. This integration is still unclear and depends on the public services and software developers' strategies. This research is an attempt to introduce and apply some of these possibilities in a geo-data collection strategy and deals with several sources of uncertainty. This strategy allows the researchers to confirm a complex, alphanumeric and spatial, normalised database with comparatively less effort and intrusion than other similar surveys, with the maximum depth of parameters and a variable controlled uncertainty. Nevertheless, there is still great room for improvement, as commented, based on improvements in the interrelation of data, access to public data, and the new techniques for processing this information.

This paper brings to light several issues with contemporary research in architecture: the need to advance in more comprehensive surveys, leveraging technology with more automation, respecting privacy, being less intrusive and maintaining enough depth. Some of the terms are contradictory, so the study of the difficulties, possible balances, and the strategies to face them are intended to be contributions of this manuscript.

5. Conclusions and Next Steps in the Research

This paper shows an original approach to the collection of different types of data, taking advantage of an accessible and participative group – undergraduate students –, the

latest technologies, access databases and information, and the notion of the underlying shared parameters of ordinary buildings.

This strategy to collect information has brought to light remarkable efficacy and utility. Some methods can be used to decrease respondents' effort and boost their participation, and others to minimise research work and obtain normalised data. Researchers can take advantage of powerful, accessible databases and new technologies and insights. Less-intrusive methods introduce a variable uncertainty that must be considered. This survey takes advantage of several advances in terms of efficiency, and some improvements are proposed, but many problems remain in terms of data collection and processing before obtaining an expected, integrated, non-intrusive workflow.

Regarding the students' housing quality, different levels and standards were seen, especially when students' flats and families' residences are compared. The relationships between the residences' qualities and other parameters (social origin, position within the city, price, age, geographic origin, etc.) are rather complex and can be affected by social attitudes, subjective appreciations based on these parameters, and the survey's internal uncertainty. Partial correlations would be found following this strategy between the housing's material quality and users' economic parameters if the results confirmed the lines of research pointed out by the preliminary results of the pilot group.

The normalised multi-type database obtained is a good asset for the next steps of the research, which are:

- correlations and multi-factorial analyses of students' variables and satisfaction, with spatial/graph representations;
- advances in automatic modelling, integration GIS-BIM, and quality assessment for ordinary buildings;
- an in-depth study of quality, developing a synthetic index to relate building qualities to users' capitals.

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Structural Expertise Through BIM

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Building Information Modelling (BIM) is a leading technology in the Architecture, Engineering and Construction Industry (AEC Industry) and nowadays is being adopted for most professionals and improving its capabilities. There is another big trend in the AEC Industries, the rehabilitation of unused or old buildings and its adaptation to the new demands. Lately, building renovation and rehabilitation have produced more income than the construction of new buildings in the Spanish housing market. The use of BIM for existing buildings combines the BIM data management abilities with the economic trends in the industry giving the professionals new tools to adapt those buildings. Structural reinforcement may be needed during the rehabilitations so structural expertise is usually performed. In this paper, we have created a tool linked to Autodesk Revit that can extract the necessary data from the BIM model and perform an expertise test through a concrete beam. By using BIM for this purpose, we can use the data stored in the BIM model to determine the necessity or not of structural reinforcement and give the professional more control over the project. The use of that stored data shortens the working time for the professional and avoids errors and oversights in the design. Since the building information model is a rich information database it can provide the necessary data to ensure the analysis. A case study is performed showing the capabilities of the tool. The research contributes to integrating structural rehabilitation into the BIM environments reducing the redundancy in software and unifying both, data storage and data analysis via the BIM methodology.

1. Introduction

Building rehabilitation and renovation are becoming more and more important for the Spanish building sector. As the data shows there has been a total shift in transactions regarding new and used homes (*Observatorio de Vivienda y Suelo. Boletín anual 2019*, 2019). In 2003 the

turnover from the construction of new buildings in Spain was 8.931,1 million euros and 18.558,3 million for restoration and conservation. In 2018 this turnover was 25.693,7 and 30.545,3 million euros respectively. Apart from the general turnover reduction due to the explosion of the housing bubble in Spain in 2009 there has been a change as the investment in renovation is growing while the invest-

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ment in new housing has been decreasing severely across the last decade. This means that in 2003 the turnover distribution was at 82,4% for new buildings and 17,6% for renovation and in 2018 the distribution was 45,7% and 54,3% respectively.

In the same study, we can also look at the number of transactions regarding new and used houses. The number of transactions has been reduced due to the economic crisis. This reduction has supposed a greater impact on the transaction in new buildings. From 2005 to 2019 there has been a reduction of 48,97% in the number of housing transactions in the Spanish market. The reduction in these operations for new houses was 79,08% and for used ones 25,42% along the same years. Several reasons are causing this change that is listed in the study and are out of the scope of this research, but the tendency is clear, and in the coming years is it easy to think that professional activity is going to grow towards building renovation.

Parallely, during the same years, there was a change in technology affecting the Architectural, Engineering and Construction Industry (AEC Industry) with the growing adoption of the Building Information Modelling (BIM) paradigm by different professionals. During this last decade, BIM has proven itself to be of value to professionals as it can reduce the time investment by 7% and production costs by 10% (Azhar, 2011). BIM works as an n-dimensional database that stores, relates, shows, and modifies all the parameters in the project allowing the professionals to have complete control over them, their state, and their relationship. BIM environments need a holistic approach and new methodologies. But changes in the project are much easier to implement.

One of the great advantages of BIM is the interoperability that it is capable of. Every parameter in the BIM Model is linked together and altering it automatically updates the whole model. This has made allowed the creation of several Building Performance Simulation Tools (BPS Tools). These, are digital tools with the purpose to analyze and evaluate a certain aspect of the building design and aid the professional in that particular field (Eastman et al., 2011). Most of the research effort related to BIM is centred upon the development of various kinds of these tools and automating the procedures in the AEC Industry. Multi-Criteria Decision Making processes has been an increasing research topic as an automatization measure (Tan et al., 2021). There has been great interest in the use of BIM to improve the structural performance of a building in a BIM environment by optimizing the structural design (Abdalla & Eltayeb, 2018; Eleftheriadis et al., 2017), reducing its cost (Peeraya Inyim et al., 2015), or reducing the CO2 emissions from its construction and improving the general sustainability of the project (Diao et al., 2011). There are also studies to implement the LEED certification in BIM (Wu Wei & Issa Raja R. A., 2015). But the automation of different procedures in BIM can also increment the risk of making mistakes if the professional is not aware of the limitations of the BPS Tool being used, this increases the Black Box Effect (Cauer et al., 2000), reducing the info from the analysis process known by the user, as more automation means more opaqueness in the modelling which can involve several risks (Fernández-Mora, 2018).

1.1 BIM in Building Restoration

Typically, BIM is used to develop projects for new buildings, most of the tools presented earlier aim to help the professionals in the design phase where there is a greater degree of freedom in the design. Using BIM for building restorations has some barriers that have to be overcome related to uncertainty and undefinitions in the knowledge of the building such as material specifications or design purposes. Modelling the building can be a huge investment in time and effort and so, discourage the use of the BIM environment for this purpose (Fernández-Mora & Yepes, 2019)

Despite these barriers, BIM's abilities to handle time-related data and define objects which are modified along a timeline are really interesting. This is used to implement renovation into BIM in several different ways (Volk et al., 2014) and has led to a new research field in HBIM or BIM for heritage building (Lopez et al., 2018). To create BIM Models for existing buildings technologies like laser-scanning and 3D point cloud (Jung et al., 2016) is being used on several patrimonial buildings (Angulo & Castellano-Román, 2020; Rodrigues et al., 2018). HBIM has also been used to analyze patrimonial structures like vaults (Argiolas et al., 2019) and ancient wooden structures (Jiang et al., 2020).

The growing interest in the renovation building and the ability to perform time-based abilities added to the other advantages of BIM, making it suited for building renovation. The widespread adoption of BIM in these last years by the AEC Industry is also a reason for the professionals to use it more frequently as they are more used to the methodology.

1.2. Structural Expertise

The task to evaluate and study an existing building structure to determine its capabilities to receive the loads and demands which it is being subdued is the structural expertise. It is, in fact, the conclusion at which a professional arrives after performing a methodical and strict analysis following the regulations and represents the structural stability of the building.

To perform structural expertise the professional must study, review, research, and analyze the state of the building and evaluate it to determine if intervention is needed. In case of need, he must also design the solution to solve the detected problem.

1.3. Aim of the paper

According to our knowledge, BIM usage in existing buildings is an open research line. Currently, the research is focused on patrimonial buildings and the creation of accurate 3D Models. There have been shown examples of tools that, analyze the structural behaviour of certain structural elements on the building like vaults or wooden trusses. There hasn't been any example in the use of BIM to analyze non-patrimonial existing buildings in need of refurbishment.

In this paper, we aim to create a BPS Tool for structural expertise in existing buildings inside BIM environments. This tool is born from the increasing necessity in intervening in the existing buildings and adapting them to new demands as proven by the business changes shown in the

Spanish market.

The focus of the paper is to analyze the data recollected by the professionals during the study and help them in the conclusions to evaluate the structural integrity of the studied building. The tool presented in this paper can extract the necessary parameters for the structural expertise in the BIM model, analyze the structural element on its own and set the result on the model. The automation of the process reduces the working time for the professionals, and keeping the data stored in the model reduces errors. By storing the result of the analysis on the BIM Model the data can be consulted at any given time, which the user better control and knowledge about the building and its necessities.

2. Development

To develop a tool able to perform a BPS Tool like previously described a systematic step-by-step approach has been followed to overcome the different barriers in the adoption of BIM for structural expertise. As observed in the bibliographical research the main barrier in the adoption of BIM for structural rehabilitation lies in the uncertainty and the inaccuracy of the model (Fernández-Mora & Yepes, 2019). This gap has to be overcome to guarantee the result of the expertise and the safety of the analyzed structure.

In this regard, we can define this inaccuracy as affecting three different aspects of the data retrieved from the existing structure:

- Uncertainty in the structural behaviour: Referred as the set of inaccuracies due to unknown structural behaviour in the elements.
- Uncertainty in the materials: Inaccuracy in the exact material properties used in the past to build the structure.
- Uncertainty in the design: Uncertainty created by unknown the design criteria for the original structure.

The plugin is designed so the data has to be used after an inspection of the building has been carried out by the professional, this way data has to be interpreted and pondered by the user before its use. To perform the analysis for a structural element there is a need to collect some data before introducing it in the BIM model. This will allow us to reach a point in knowing where we can be certain of how the structure is working and its characteristics. The collected data will be inputted into the BIM model to recreate its state. The aim is that the structural engineers can perform the expertise by using all the information available to them. The BIM Model summarizes the geometric shape of the object, loads upon it, material properties, and code limits and performs the structural analysis.

3. Workflow for structural expertise

One of the main goals of the tool is to be practical. For this reason, it has been designed in a way that functions according to the workflow followed by professionals. This workflow was previously researched has been used to find the spot where this plugin would properly fit without adding any steps to the current structural expertise workflow.

“Most of the time the professional is contacted by the build-

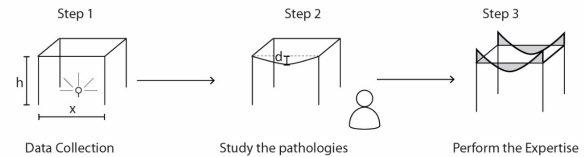


Figure 1. Workflow for the structural expertise

ing’s responsible who exposes the new needs of the building and its actual problems. With that in mind the data collection phase starts, the professional must collect data from the building, its state, possible affection, and if possible, historical data. Once the data is collected, it is time to create a structural model of the building, study the new demands for the structure, and determine the contribution that the existing element can make to the new structure. In case the existing structure proves insufficient for the new loads, reinforcement must be designed and built guaranteeing the right connections between the old and the new parts.” (Fernández-Mora & Yepes, 2019)

In this article we assume the usage of the tool following the steps that have been defined to perform the expertise:

- Step 1: Collect data from the element. The cross-section dimensions, rebar sizes, and numbers can be collected directly from the model. The materials’ tensile strength can also be studied to create a more accurate model.
- Step 2: Study the possible pathologies and alterations in the element and its new requirements. Any damage shown in the structural element has to be studied to determine its affection depending on the pathology and its causes.
- Step 3: Proceed with the expertise. After collecting the data, the BIM model is created. The model for each structural element contains the retrieved data describing the element and its behaviour. Then the structural analysis is performed on each element that requires it by using the plugin.

The input parameters for the expertise describe the state of the structural element. It is the professional who has to measure the importance of each one based on the beam that is being studied. They have to be quantified and introduced into the BIM model using the Graphic User Interface (GUI) for parameters in families inside Autodesk Revit. This interactive approach leaves in the hands of the professional the definition of the solution space, giving him a certain degree of freedom to model the structural constraints, requirements, and capacities of the model.

There are a minimum number of parameters that need to be defined to develop the expertise. These parameters are the geometrical shape of the element (width, height, and length), its material properties, and the load cases. The structural linkage with adjacent elements can also be defined by the professional upon its knowledge.

4. The difficulty in the structural model

Usually, a structure is designed using theoretical models

based on material theory to meet some structural requirements. Later on, it is built following the design reached. It is a translation from the theoretical world to reality. Structural expertise flips this process and the professional must decompose the reality into physical relationships.

The expertise must always be based on the built structure and has to represent the current structural behaviour of an environment. Since its initial theoretical design, it would have suffered a lot of changes, being modification during the building phase (maybe the rebars are placed in a different position or a change in size was needed), or posterior alterations (new constraints or loads may appear during the life cycle of a building). So, the professional must describe the real behaviour of the structure and its conditions, considering the current and new loads and requirements.

Design and working loads are very different. The first one is an estimation given to the professional by the regulations, based on statistical data and security margins. Environment and maintenance affect the lifetime of a concrete structure. Fissures and other pathologies have to be studied before starting the structural analysis. The project is a guideline that provides useful information about the structure and how it was designed to work, but it may not correspond with how it works in reality.

5. Structural model

The scope of the plugin is to perform structural expertise for a concrete beam in an existing building and subject to new loads or conditions. The structural behaviour of the beams can differ after it is built, but their joints will always have a certain degree of stiffness and therefore the ability to transfer bending moment onto the vertical structure.

The structural model used for this research is a concrete beam with joints on both endings. The movements in the three axes are considered to be 0 and the rotation for every axis is also restrained to 0 except for the Z-axis. This last axis rotation can be modified by the professional between 0 and 1. Considering 0 a full restriction in the rotation about the Z-axis and 1 that there is no restraint at all.

As the plugin is limited to building structures the loads that can be applied to the beam are limited to uniform loads. These loads cover most of the load cases in building structures. A differentiation between dead and live loads has been made, and the user can apply them separately.

The professional can modify the bending constraints if the element is not well connected enough and has a certain degree of freedom for the movement or if there is any kind of damage. The professional also has to determine the working loads to which the beam is going to be subjected. This opens the analysis to recreate the real behaviour of the structure.

6. BIM Integration

The interoperability between the Finite Element Model (FEM) generated and BIM is key to the success of the BPS Tool as it is an important characteristic of the proposed system. Regarding the BIM environment, Autodesk Revit was used and the FEM tool needed was programmed ad hoc for this research. There is direct interoperability between the FEM Model and the BIM Model as it is possible to trans-

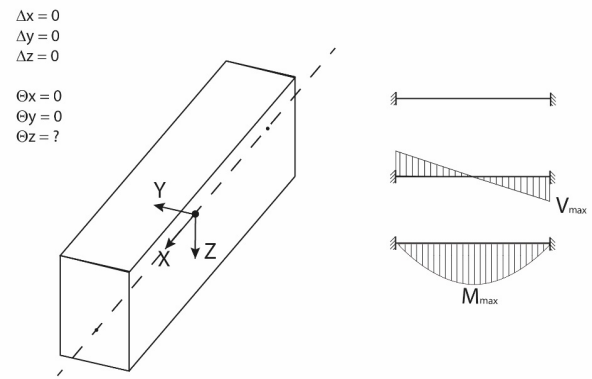


Figure 2. Beam axis and freedom degree in the FE Model

fer design elements, geometric layouts, and material properties back and forth between them.

The integration with BIM is done through the creation of a plug-in able to extract the data from the building model and analyze it considering the different parameters. The interoperability between BIM and FEM analysis has been made guaranteeing the data exchange through a plugin. In this research, C# programming language has been used to access the .NET framework of Revit using Visual Studio 2015 using Revit's API. The API access provides control over different attributes defined on the BIM model: geometry, model analysis, material properties, load cases, etc. A full list of the extracted parameters will be provided later in this paper.

The data exchange between BIM and FEM is implemented in two different functionalities. The first one is the extraction of the data required to perform the expertise from the BIM model (Downstream) and the second one is the data returned in BIM (Upstream).

First, downstream, the topology of the beam is directly imported from BIM to the FEM without any user interaction, the user-defined parameters must be defined before activating this exchange. Then, after performing the expertise procedure shown in the figure the aptitude of the element to the new structural loads is evaluated and transposed back to BIM, upstream. This info is kept inside the BIM model so the professional can review it later on in case of need without repeating the procedure.

7. Regulations

While structural behaviour is a physical interaction and is the same for the whole globe, one cannot say the same for the structural requirement as they vary for every country and they also influence the final structural design. It is really important to know the historical point in which the building was constructed and the structure designed as this is directly related to the structural design and real behaviour. It is important to define which regulation is used in the structural expertise as it can influence when determining the viability of the structural element and considering it

valid for the new structural demands.

Reinforced concrete is a relatively new material as it was widely adopted in the early years of the 20th century. As it became more used more research was done and there were more publications regarding calculus rules or design recommendations. It is not until the second half of the century that regulations start to appear, giving the professionals a common framework for concrete structural design. In this regard, each country had a different development.

In Spain, the first mandatory regulation was published in 1939 and approved in 1944 with the name *Instrucción de Hormigón Armado* (Regulation for Reinforced Concrete). Before that year the design was done following earlier codes from other European countries like Switzerland (1903), Prussia (1904), Germany (1904), and France (1906). The code written in 1939 was in use until 1961 when the new code was published adapting the regulations to the new theory of Limit State Design. The regulation maintained the name and was known as HE-61. In the year 1973 the new code, EH-73, added security margins for the material tensile strengths. From there several codes have been published over the years, with changes mostly on building recommendations. There has been a total of four more different codes in the Spanish environment in the years 1982, 1991, 1998, and 2008. This last one, EHE-08 (*Instrucción de Hormigón Estructural, EHE-08, 2008*), is the one currently in use by the professionals concrete structural design. The next image shows a timeline summarizing the evolution of Spanish concrete regulations across the years.

As time passes the regulations change and its requirements are different. New regulations tend to be more restrictive, implementing new requirements as the knowledge grows. While the structural expertise should be performed using the current regulation, as it is stated in it, it is important to keep in mind the regulation used in the design. Some requirements do not make sense when an existing building is examined with the current regulation as its design rules were different. For example, reinforced concrete structures with a tensile strength lower than 25 MPa were allowed in EHE-73 but not in the current EHE-08, same happens with rebar distribution.

In the examples shown in this article, we have used the requirements and loads for the current regulation in Spain (EHE-08) with some exceptions. The tensile strength for the materials corresponds with the one according to the building period, despite it being inferior to the lower limits allowed nowadays. The different geometrical minimum reinforcement established in the regulation are ignored as they will probably be incoherent with the existing design. In general, structural restrictions are used, while design restrictions are avoided.

Regarding the security margins established by the regulations, we have considered the ones affecting the tensile strength of the material and denied the ones affecting the loads. The materials have suffered degradations procedures by being exposed to the environment and that has to be reflected. On the contrary, the new loads are well-known during the analysis and can be accurately defined and established. Therefore, the decision to ignore security margins affecting the new loads, reducing the overall security margin significantly, to not penalize the structural element in

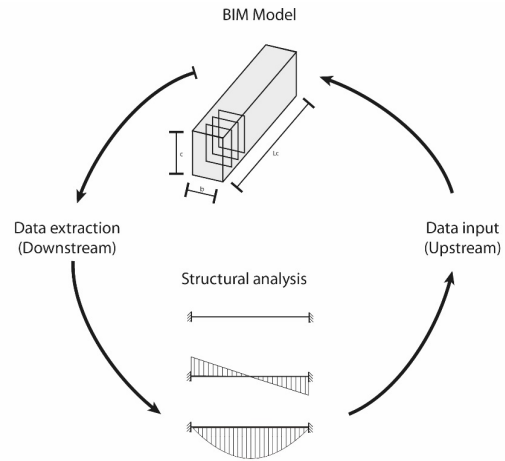


Figure 3. Analysis procedure

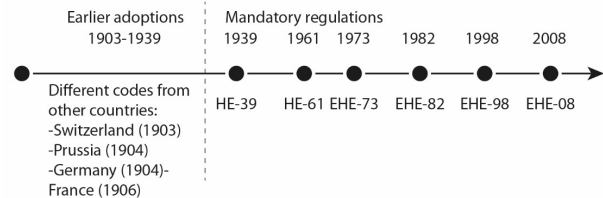


Figure 4. Spanish concrete structural regulations timeline

excess. The expertise is then performed with a smaller security margin than the one defined by the regulation.

8. Results

8.1. List of parameters

The list of parameters used to recreate the FEM for the concrete beam cover the design element, geometric layouts, material properties, and load cases upon the studied element. The value of these parameters is embedded in a Revit family created for this purpose and connected to the plugin. In Autodesk Revit, a family is a group of elements with a common set of properties, called parameters, and a related graphical representation.

Based on interoperability among different files, in Autodesk Revit, there are three different kinds of parameters that can be used in its families. Following Revit's terminology, there are "Project Parameters" that are common for a certain project or file, "Family Parameters" that are shared among the same family in the model, or "Shared Parameters" which can be assigned freely and can be used in different files with the same definition. In the research, we have used "Shared Parameters" as they can share their properties among different files and it's easier to extract them externally, as they are always referred to in the same way in the API. These parameters can contain any kind of data, either

Table 1. List of parameters used in the analysis

Table of parameters			
Geometrical parameters		Non-geometrical parameters	
Parameter	Unit	Parameter	Unit
width (w)	Centimetres	Concrete tensile strength	Newton per square millimetre
Height (h)	Centimetres	Steel tensile strength	Newton per square millimetre
Cover (c)	Centimetres	Embedment Coefficient	0-1
Bottom-side diameter (D1)	Millimetres	Dead Load	Kilonewton per meter
Top-side diameter (D2)	Millimetres	Live Load	Kilonewton per meter
Transversal diameter (D3)	Millimetres		
Number of bars in the bottom (n1)	Direct amount		
Number of bars in the top (n2)	Direct amount		
Spacing between transversal bars (sep3)	Centimetres		

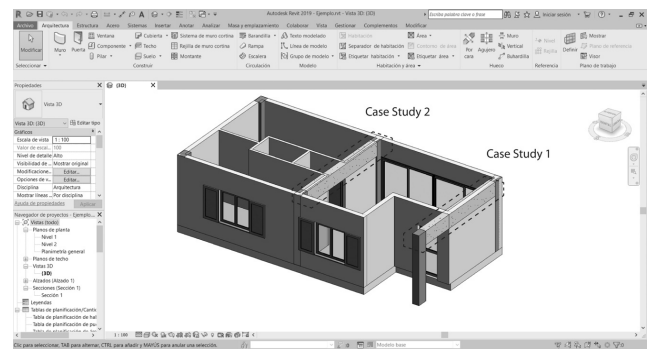
numeric or text entries. In the presented plugin, only numeric parameters have been used. A complete list of the parameters and their definition can be found in [Table 1](#).

Geometrical parameters contain data that can be measured in space, and so it is represented in the BIM Model. Non-geometrical ones contain data describing properties of the element and can't be visualized in Revit's GUI, but can be accessed and edited from there. One of the risks to automating the structural expertise is that the FEM created and analyzed may not represent reality. The chosen parameters make it possible to model an accurate FEM including some issues that the element may have suffered such as material properties degradation, geometrical variations, or excessive bending. With these parameters, the user can represent the real state of the beam and avoid the Black Box Effect derived from the automation of this procedure.

The Embedment Coefficient plays a key role in representing the real behaviour of the beam. Its value varies from 0 to 1 and represents the embedment of the element with the rest of the structure. This parameter measures the capability of the beam to redistribute the bending force to another element where it connects. If considered 0, the connection will behave like a hinge, if considered 1 it will behave as a rigid connection, any in-between value will act as semi-rigid.

9. Case Studies

The case example presented in this paper is a theoretical residential building in Spain. Only one of the apartments has been modelled in BIM as shown in the following images. The concrete beam has a cross-section of 0,3x0,4 meters and starts and finishes on two columns, its rebar reinforcement is shown in the image. There is no damage affecting the transmission of the bending but some material degradation (the concrete tensile strength considered is 15 N/mm²). The load cases in the building include dead loads and live loads. The loads considered follow the Spanish regulations for the residential areas: dead load is 4,5 KN/m² and live load is 2,0 KN/m². The loads are uniformly distributed on

**Figure 5. Case Study**

the whole floor and the bay distances are 5 and 3 m.

In the same dwelling, we are going to perform tests upon two different beams. The first beam has a total span of 5 m. and it presents no pathologies of any sort, so the Embedment Coefficient considered has the value of 1. The second beam has suffered from creep issues and has an excess deflection. As a result, some part of the load from the beam has been carried by the wall under it had made some cracks in it. In this second case, we have a reduced span of 3 m. but we cannot guarantee the right embedment of the beam, so the value of the coefficient is 0.

10. Analysis of the results

After performing the expertise, the plugin output the result indicating the aptitude or not of the element and informing the professional of it. This is shown through a window with a text that states the result of the test. The result is then stored in the parameter named "Viability" inside the family. After performing the tests on the two case studies the results are the following.

After performing the expertise, the "Viability" for both study cases is 1, meaning that both are sufficient to handle their new demands upon their new constraints. Neither of them requires a structural reinforcement. Case Study 1 has

Table 2. Results Obtained after the expertise

	Case Study 1	Case Study 2
Embedment	1	0
M_d	47,26 mKN	51,04 mKN
Viability	1	1

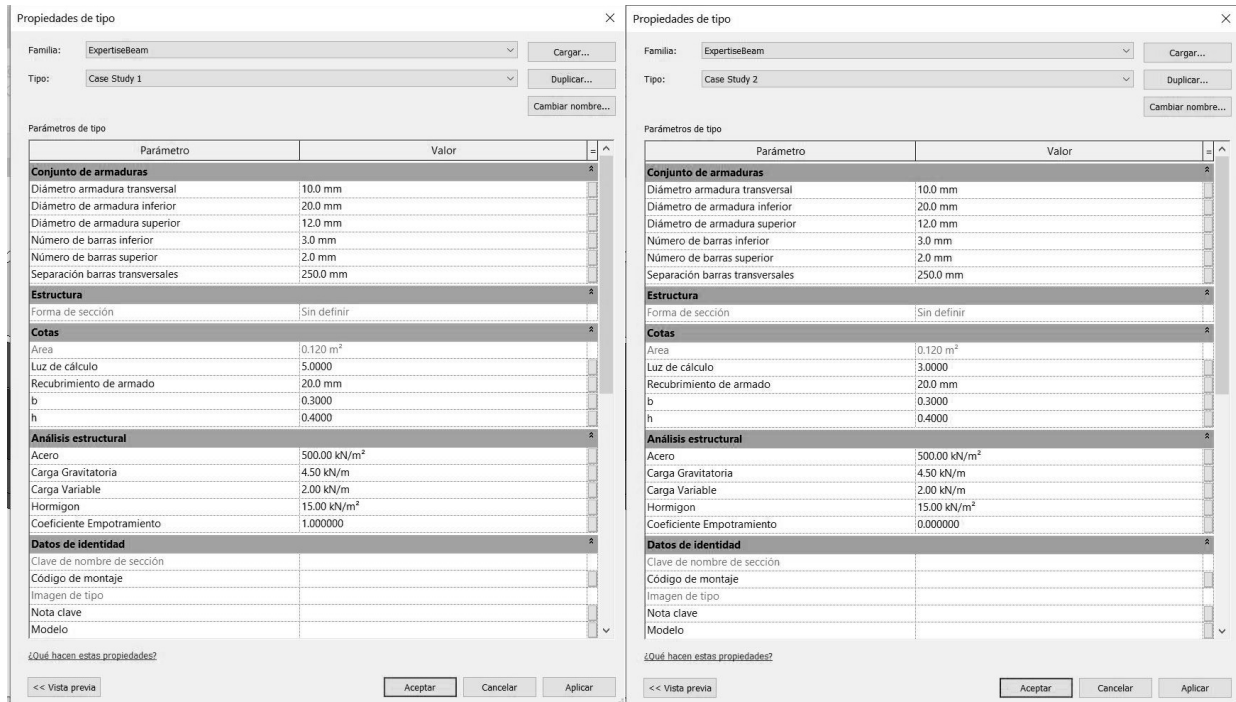


Figure 6. Parameters used in Case Study 1 (left) and Case Study 2 (right).

been modelled following a “healthy” hypothesis, where the beam has not suffered any damage through its life cycle. It is considered a control element, validating the design of the structure. On the other hand, Case Study 2, suffered some pathologies during its lifecycle, losing its perfect embedment with supports. Despite that, it had found a stable state by unloading some load onto a wall. While both structural elements are structurally stable, they are not in the same situation. Case Study 2 has suffered an important alteration and it needs further study to establish if the degradation process has stopped or can increase.

The parameter “Viability” value is stored inside each one of the elements studied. This output parameter has been added so it can be reviewed later on straightforwardly. This parameter can be listed in the BIM model to obtain a table that relates the structural feasibility of the element and the description of the element, making use of BIM’s natural interoperability. After performing the expertise in the different structural objects, it can be easily tracked which elements are valid and which ones do require structural reinforcement to be able to function and to support the new demands.

11. Conclusion

In this paper, an Autodesk Revit plugin able to perform structural expertise on a single concrete beam has been developed and tested on two separate case studies. This plugin extracts the data from the BIM Model, performs the analysis, and introduces back the result, informing the professional of the suitability of the element to support the new demands. The tool presented is in a preliminary phase of development, right now it can perform the task, but more study cases have to be tested to ensure the feasibility of its results.

In the current version, the data extracted is defined by the user and contains the size of the element, material properties, load case, and conservation state, represented by the embedment coefficient. The parameters introduced to perform the expertise have been selected to allow the professional to recreate the actual state of the element including pathologies that could have affected it through its life cycle.

As presented, the analysis tool has been limited to analysis only isolated concrete beams. This limitation has been established to help the professional to perform more accurately expertise. By editing the parameter values the user may alter the FEM used for the analysis and customize it to

reflect the real state of the structure.

In the paper, two examples have been shown of how the tool works and integrates the results into the BIM Model. The different examples show the failure of the element and its acceptance. The analysis covers all the structural requirements defined nowadays by the Spanish concrete regulation EHE-08 with the exceptions regarding minimum reinforcement required.

11.1. Scalability to the whole structure

The plugin presented in this paper can only perform the structural expertise of a single structural element. This has been a design decision. The structural expertise must be performed with care and each element has to be evaluated before deciding if it is necessary to analyze it, this decision relies upon the professional. The BIM and the FEM can be done considering the whole structure, but it becomes more and more difficult as the structure grows to consider the different conditions of each element. Further research is needed in this field to determine if the advantages of performing whole structure expertise are enough despite the difficulty in the model and how to deal with the issues re-

lated to the different elements being in different conditions.

11.2. Future research lines

The plugin presented in the paper performs the structural expertise for a single structural element evaluating if it is fitted or not for the new structural demands. Further research is required to study and develop an environment inside BIM able, not only to perform the structural expertise for a single element but also to help the professional in the design of the structural reinforcement when it is needed. Further research is also needed to determine the critical points that have proven insufficient by the structural expertise and optimize the needed structural reinforcement. The plugin presented in this paper is a preliminary phase of ongoing research, more development is needed to ensure and guarantee the results and its suitability to be used by professionals.

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The Damage Survey Forms for Cultural Heritage Between Simplified Procedures and Needs for Implementation: A Critical Analysis of Data Collected for the Cemetery Type After the “2012 Emilia” Earthquake

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Keywords: specialised type, cultural heritage, cemetery type interpretation, damage survey tools

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The Guidelines for the evaluation and reduction of seismic risk on Cultural Heritage and the Directive 12/12/2013 of MIC identify as the first cognitive procedure the compilation of specific forms to describe vulnerabilities and damage level on movable and immovable assets after an earthquake. Specifically, they refer to two important survey instruments: the A-DC Church and the B-DP Stately Buildings forms. These are the only two tools used between 2012 and 2013 for the damage level characterization of the Cultural Heritage caused by the “Emilia 2012” earthquake. The widespread use of these forms has brought to light several problems that have negatively affected the successive economic assessment of the intervention.

If these sheets well describe the vulnerabilities of the specialized *types* of Churches or Stately Buildings, they are ill-suited to *types* with different features. In particular, in Emilia-Romagna, one of the most relevant samples of these *types* is the *cemetery type*. Starting from a knowledge of the *cemetery type*, the present paper will analyse the use of these instruments in the cemetery survey to identify the critical points within a damage survey conducted through tools not specifically suited for the *type*. The aim is to deliver a conscious interpretation of the criticality and in the final part define a starting point for a new survey tool.

1. Introduction

The earthquake that struck the Emilia-Romagna Region on May 20 and 29, 2012, severely tested a socio-economic system that alone produced 2% of Italy’s GDP. Nine years later, it is clear that this system has had a remarkable resilience, and today only the reconstruction of Cultural Heritage, the last priority set by the Region, is still in the middle of its activities. In fact, in the field of Cultural Heritage, the earthquake made us more aware of the building evolution (Bartolomucci et al., 2012) but at the same time, it puts to a test both its structures and its conservative principles (Dalla Negra, 2012), leading to a longer and more complex reconstruction phase. In this context, the damage survey is among the first operations to carry out in an emergency phase with the hard task of identifying all buildings requirements (structural, conservative and economic). This survey aims at leading surveyors to define vulnerabilities and collapse mechanisms (which are the required informa-

tion for an economic and non-economic damage quantification) starting with the observation of the cracks (the starting date). It is a quick and simplified procedure that, using a “*behavioural approach*” (Baggio et al., 2009), is geared towards obtaining a homogeneous damage indication on a large scale by immediately relating the cracks to the corresponding collapse mechanisms. However, the main critical point is that “...*Simplification generally leads to greater data reliability, as long as the ultimate decision-making [...] is well guided.*” (Baggio et al., 2009).

In Emilia-Romagna, where almost 80% of the damaged public buildings is under protection, the survey campaign on Cultural Heritage has shown some peculiarities in the damage survey report that negatively affected the subsequent process. During the emergency phases, it has emerged the existence of building *types* that, due to their morphological and typological specificities, do not allow the direct application of the tools and procedures already validated. For these *types*, the respective form A-DC Church

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or FORM B-DP Stately Building, the two forms applied to Cultural Heritage, have proved to be unsuitable to draw a picture of the damage suffered and identify the correct economical assessment. In this framework, one of the most challenging *types* of buildings is the cemetery. Only 34% of the cemeteries in the preliminary phases were economically well estimated using these existing tools.

To illustrate the challenges faced in 2012 by surveyors, the first part of the research paper presents the morphological features of *cemetery type* carried out according to the Saverio Muratori School's interpretation and describes the structure and the peculiarities of the existing tools of damage survey. The second part lists the main problems arising from the use of non-dedicated tools for the cemetery damage survey to demonstrate how it is necessary today to resume studies on damage survey to implement the effectiveness of the tools for Cultural Heritage. In the last chapter, a hypothesis of some data re-interpretation provides a possible solution for the *type* investigated.

2. Interpreting the Cemetery Type

The design of a damage survey tool requires first the awareness of the investigated *type* and its development to define and structurally re-classify its features to allow the surveyors on-site to interpret each building belonging to the *type*. The analysis of the *cemetery type* below, compared to how the current instruments are structured, demonstrate the distance between them and the *cemetery type*, thus justifying the difficulties faced by surveyors between 2012 and 2013 in Emilia-Romagna.

Historically, modern cemeteries were born in 1804 with the Saint-Cloud edict through which Napoleon Bonaparte regulated the cemeteries construction and demanded to build them far from urban areas. Considered the founding event of the “*culte des morts*” (veneration of the dead) in the modern western culture (Aries, 1977), it is the act through which in France and then in Italy the criteria for planning new cemeteries were definitively established. The modern cemetery was seen as a mirror of society and the new hierarchical organization. Nevertheless, this new attitude toward death did not lead to a new dedicated space but, according to the Saverio Muratori School's interpretation, it changed the features of the pre-existing cemeteries, emphasizing some peculiarities and determining the definition of two typological series connected to different matrices of specialization (Maffei & Maffei, 2011).

Through the ban of the stacked burial in the mass graves and the establishment of the practice of the singular burial as mandatory, sometimes combined with the incineration as well (Ragon, 1986), still the new rules of the edict demanded a rethinking of the model for burials.

On one hand, we see the definition of garden-cemetery. In this case, the matrix of specialization is a naturalistic one and it comes from the medieval cemetery built outside the city and settled in the twelfth century. Characterized by a wide but enclosed perimeter, the abundance of space makes family chapels and great singular tombs the primary and preferred method of burial here.

On the other hand, especially in southern Europe, the Saint Cloud edict collided with a still strong medieval tra-

dition, the “*Camposanto*” (literally “holy field”), a cemetery with large porticoed wings where bones of exhumed bodies were drained before placing them in the ossuaries above. The new cemetery codes were incorporated into this pre-existing cemetery model defining a second typological series called by Donghi (Donghi, 1935) “*a pianta architettonica*” (architectural drawing). It adapts its pre-existing architectural features to the new regulatory requirements by reintroducing an archaic burial model that allowed responding to the new needs of singularity and recognisability, while also maximizing the use of space: the columbarium. This is a high architectural value solution, characterized by quadrangular areas fenced by walls, with porticoes of different sizes, in which are placed the new burials. It is the most used solution in all small-and-medium-size cemeteries in Italy, especially in the area that we are examining: the Emilia-Romagna Region. Based on it we identify three different variants: a cemetery delimited by porticoes with a central chapel, a cemetery delimited by porticoes without a central chapel and the reuse of huge buildings outside the city. These variants later have developed in different manners. A first growth was made possible through an infill process of the enclosure, through the porticos' extension, or the combination of family vaults next to each other. Alternatively, the cemetery has doubled in the area behind. Once the space of the first enclosure was full, the enlargement has followed the successive doubling law (Caniggia & Maffei, 1987). Cemeteries extended more and more and the whole area doubled in volume.

Further observations on Emilia-Romagna cemeteries can also be made from a constructive point of view. The huge time windows of building development (from the second half of the 19th century – ongoing) coincide in the initial phases with a great transformation of the building process as a result of the introduction of new industrial materials and techniques: reinforced concrete and steel. A first analysis reveals how cemeteries were initially made of long porticoes, often in masonry, that enlarged over time and showed more frequent use of reinforced concrete. Due to these progressive add-ons and juxtapositions, cemeteries are an extremely complicated *building type*, also because traditional technologies exist alongside new materials like reinforced concrete and steel.

In conclusion, a cemetery is a complex *building type*, where *morphological variants* and developments are combined with a variety of building techniques. The outcome from a structural point of view is a structure with some peculiar vulnerabilities such as the porticoes or projection elements tipping over, the damage to the vaults and suspended ceilings, the damage to surrounding walls etc...

3. Forms for the Damage Survey on Architectural Heritage

3.1. History and Principle of Damage Survey Forms for Cultural Heritage

The earthquakes that occurred in the last 30 years have revealed the significant vulnerabilities of architectural heritage. These are strictly related to the building construction quality, the form and dimension of architectural components and anti-seismic devices which are connected to the

seismic activity of the area and to the time distance between construction/renovation and the earthquake (Lagomarsino & Podestà, 2005). A proper identification both of historic buildings' vulnerabilities and related activation levels of collapse is a useful tool for prevention and for managing the after-earthquake reconstruction phase. To provide support in the complex and delicate emergency management phase, in Italy a series of forms of different levels have been studied, that through a guided procedure should eventually assess vulnerability, damage (Papa & Di Pasquale, 2013), practicability and lastly the intervention costs.

The forms currently in use are the result of several studies and experiences. These range from studies of the research unit coordinated by Doglioni on all churches in the Friuli Region damaged by the 1976 earthquake (Doglioni et al., 1994) to researches carried out by GNDT, INGV and the Department of Engineering of Genova coordinated by Lagomarsino (Lagomarsino & Podestà, 2004a, 2004b, 2004c), regarding religious buildings first, and then enlarged to several *buildings type* (D'Ayala & Spence, 1995; Mouroux & Le Brun, 2006).

The fact that churches are more vulnerable compared to other historical buildings led in 1987 to a practical application of the first damage survey form, the GNDT-S3, which later would become the well-known "FORM A-DC church". This form was officially adopted for all religious buildings in 2001 (Presidenza del Consiglio dei Ministri, 2001), later modified and re-approved in 2006 (Presidenza del Consiglio dei Ministri, 2006). More forms have been added over the years, related both to movable assets and to other *buildings types*. Therefore, it was created the "FORM B -DP Stately Building" for the most relevant historical buildings, which is quite recent and for this reason, it is still the object of discussion, improvement and optimization.

The theoretical framework from which the damage survey tools arise is based on the idea that analogous structural elements tend to suffer similar damage regardless of the time of construction and the used materials, factors that may increase or decrease the level of vulnerability but not eliminate the vulnerability itself (behavioural approach). Assuming this, the instruments have been designed by the observation of the real recurrent damage that occurred on structures belonging to the same typology. The damage was mapped, interpreted and embedded in specific abacuses which, according to the *building type*, illustrate how the structural problems appear in the buildings through the use of a simplified scheme that exemplifies how cracks are located about collapse mechanisms. These schemes represent a synthesis of structural behaviours related to macro-elements (Doglioni et al., 1994) into which a building can be divided. Since structural behaviour in the case of an earthquake has a limited number of possibilities, the core of a suitable Cultural Heritage damage assessment is then represented by how effective are these abacuses in respect to the building investigated. In fact, since the forms in the Cultural Heritage field are used by professionals coming from different areas, such as art historians, archaeologists and architects, these abacuses must guide the surveyors to select only the cracks that they can include within these simplified schemes.

3.2. Structure and content of current damage survey forms for Cultural Heritage

The form A-DC Church (hereafter A-DC form) has been studied since the 1976 earthquake specifically for churches, and in its final design, it includes an of list 28 collapse mechanisms related to macro-elements such as the façade, the nave, the aisles, the apse, the chapels and the tower bell, typical churches architectural features.

The form is divided into two sections. The first aims at locating the property, and identifying all pieces of art. The second one assesses the conservative state, the damage index, the practicability and the repair costs. In particular, the damage index is calculated by taking into account all possible collapse mechanisms that may be activated among the 28 present (it determines the parameter "n") and the level of damage associated with each of them (it determines the parameter "d"). The damage index, $I_d = d/5n$, is then obtained by the ratio of the two factors collected. It is worth mentioning that "n" is represented by the sum of all possible mechanisms, regardless of how many times a macro element is used. The presence, as an example, of three or five aisles is therefore irrelevant for the index calculation. Finally, to calculate "n", each collapse mechanism associated with a macro-element must be considered as vulnerable just because the macro-element is in the church.

FORM B-DP Stately Building (hereafter B-DP form) is divided into two sections as A-DC form but, if the first section is almost alike, the second section is set up differently. Although it aims at collecting the same type of data of the A-DC form, the B-DP form has more generic and smaller macro-elements as well as external walls, inner walls, floors, stairs, porches, etc...

In this case, before identifying the activated collapse mechanisms, surveyors are required to provide a long and detailed description of materials, dimensions, and damage state of each component. Once this survey is being meticulously carried out, it would be possible to identify collapse mechanisms, their activation level, and calculate the damage index, but even if the damage index formula is the same, the identification of parameters for calculation ("n" and "d") is quite different from A-DC form. In fact, for "n" identification must be considered only the total number of macro-elements and not their possible structural behaviour during an earthquake.

An additional difference in the index calculation is the introduction of the "secondary" mechanisms concept in the section of damage identification. This integration in B-DP form is related to the complexity of stately buildings which are generally multi-storey buildings. In some macro-element, we can observe different mechanisms on some floors with their related damage levels. In order not to overestimate the damage level in a component, the code "secondary" should therefore be attributed to all collapse mechanisms with the lowest damaging effect in the same macro-element. The code indicates that the damage level should not be counted in the "d" calculation. This means that each macro-element should be considered only the collapse mechanism with the highest damage value.

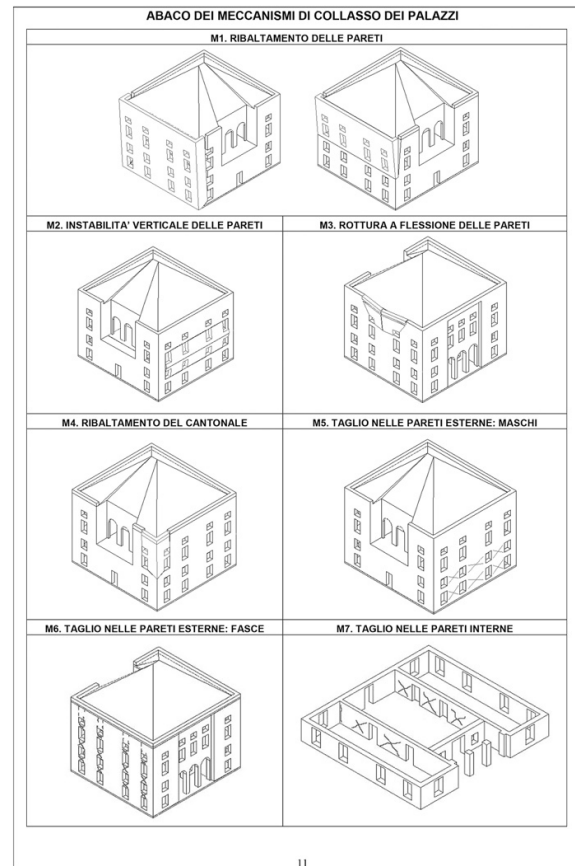
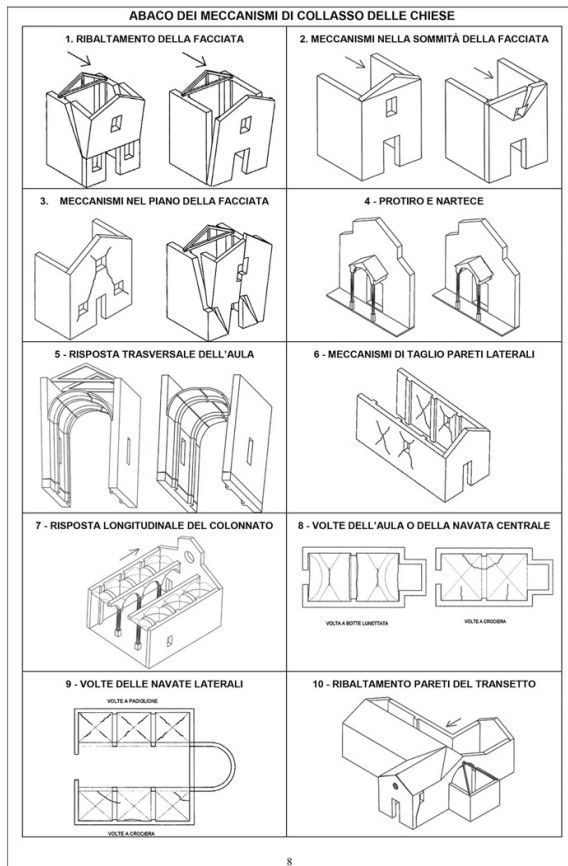


Figure 1. Extract from collapse mechanisms lists for churches and stately buildings attached to the respective forms.

Source: A-DC and B-DP forms

4. Analysis of Cemetery Damage Survey Forms Fulfilled in Emilia-Romagna

Even though A-DC and B-DP forms are very different in the damage is represented and identified, as shown in Fig. 1, still, these were the only two tools through which cemeteries were surveyed between 2012 and 2013. The first form is closely linked to the architectural and functional aspects of churches, the second one is open to different spatial configurations as long as they can all be investigated. The use of these tools, strictly connected to the *type* they describe, even if they are the only ones currently available, has highlighted the need to intervene with appropriate adjustments, in particular concerning *types* of different nature such as cemeteries. Neither of these instruments after the analysis of their application appeared completely suited to the damage survey for *cemetery type*. The analysis was carried out through the identification and comparison of the following parameters relating to the forms filled in:

- type and number of forms filled out per cemetery
- correspondence between described and observed damage
- formal accuracy of the damage index

presence of ambiguous fields and comparison of relative solutions to perform the analysis according to the parameters, the corresponding abacus of the recurrent collapse mechanisms for the *investigated type* was preliminarily cre-

ated (Fig. 2). This is based on the morphological analysis previously described for the identification of macro-elements and on the structural analysis of the actual recurrent damage observed, based on Giuffrè (Giuffrè, 1991) historical construction interpretation, through the use of the photographic data which accompany each inspection carried out between 2012 and 2013.

The results of this analysis highlighted the following problems that affected the damage survey process:

- Criticalities related to tool choice. First of all, the operators' problem was the choice of the most suitable form to use. The answer to this question in 2012 was ambiguous and followed three different approaches. In some cases, the choice fell on the use of only the A-DC form. This preference, which has the certain advantage of embracing all the aspects borrowed from ecclesiastical buildings (chapels with apses, domes, pediments, etc.), probably arises from the willingness to identify the element of greatest vulnerability in the portico. In contrast, this form does not face a problem such as the large spatial articulation of cemeteries, the wings of which can be damaged in different ways. Probably, for this reason, most compilers decided to use the B-DP form. It is a model that, since it is studied for buildings, employing dividing it into areas, allows greater articulation in damage description, considering the responses of the structure and different

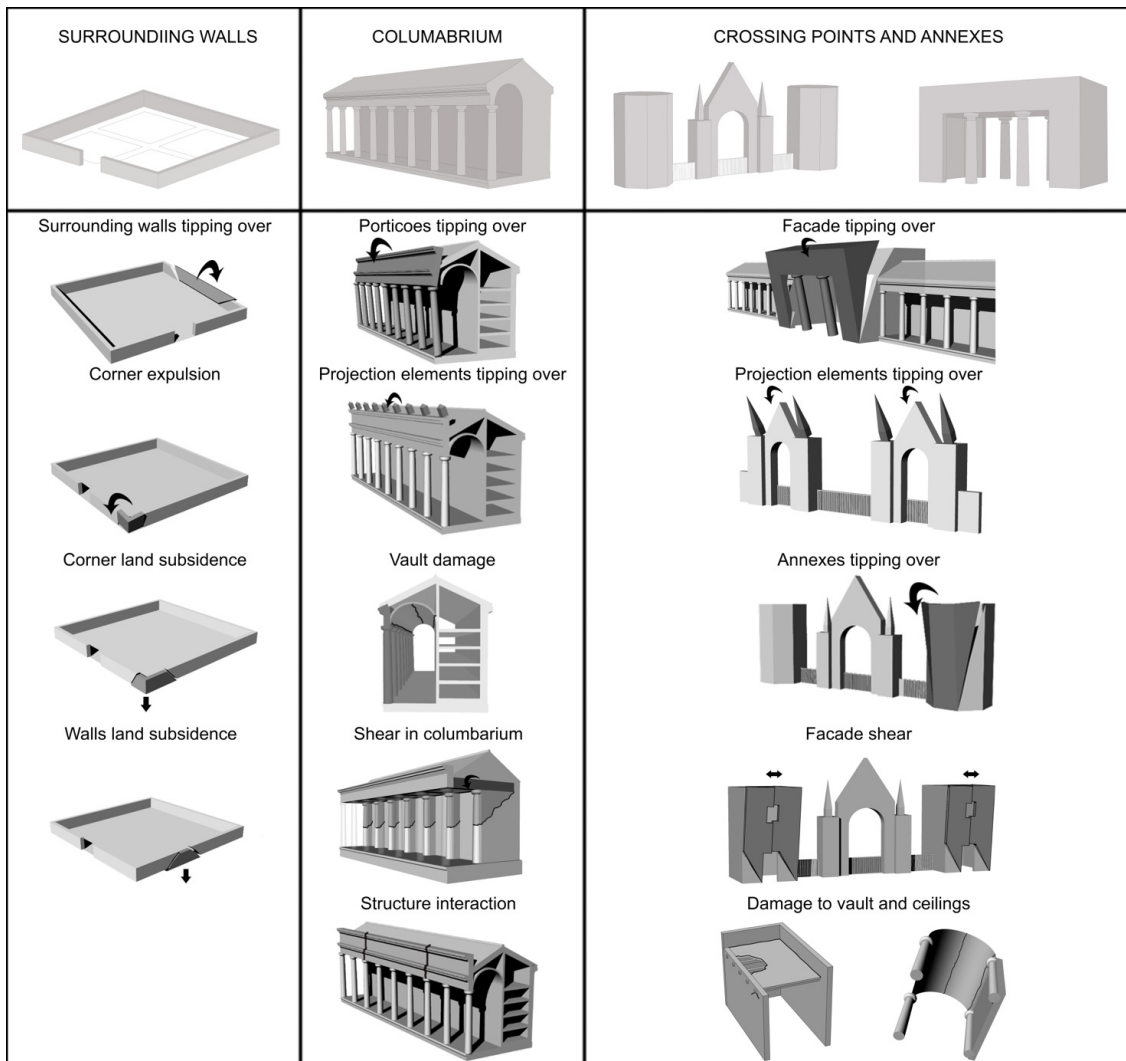


Figure 2. Extract of abacus created for *cemetery type*.

Source: own elaboration

collapse mechanisms for the different parts.

Although from a first analysis, the form seems to allow greater descriptive freedom, it however lacks the description of the typical mechanisms of large halls of an ecclesiastical nature. The impossibility of indicating the mechanism in the section dedicated to the calculation of the damage index prevents the correct calculation of the index itself.

Probably, the need to combine some elements of the two forms pushed a certain number of compilers to break down the cemetery into two models, using the A-DC form for the mortuary chapel and B-DP form for the remaining areas. Although the choice seems to be the natural solution to the problem of the inadequacy of a single instrument it does not provide a uniform indication of the damage to the building.

- Criticalities related to macro-elements identification. The identification of the macro-elements is the core of the damage survey. Their subdivision and diagrams according to recurrent behaviours patterns are guidelines followed by the surveyors to identify which collapse mechanisms have been activated after the

earthquake. Although the 28 mechanisms in the A-DC form and the 22 in B-DP form well describe the *types* for which they have been created, once applied to other *types* they generated considerable uncertainty. Once the surveyors chose a specific tool, their approach to *cemetery type* followed different paths by associating the architectural features of cemeteries with some macro-elements in the forms. For example, in D-BP form, an M18 mechanism, “damage to projecting elements”, is used to describe damage to gables or attics even if in the diagrams it refers to dormers and balconies. In other cases, instead, they added in D-BP form completely new elements and/or additional macro-elements from the A-DC form. As a result, M23 and M24 appear in the list, making it possible to identify any damage to apses, gables and surrounding walls. In many cases, not knowing which collapse mechanisms to refer to, has led surveyors to report minor damage in the note, not including it in the damage index.

We should also consider that cemetery structures are not easily accessible. We refer here to the columbaria

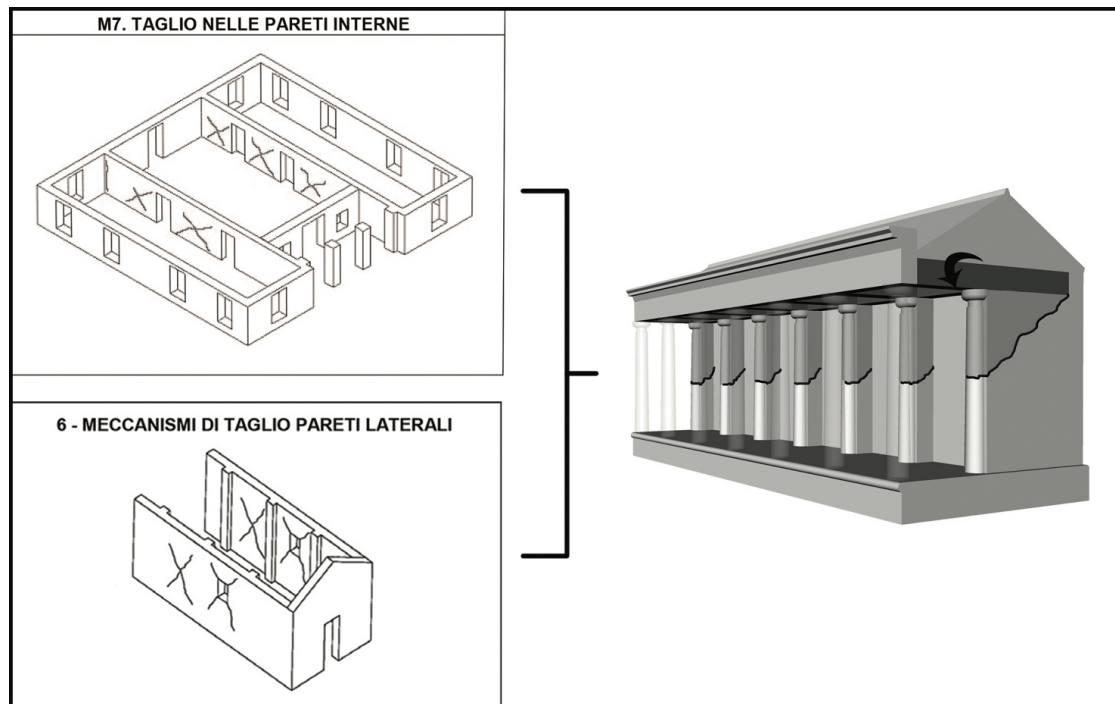


Figure 3. Difference between how shear is diagrammed in the abacuses for Churches and Stately buildings and how this could be schematized for cemeteries.

Source: own elaboration

cross walls, where the only part we can see is the thickness between burial niches. We can survey the columbaria cross walls as macro-element inner walls of the B-DP form, but we cannot recognise any damage by using schemes of pre-existing forms (Fig. 3). The diagrams let us understand the structural behaviour by observing the cracks mainly from a frontal wall view or, in challenging cases, by observing them from other sides. Since it is impossible to recognise the damage by solely observing the wall thickness the macro-element has often been neglected.

As a result, we collected a set of unreliable and inconsistent data. Since there are no clear and univocal guidelines, a correct survey depends first on the operator's ability to summarise the behavioural cemetery features without necessarily having any previous knowledge, and then on relating them to the existing tools.

- Criticalities related to damage index calculation. The identification of the damage index is one of the final aims of the damage survey. In addition to providing an overview of the damage, the index should also identify a parametric cost to be multiplied by the building area.

With the same index formula, $I_d = d/5n$, the parameters "d" and "n" are counted differently in the two forms, but in both the expected result is a number on a scale from 0 to 1, where 0 means lack of damage and 1 the almost totally building collapse (Grüntal, 1998). The difference in calculation has been leading to many mistakes. If the setting of the A-DC form (collapse mechanism on the macro element: activat-

able YES/NO + damage level from 0 to 5) hardly leads to an incorrect compilation, the situation is different for the B-DP form. On one hand, being familiar with the older A-DC form has been leading surveyors to use the same calculation while dealing with the same formula, on the other hand, the length and the fragmentary organisation of the data have been generating a few miscalculations. The most common mistake in the "d" calculation is the not-attribution of the "secondary" parameter, overestimating the damage.

For what concern the "n" parameter thought, we can find several errors, ranging from the not-counting of the pre-marked parts to the incorrect counting of macro-elements (indication of several macro-elements different from those detected in the previous section). Common mistakes are also the non-multiplication of macro-elements inner walls (indicated in the form) and, in the worst case, the multiplication of the macro-elements by the collapse mechanisms that have been activated, seriously underestimating the index. The result is damage indices which are in some cases only slightly different from the correct ones but in other cases are even greater than 1, a meaningless result.

- Criticalities related to experimental form introduction. A further issue in the damage characterization process is linked to the experimentation, during 2013, of a new B form aimed at facilitating the compilation of the one adopted to date, which is considered too complex and not very expeditious. The attempt to simplify the new form - which no longer required a detailed description of all the walls, but a twofold rating of the level of damage and on the level of vulnera-

bility - has proved to be particularly complex for compilers. A large number of forms were not filled in the damage section, often preferring a detailed description of the damage in the notes.

Furthermore, the analysis of collapse mechanisms identified by the two forms, at first sight, seemed to display a different tendency in the *cemetery type* collapsing.

The damage survey carried out in 2012 with the B-DP form shows a prevalence of M9 damage mechanism, while, although still present, this predominance decreased significantly in the 2013 survey using the experimental form. Conversely, mechanisms from M10 to M13, which were hardly identified in 2012, appeared to be increasing.

This, however, is not related to the activation of different collapse mechanisms in cemeteries, but it shows how much the design of these forms influences the surveyors' choices and how the use of unsuitable tools can lead them in completely different directions.

Between the B-DP form and its simplified version, there has been a change in terminology that drastically changed the survey. The adopted form identifies mechanism M9 as damage to porticos and loggias. This definition seems to include both in-plan and out-of-plan mechanisms. Moreover, the scheme associated with this damage displays squashing cracks in columns, cracks in the longitudinal direction of arches and cracks in the vaults. Therefore, it has led to a strong reduction in the identification of other mechanisms which were considered already included in M9. In the 2013 simplified form, the same M9 mechanism was defined as damage of slender elements by compression, associating the damage to columns crushing only. This definition increased the identification of collapse mechanisms related to vaults and floors (from M10 to M13).

Finally, it is worth noting that both the recognition of vulnerabilities due to constructive (M19) and shape (M20) irregularities and the preference to consider surrounding walls as a new macro-element were increasing. We could explain the variation above by analysing a further parameter: the surveyors. In 2012, twenty-seven people carried out the survey filling in an average of two forms each. In 2013, there were only seven surveyors instead. Four out of seven surveyors completed no more than 2 forms each, while the remaining three carried out most of the survey. In the second case, the surveyors gained more knowledge about *cemetery type* by visiting a larger number of cemetery buildings. Consequently, the surveyors improved their abilities in the identification of vulnerabilities and damage that they had understood to

be recurring, such as damage to surrounding walls or M19 and M20.

5. Conclusion and Possible Development

After the analysis, it is possible to state that the morphological and structural distance between some *building's types*, such as cemetery, and the existing damage survey instruments, not specifically designed for them, is the cause of incorrect damage survey. Since it was not possible to calculate a univocal and right damage index, it was also difficult to properly describe the damage state of Cultural Heritage and identify a correct parametric cost, affecting the subsequent reconstruction phase.

Additionally, the mistakes in the application of the damage index formula, which is mathematically simple, claims the need to provide greater and adequate training for the surveyors who are now cyclically called upon to carry out the damage survey. 20 years after the introduction of the forms in the Italian legal system, a lack of training of the operators can no longer be accepted.

A further conclusion can be drawn from the failure of the experimental B form. It demonstrates how the design of such as these tools is a long-term process whose success is achieved by mediating between the needs of quickness and the needs of data accuracy, and therefore it is necessary today to persist in the studies to improve the B-DP form or to create a new one. In addition, it also illustrates how a little change in an ambiguous parameter can transform the survey outcomes.

However, if on one hand, the analysis of damage forms applied to cemeteries in the 2012 earthquake highlights the criticality of their application to the *type*, on the other hand, it offered us an opportunity to improve the effectiveness of existing tools by introducing new ones. The data and the analyses already collected can be re-organized and systematized to acquire useful information for the development of a new tool for the *cemetery type*.

To compare the forms produced, it was necessary to perform a morphological and damage status analysis of the cemeteries to create an abacus of recurrent mechanisms based on the actual damage of the investigation set. This is the first step for the implementation of a new damage form for *cemetery type* as it provides an exemplification of the recurrent behaviours. The identification of the most suitable design for the data acquisition based on these schemes is the next step to complete for configuring a new tool calibrated on the complexity of the cemeteries.

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Data Matters: Two Pioneering Projects of Interactivity in Architecture

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Keywords: interactivity, adaptivity, digital architecture, data, it revolution in architecture

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The widespread and the ease of use of data in contemporary society represent a fundamental element for its growth and the main link between architecture and different disciplines. Seeking the origin of this trend that joins architecture and digital information means to firstly research on the epistemological field, to understand why it is important to implement architecture with new technological yet digital features and with new social values this process can bring (van den Hoven et al., 2015). This paper aims to describe this phenomenon through two emblematic and pioneering case studies that represent an important moment for the physical and virtual interaction between buildings, data and environment. In two different ways, the Saltwater pavilion and the Blur Building put in practice the theorized intention to let users interact with architectural matter and environmental elements through data sharing, and by doing so, they reshape the space according to personal behaviours.

1. Introduction

In the wake of the Second World War, the myth of progress, machine, speed and change permeates modern architecture and its iconic representation, becoming its symbol and invoking a new ideal of progress. It soon became necessary to give a physical (not necessarily material) aspect to what would later become the pivotal point of the IT revolution: the matter of information (Picon, 2010). This defines the paradigm of the “information society”, the post-industrial society characterised by the prevalence over the industry of immaterial goods, information and a large amount of data produced and requested in several disciplinary fields. Architecture, as a situated cultural production and a reflection of the changes in society and in its time, soon approached this silent revolution that in a brief time would colonise many different areas: the IT revolution. From the 1950s onwards, the widespread diffusion of information technology and, above all, the transposition of com-

putational processes into different spheres, characterised the industrial, technological and social development, in an attempt to tackle and resolve the so-called crisis of control (Beniger, 1986), i.e. the need to manage increasingly complex and numerous data.

This change is emblematic of what digital technology has brought about in many areas, namely the shift of the project's focus from the ‘object’ to the ‘subject’ (Saggio, 2010). Information technology¹ introduces the concept of automation, i.e. the possibility of automatically processing data, according to the rules and principles of computer science and transforming them into information. In this sense, it is fundamental to understand how it has produced an evolution of knowledge from an epistemological point of view: it attributes content to data only through direct correspondence with a system of reading and coding symbols, capable of defining a meaning. Only in this way it can an element of knowledge. Therefore, data can be considered as an architectural subject (as they are translated into infor-

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¹ Related to this revolution, it is important to remember also the definition of the “information society”, the post-industrial society characterised by the prevalence on industry of an intangible asset, information (a large amount of data produced and required by research from different disciplinary fields).

mation) that constitute an important step in the learning process (Ackoff, 1989). The ‘signifier’ (the data as raw material, without explicit intention), collected through the most modern technologies from the surrounding environment, becomes ‘signified’ and lends itself to the reading and interpretation of the architectural fact (Kitchin, 2014). This means that in this specific historical and cultural moment, architecture is the receiver of a complex system of information that contributes to its change in terms of form-finding and construction. In the same way, architecture, reflecting changes in society, has also absorbed the computer and digital components in its definition and production processes. As architecture has incorporated the digital transition, or the so-called “Second Digital Turn”, by trying to adapt its methodology to an exclusively technology-driven approach, it has shown its aptitude to reflect the cultural values of its time, space and society. What, however, can be noted is that the new tools, that have been introduced to facilitate and empower architecture, have replaced not only the process of creation but also the process of conception, so much so that Mario Carpo believes that architecture has absorbed the results of the digital revolution entirely passively (Carpo, 2017).

2. Shape and Process: Two Different Approaches

As known from history, at the end of the Twentieth century, society was moving towards an epoch-making innovation, in a cultural moment of social and productive impetus which would intensify its production until modern days. First, the computer revolution and then the digital revolution were greeted in architecture with both great diffidence and exaltation. In contrast with the idea of standardisation, the IT revolution introduced, on the one hand, the concept of complexity of forms, processes and relationships - through the tool of the diagram for example (Van Berkel & Bos, 2002)- and on the other the feature of interactivity. The introduction of interactivity has been a pivotal moment in the definition of new relationships between the building, the user and the environment, in a dual and complex relationship (Fox, 2016). It is possible to identify two different types of interaction: the first one focuses on the spatial transformations introduced by the digital tool’s ability to manage the complexity of shapes²; the second one, instead, relates to the design operations that the project can show within the communication with the external factors (Fig.1).

This latter type introduced the ability to define new relationships within the transition from the mass to the individual (and therefore to progressive customisation not only of the needs of the individual but above all of the products). Also, architecture, reversed this way of thinking,



Figure 1.

quickly highlighting its ability to become interactive. This new feature allows establishing an active dialogue between the building, man and the environment, thus underlining a connection between ethical and aesthetic aspects. This led to two different trends: on the one hand, the central role of information, making explicit its representative and symbolic value; on the other hand, the progressive exaltation of action and performance, as a means of emphasising the pedagogical character of buildings at different scales.

With this premise, this article aims to suggest a parallel reading of two emblematic cases study which, a few years apart, have shown this difference in the approach to architecture and interactivity: the Saltwater pavilion (K. Oosterhuis, 1997, Neeltje Jans) and the Blur building (Diller and Scofidio, 2002, Yverdon-Les-Bains). Both associated with the desire to exploit technological data to design from it (in this sense also providing interesting ideas for *data visualisation*), these two buildings show a point of rupture with the past, and yet with their current time. Their relevance lies not only in this reason but especially in the context they have been built in. Architecture, on the turning of the century, is rapidly changing: on a hand, in the definition of the form, more fluid and digitally controlled, along with the idea that will be later defined as ‘frozen flow’ (Picon, 2010); on the other, on the relation that the buildings (for different reasons) create with the environment. Certainly, these two buildings are not the first attempt to try to create a relationship with the environment: vernacular architecture has always tried to create an environment-based solution to make the building more efficient. What can instead be considered an interesting exploration in the same period is the IMA (Institut du monde arabe), built-in Paris in 1987 and designed by Jean Nouvel. The complex façade

² Numerous currents have followed the development of the IT revolution in architecture, especially with regard to form. Among these, Greg Lynn’s thought on the fold as the main means to manage the digital project, starting from a re-reading of Gilles Deleuze’s book *The Fold: Leibniz and the Baroque* it is remarkable. The complexity managed through processes of visualisation and numerical management of information appears to be the central theme of the introduction of the digital elements in architecture, which has triggered profound reflections on the concept of a new aesthetic. In this way, it stages and prefigures relationships of a topological or parametric type, capable of constituting a genetic code which is both a generator and a regulator of the project.

system, which recalls the *moucharabieh* pattern, was supposed to change (with an open/close movement) concerning the outdoor lightning, so to give the inner space different atmospheres. The reason behind it was mostly related to the intention of creating a connection with the Arab world, rather than establishing a relationship between the environment and the user or, to have a real impact on the environment itself. The difference pointed out ten years later is that through data it is possible to transmit a specific knowledge and also that it is possible to establish a direct interaction between users, building and the environment. The two pavilions presented in this paper, envision the idea that a building can be capable of adapting to the needs of its environment and providing new forms of knowledge by raising awareness of external environmental changes. Therefore, within this framework of the investigation, it is possible to understand that the element of the facade can have (again) a pedagogical character. Furthermore, it also breaks away from the initial interpretation of the façade as a 'screen' and becomes something other than itself. Although with different purposes and timeframes, the Saltwater pavilion and the Blur building are two buildings with the same functional programme, i.e. they are two collective cultural buildings, which show investment in the latest technologies for digital design processes.

3. Saltwater Pavilion: a Sensorial Journey into the Intangible

The digitalization of architecture has inevitably brought to a moment of transition that emphasized several changes. At first, the way the project is represented was changed -at first in two-dimensional form, then three-dimensional and finally today through complex information management systems- but also how the project itself is conceived (Nicolin, 2006). Although great attention was first paid to the morphological aspect of the building, through the distortion of forms and then the modelling of the envelopes, at the end of the Nineties new technologies allowed to assimilate the characteristics of computer systems within buildings. This introduced the possibility of putting on the scene -metaphorically or purposely- a correspondence between information through the architectural elements themselves, introducing what the Dutch architect Kas Oosterhuis would later call the *Hyperbody* (Oosterhuis, 2003). The building thus begins to be understood as a dynamic, inter-

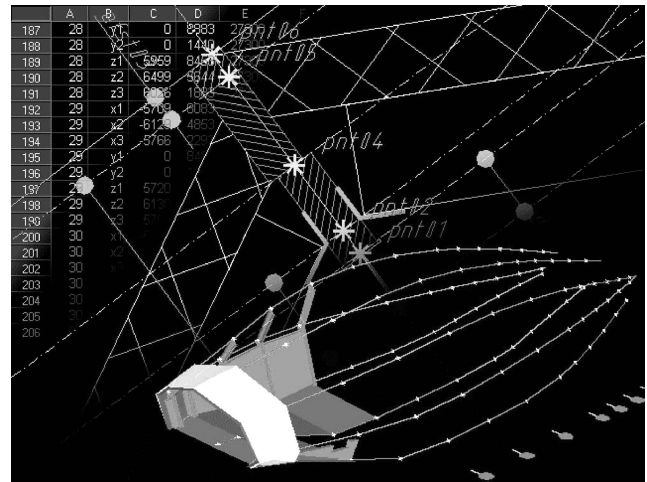


Figure 2.

connected and mutable object, in line with the development of computer systems and the first websites³.

In the Saltwater Pavilion, built-in 1997 in Neeltje Jans in physical continuity with the Freshwater Pavilion by NOX studio (built as well in 1997), the entire design process is centred on the elaboration of flow diagrams which define the relationships between the parts (along a process that is certainly not new to a certain kind of architects⁴): it allows the whole envelope and the structure to be conceived entirely on digital software, through the relationship between points on control lines and management software (Fig.2). The input sensors, the interfaces, and outputs -that control the behavioural system of the building- are firmly introduced (Oosterhuis & Engeli, 2002) and constitute the relevant main elements of the building. Identified as the first «concrete fiction» (Oosterhuis & Engeli, 2002, p. 17) of the ONL study and conceived as a Hydra that follows the visitor in the form of a structural element, the building is directly linked to a weather station positioned on a buoy in the North Sea. This connection with a data collection infrastructure transmits the gathered information to a computer which processes and subsequent transmits it to the actuators in the building. This connection marks the difference with the contemporary building that engages the relation with the environment, thanks to its dynamic process.

Based on the information received, the building adapts

³ It is no coincidence that liquid spaces or declared biomorphic systems, as Marcos Novak describes in *Liquid Architecture in Cyberspace*, are a main matter of interest: «[...] Liquid cyberspace, liquid architecture, liquid cities. Liquid architecture is something more than kinetic architecture and robotic architecture, an architecture of fixed parts and variable links. Liquid architecture is a breathing, pulsating architecture. [...] Liquid architecture produces liquid cities, cities that change when a value changes, where visitors with different backgrounds see different landscapes, where surroundings change with shared ideas, and develop as ideas mature or dissolve.» (Novak, 1993).

⁴ This element is central to the debate of the end of the century, especially in terms of the new aesthetics that derived from it: furthermore, it introduced into the representation new elements proper to computer science, thus adapted to better explain architectural complexity. Computer systems work through simple relationship between complex elements, usually represented by flowcharts, which are graphic representations of the operations to carry out in order to execute an algorithm. These graphical elaborations, suddenly applied in the architectural field, make explicit the need to establish hierarchical and causal relationships between different elements that constitute the building, not only at a technological level, but above all at a spatial level. A first clear example is represented by the diagrams drawn up by Cedric Price to determine a dual relationship between the actions of the building and the user. The building is thus configured as a place of constantly evolving practices, a physical and spatial construction of that continuous movement that the avant-gardes of the early 20th century had already studied and represented through new languages. (Andaloro, 2021)

in real-time its light and sound effects on the inside of the building, through the use of fibre optic lights and diffusion elements. At the same time, with a sensor board, the visitors can interact with the indoor space using devices that affect lighting and sound (Oosterhuis & Biloria, 2008). A result is a place always manifested in different ways, which is constantly based, on the one hand on the behaviour of the visitors, and on the other hand on changing external weather conditions (Fig. 3). The singular behaviour allowed by the new technological components introduces the *swarm paradigm*: the building is conceived as a set of different and autonomous elements (each of them has its shape, position, colour and code) which are inextricably connected to work simultaneously. The biological metaphor is predominant in the production of Oosterhuis, who identifies the genetic code as the generating element of the project itself⁵. The interest for the biologic element is not intended as an organic metaphor (as the middle-Nineties production would have suggested): on the contrary, the Dutch architect meant it as a way to extract from nature a 'living' pattern so to create a computational system able to execute complex interaction in real-time (Oosterhuis, 2011).

In this sense, he transposes the natural behaviour into the design process, justifying and enabling several adaptive transformations (Fig. 4). The building itself is a sensor-adaptive system as it is conceived as a living body, capable of changing form and content in real-time. Furthermore, at the same time, it is itself part of a network in which data is continuously shared and information is continuously produced. This characteristic defines the building as a flexible networked information processor within a continuous self-learning environment. This capacity, together with flexibility, marks the difference between reactive and interactive, the latter being understood as a circular 'demand-response-demand' system (Elmokadem et al., 2018), whether analogue (deliberate control), automatic (reflexive control) or hybrid (Kolarevic, 2009; Sterk, 2005). The idea of a circular system, therefore, is easily linked to the possibility of having a structure built in a continuous state of the computation, adapting its structure and envelopes, its colours and patterns: a Hyperbody that changes in real-time.

4. Blur Building: Making the Tangible Invisible

Similarly, in the Swiss pavilion designed and built-in Yverdon-Les-Bains by Diller and Scofidio for Expo.02 in 2002, the interaction between the user, the building and its surroundings is put on the scene on the borderline between art and architecture. Many reminiscences of Buckminster Fuller's projects of large structures enveloping a space are transposed in the Blur building, defining an enormous tensegrity machine, a ninety-meter oval loaded on bipyramidal supports and steel pillars (Fig. 5). This slender structure, compared to the large proportions of the pavilion, stands fifteen metres above the water level of Lake

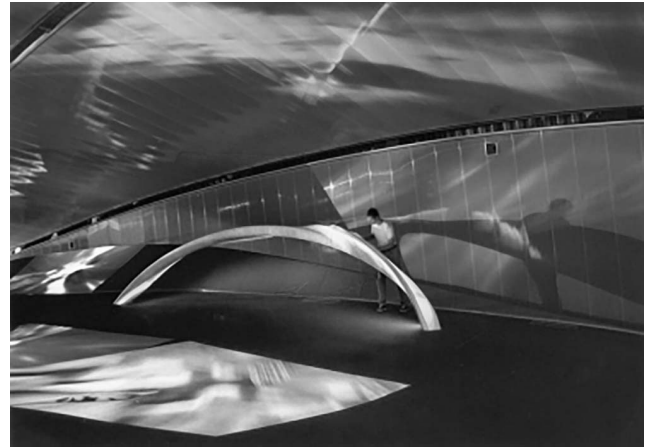


Figure 3.

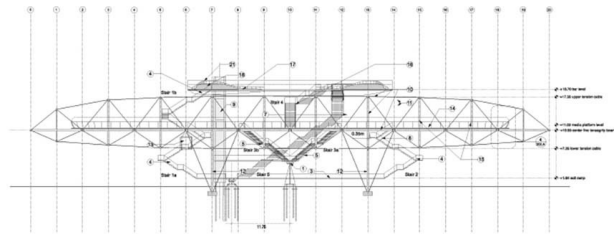


Figure 4.



Figure 5.

Neuchâtel, to which it is connected by a footbridge.

The building is based on a very high level of technological complexity, concealed behind the simplicity of the materials used: a network of sensors on the outside of the building detect the humidity, temperature and wind and transmit this information to the actuators inside the build-

⁵ «The essence is in the genetic code. The genetic code of a building body is a set of rules and algorithms, animated by the circumstantial parametric values placed into the formula's making up the genetic code. The visual appearance is the outcome of the process running the genetic script in a site-specific and time-specific environment.» (Oosterhuis, 2003, p. 38-39).

ing. The information processed activates the mechanisms of the numerous nozzles on the surface of the building, which spray water mist from the lake at different intensities depending on the data collected. The artistic intervention puts in place two types of interactions (at two different scales): in both of them, the building plays a crucial role. The first establishes an inter-relationship between the building and the environment, whilst, on a smaller scale, the second one relates the building and the visitor, through the sensors on the 'brain coat'⁶. In this way, the Blur building stages a new relationship between architecture and the digital world in an overtly spectacular way, suggesting a change of perspective around the central theme of 'looking'. If visitors expect to see something once they arrive at the pavilion, what they will see is nothing, "spectacularly (about) nothing" (Marotta, 2005).

The result is that the façade of the building cannot be a subject of interpretation, it is never identifiable, its shape is in constant movement and the transformation is unpredictable. The visitor passes through an ever-changing environment, perceives an iridescent panorama and can relate the variation of the natural phenomena around him from the intensity of the steam emitted. In a more accentuated sense, Blur is itself information: the collected element defines the character of the building and prompts a formal transformation. In this sense, the traditional antinomies of inside-outside, open-closed and near-far are broken down. However, this pavilion shows a way of linking the 'material' and the 'immaterial', the 'physical' and the 'virtual', giving a changing aspect to external variations in real-time through data.

5. Conclusions

Both examples show an embryonic approach to interactivity, suggesting that with technological advancement, those elements that at the beginning of the year 2000 introduced the possibility of multiple reactions (related to the lighting system, sounds, and smells) could later constitute a more complex architectural project. Architecture is also a matter of prefiguration within the toll of the imaginary.

With a multidirectional and non-recursive idea of time, the architectural project can nowadays be conceived as a process open to non-(de)finite scenarios, as well as to different configurations and interactions between all its parts. Therefore, introducing interactivity meant, on the one hand, to crystallise a paradigm shift in the design process, putting the subject before the object, personalisation before standardisation and variability before seriality; on the other, it implied –and still does– a radical change in the core idea of time, which allows for continuous spatial configurations based on the interconnected properties of the parts of an overall complex system. The search for the interaction

between building, exterior and also user, provides nowadays a new tool of knowledge that the project itself controls and manages. In other words, these buildings state the difference with the past (and with the already mentioned IMA) because of the presence of the digital element which allows data not just to be captured and stored but, especially manipulated. They can thus be considered as complex computer machines which can put in place (or put on the scene, according to their performative character) a spatial manipulation of digital data. In this definition, it is then possible to recall Manovich's definition of 'new media, especially for their programmable nature, that allows them to be altered through a computer (Manovich, 2002).

In conclusion, in these cases study, the two buildings are both producers and a store of data: the mixture of the physical and immaterial aspects of architecture is mediated by IT and digital procedures, allowing information to be considered as a real constitutive material of the architectural project. It is not then just a matter of (virtual) connections: the change induced by the information collected does have a spatial impact on the building itself. The visitors of the pavilion would not be able to experience the same kind of space twice because the external conditions would never be the same: this means that this kind of architecture also implied a certain level of unpredictability. In the same way, the active interaction between the building and the users would stimulate an always-new response or a change of habits in the users, whose awareness about environmental issues would be indirectly raised. In this sense, it is a scope of the author to underline the importance of the cases study not only for understanding the innovation that they brought to the architecture and technology field, but mainly for the inner purpose of using the architectural elements (such as the façade) and some specific characters (such as the multi-temporality or the multi-scalarity of the building) to create a bond between the building, the user and the environment. In a historical moment in which architecture was not yet merged with mass media communication, ONL Diller and Scofidio implicitly attribute the facades to the pedagogic role of architecture. The meaning extracted by the collected data is clearly shown on the façade (even when it does not appear) through a specific and unique code. At the basis of the responsive and adaptive architecture that in more contemporary times has been designed, and that evolves from these embryonic interactions, there is still the idea of relating the (in)tangible and the (in)visible. The information considered as a real constitutive material of the architectural project defines the set of relationships that the building establishes with its surrounding environment.

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⁶ The project of the 'braincoat' by the same architects should have allowed people to express their characters through the use of a smart raincoat provided at the entrance of the building. In order to furnish visitors an alternative way to see in the fog and meet other people, Diller and Scofidio developed the idea of using lights for people to communicate to each other. Based on a form that visitors filled in at the entrance, each braincoat was able to create a personal profile the would be able to create an involuntary reaction when approached to another 'braincoat', based on the information received. A panel on the chest would show the affinity or antipathy with a range of colours from warm red to blue-green.

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